

Design of Hood Stiffener of a Sedan Car for Pedestrian Safety

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Abstract

Safety is the most important criteria in automobile designs which concentrates on both pedestrian and occupant safety. The pedestrians are the most vulnerable road users and are at high risk of traffic accidents. The major reason for the fatality of the pedestrian in traffic accident is due to the head injury resulting from the hard impact of the head against the stiffer hood or the ground. This leads to the necessity of new inner hood panel which is less stiffer and pedestrian friendly.

The head impact analysis on the present hood of the car was done to study the response of the adult head form at two different locations. Structural and modal analysis for the same present hood assembly was done to observe the local and global stiffness. In order to reduce the head injury of the pedestrian the local stiffness over the area of head impact has to be reduced thus the new design of hood inner panel was focused on that and the structural and modal analysis was done for the new design. The design with lesser local stiffness and similar global stiffness compared to the existing hood was finalized.

The head impact analysis for the new design of hood inner panel was performed. The HIC values of the adult head form for two different locations are found to be 706 and 948 which meets the safety limitations of the adult head acceleration during impact as proposed by EECV WG17 and Euro NCAP regulations. Thus the new design of the hood is pedestrian friendly, considerably maintaining the overall global stiffness of the hood.

Key Words: Pedestrian Safety, Head Injury Criteria, Stiffness, Inner Hood Panel

Nomenclature

A	Acceleration (mm/s^2)
ρ	Density (ton/mm^3)
t	Time (s)
v	Velocity (mm/s)

Abbreviations

CG	Centre of Gravity
DOF	Degrees of freedom
EEVC	European Enhanced Vehicle-Safety Committee
HIC	Head Injury Criteria
NCAC	National Crash Analysis Centre
NCAP	New Car Assessment Program
WAD	Wrap Around Distance

1. INTRODUCTION

Pedestrians are the most vulnerable road users who are at the high risk of vehicle collisions in traffic, Almost 1.2 million pedestrians are killed annually in road traffic accidents worldwide. The major injuries occur in lower, upper leg and head of the pedestrian, where the fatalities of the pedestrians in the accident is mainly due to head injury resulting from the hard impact of the head against the stiff hood or to the ground. In recent years, engineers are working on the vehicle front end design which includes bumper and hood to reduce the injuries to the pedestrians in the event of pedestrian-vehicle collision.

1.1 Pedestrian -Vehicle Collision

Pedestrian injuries and fatalities at the time of vehicle collision are mainly due to the speed differential. The pedestrian kinematics during collision depends on the position of the pedestrian and the vehicle speed, the average speed of the vehicle at the time of crash is 40 km/h.[1] Figure 1.1 shows the type of vehicle which is involved in the road traffic accidents, and it can be observed that maximum in case of cars.

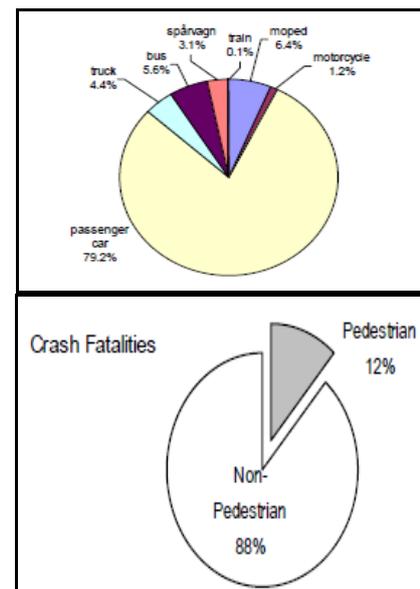


Fig. 1 Vehicles types involved in pedestrian accidents, crash fatalities [2, 3]

From figure 1 it is seen that the proportion of crash fatalities shows that 12% of them are pedestrians and the rest of those killed in the crash are vehicle occupants, motorcyclists and others. The sequence of events in car pedestrian accident happens in such a way that the lower leg of the pedestrian is first hit by the bumper and then the upper thigh comes in contact with the bonnet leading edge of the car and finally the head and the upper torso is struck hardly by the top surface of the stiff car bonnet which has rigid parts like engine under the hood that leads to serious head injury and fatalities of the pedestrian.

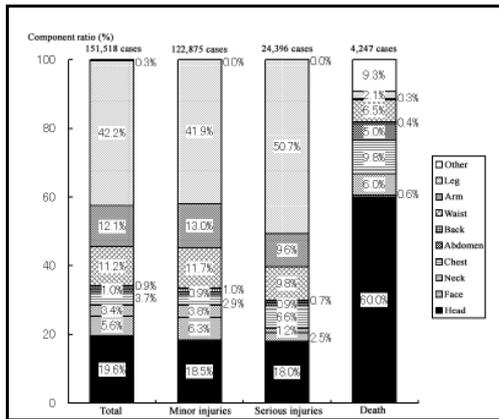


Fig. 1 Pedestrian injury region based on the severity [4]

From figure 2 it is seen that among the various injury regions like leg, head, thorax, neck, arm, abdomen, the leg region has more contribution of about 41% and 50% in minor and serious injuries followed by the arm and abdomen region. In case of pedestrian death, it is caused mainly due to the head injury with maximum contribution of 60% which leads to focus on pedestrian head protection [4].

2. LITERATURE REVIEW

European enhanced vehicle-safety committee (EEVC WG17).[1] describes the sub system test procedures for pedestrian safety during vehicle collision. For bonnet top tests the adult head form is created as per the EEVC WG17 regulation, where the outer skin of the head is about 12mm thick and the material assigned is PVC instead of Poly urethane which was used earlier and the outer diameter of the head form is 165mm. The inner skull is made of sphere and the material assigned is aluminium. The mass of the adult head form is 4.8 kg. The impact position of the adult head form on the bonnet for testing is given by the Wrap around distance of 1500 – 2100 mm and the head form is inclined to 65° with respect to ground reference line, also the test points should be within 82.5mm inside the bonnet side reference line and rear reference line and each test points should be 165mm apart.

Jason A. Stammen, Roger A. Saul and Brian Ko.,[8] has assessed the proposed head impact test procedures by the ISO and EEVC with laboratory impact tests and computer simulation and the results were compared with the actual case. Ford Taurus car model was taken for test and three different locations namely a, b and c was marked on the hood.

The locations selected has different hood structure and clearance to the under hood engine parts for the impact test. First point ‘a’ was considered as open impact area, where the hood had no reinforcement and had large clearance to the engine. The second point ‘b’ was the alternator impact point which had no reinforcement but less clearance with the alternator and the third point ‘c’ had heavy hood reinforcement with less clearance. The tested results showed higher HIC value at point c where there was less clearance and then followed by points b and a, which was similar to that of the actual case. The similarity of the results encourages the use of these techniques to make connection with injuries due to accident and acceleration or force measurement in accident reconstruction.

Tsukatada Matsumoto, Koushi Kumagai and Hideaki Arimoto.[9] has described the importance of shape of the hood inner panel as the important factor for pedestrian head protection in order to reduce the HIC values. The section geometry of the hood inner frame has been optimised to achieve the targeting value of HIC, where the height of cross section of the inner panel was 0.76 times smaller than the original one and width of the panel was 1.14 times larger than the original hood inner panel and the thickness of the panel was maintained the same. Finally the test results showed that the optimized shape has improved the probability of achieving the target HIC value by 60% to 99%.

Dr. Grace Mary Thompson, Christoph Kerkeling and Joachim Schafer.[6] described the structural hood concepts for pedestrian protection where they used two different concepts of hood to replace the traditional hood which was designed to meet the standard load cases. They designed inner hood with one having increased number of ribs and the other with multiple cone drawn structure instead of rib structure using aluminium. This structure did not have any ribs or cutouts which had continuous stiffness distribution over the panel and it was easy to change the overall stiffness as strong or weak. Pedestrian head protection was done by reducing inner panel gage thereby reducing the stiffness of the hood.

Scattina A., Gaviglio I., Belingardi G., Chiandussi G., and Gobetto E.[10] has described about the redesign of bonnet targeting lightweight and pedestrian safety. They analysed five different concepts with different materials for the inner and outer hood in which three of them showed most promising solutions. The first concept ‘C1’ was the inner hood with three long ribs which was made of short glass fibre polyamide that has good thermal properties and the outer skin was aluminium which offered a good pedestrian safety. In the second concept ‘C2’ the central portion of the inner panel was removed and full aluminium was implemented taking into consideration only the pedestrian safety and excluding the strength of the hood. The results showed that use of aluminium is the best solution for achieving weight reduction and pedestrian safety.

Finally in the third concept ‘C3’ a hybrid metal/plastic bonnet design with a net internal structure was studied. The bonnet was made of external aluminium skin, a void internal structure in aluminium and net wire made of polyamide reinforced with glass fibres which lead to

further weight reduction and better energy distribution during impact between the pedestrian head and the bonnet. The torsional stiffness of the hood was very low when compared to that of the original and thus was considered as a concept design.

Masoumi A., Mohammad Hassan Shojaeefard and Amir Najibi,[11] compared and analyzed steel, aluminium and composite bonnet for pedestrian protection. Finite element model head impactor was created and impact simulation on three bonnets with identical structure made of steel, aluminium and composite material was done on different locations of the bonnet to study the behaviour of the bonnet. From the results it was concluded that use of aluminium bonnet resulted in lower HIC and increase in head displacement when compared to that of steel and it was 50% lighter than steel bonnet which failed in strength factors. Where as composite bonnet resulted in lowest HIC value and highest head displacement, besides good torsional stiffness and light weight. Finally, the modification of inner structure which may provide lower displacement, lower HIC and less displacement of head form was suggested.

Christian Pinecki, Richard Zeitouni.,[12] discussed about the pedestrian head protection by providing clearance between the bonnet and under hood engine components and softening of the bonnet to generate more progressive head deceleration during impact so that the impactors do not come into contact with the rigid elements. Active bonnet system was used to provide space between the bonnet and the under hood engine components during impact for the vehicles which has insufficient under hood space. This system deploys as soon as the impact with the pedestrian is detected and the space under the bonnet is increased artificially in order to prevent head from impacting hard points.

Collapsible bonnet arrester was used for softening of the bonnet to generate more progressive head deceleration during head impact on bonnet. The collapsible bonnet arrester works in a way that when head impacts the bonnet, the top layer of bonnet deforms and deflects to press the arresters beneath the bonnet which is designed to collapse after certain amount of load is received and this leads to increase in the deceleration time of the head and preventing the head from moving down further to hit the rigid parts.

3. PROBLEM STATEMENT

“To study the head injury criteria of the pedestrian with the present hood of the sedan car and to reduce the same by redesigning the hood structure”

4. METHODOLOGY

- Review of various literatures present in journals, books, manuals and related technical papers were carried out.
- Finite element modeling and validating the adult head form as per EEVC WG17 and Euro NCAP regulation was done.
- Head impact analysis for the present hood was done and the pedestrian head injury level was assessed.

- Structural Analysis for the existing hood was done to assess the deformation of the hood assembly under various load cases.
- Design and modeling of new hood concepts was done focusing on lower local stiffness.
- Structural analysis for the modified hood assembly was done and the deformation of the hood under various load cases was compared with the original hood to arrive at best inner hood structure.
- Head impact analysis on the finalized design of modified hood was done.
- Comparison of the results obtained through design improvements with the earlier results was done.

5. FEA MODEL SETUP

5.1 FE Model for Baseline Head Impact Test

The front end of the car was extracted from the full vehicle model of ford taurus developed by National Crash Analysis Centre (NCAC) which was essential for the baseline head impact test. The extracted front end model of the car contains components namely Inner and Outer hood, Fenders, Engine shields, Engine, Intake air manifold and Tie bar module. The finite element model of all these components consists of 38662 elements.

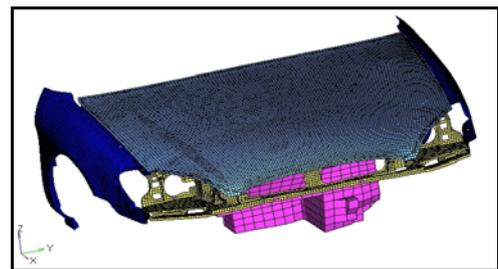
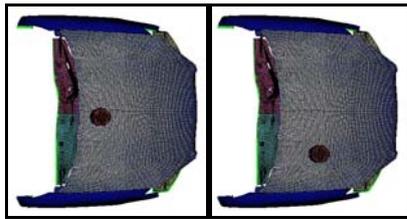


Fig. 3 Front end finite element model of benchmarked vehicle

5.2 Positioning of Head Form

The finite element model of the adult head form was positioned over the hood of the car as per EEVC WG17 regulation. Initially the adult head form was imported into the finite element model of the car and then the adult head form was rotated so that the angle of inclination of the head form was in 65° with respect to the ground and then the head form was placed between the Wrap around distance (WAD) of 1500 - 2100 mm[1] for adult pedestrians, considering the limitation that the test points should be within 82.5mm inside the hood side reference line and rear reference line and each test points should be 165mm apart.

The baseline head impact analysis was done at two positions, First the head form was placed at centre of the hood which was 100mm from the rear reference line of the hood and the second position was 350mm left from the centre of the hood and 150mm from the rear reference line of the hood.



Position 1 Position 2

Fig. 4 Head form impact positions on the hood

5.3 Initial Velocity of Head form

Since the average speed of the vehicle is 40 km/h during the pedestrian vehicle traffic collision and the head form velocity is 80% of the vehicle speed. The resultant velocity of the head form for the impact analysis was taken as 30 km/h. Since the head form was rotated to 65° the resultant velocity of the component was resolved into horizontal and vertical components as shown in figure 5. The node set was created by selecting all the nodes of the head form and the velocity for the head form was assigned by selecting the created node set ID in the load collector.

5.4 Model Setup for Structural and Modal Analysis

As the analysis was done on the hood assembly to find the stiffness, strength and natural frequencies of the hood, the finite element model of the Ford Taurus hood assembly was extracted from the full vehicle model developed by NCAC. The hood assembly consists of two components namely outer hood and inner hood stiffener.

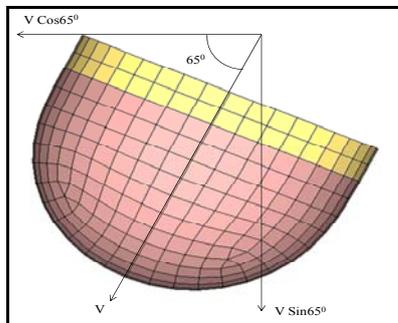


Fig. 5 Initial velocity for head form

5.5 Finite Element Model for Ansys Solver

The finite element hood model extracted was defined in LS Dyna deck and thus it was redefined for Ansys deck in Hypermesh. The hood assembly was considered to be a single component in order to find the stiffness and strength of the complete hood assembly and thus the outer hood and inner frame was connected by means of 1-D rigid element (CERIG) by selecting the node to node option.

5.6 Boundary Conditions and Load Cases

Three different structural analysis of the hood such as oil canning, self weight and torsion analysis were done in order to find the local, global and torsional stiffness of the hood assembly respectively.

5.6.1 Oil Canning Analysis [15]

Oil Canning analysis was done in order to find the local stiffness of the hood assembly at the location where the point load was acting. The boundary condition for this analysis is based on the hood hinge and latch points. Point A and B in the figure 6 represent the hinge points of the hood and point C represents the latch point. At point A and B all the five degrees of freedom namely translational motion UX, UY, UZ and rotational motion RY, RZ are arrested without arresting the rotational motion RX. At point C in the hood all the six degrees of freedom including RX is arrested. A concentrated load of 50N was applied at two different locations on the hood as shown in figure 6.

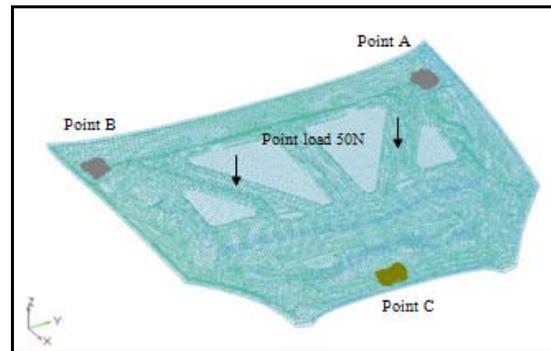


Fig. 6 Boundary conditions and load case for oil canning analysis

5.6.2 Self Weight Analysis [15]

Self weight analysis was done in order to find the global stiffness of the hood assembly and the boundary condition for this analysis is same as oil canning analysis discussed above. The loading for this case is the gravitational force of the hood assembly itself.

5.6.3 Torsion Analysis [16]

Torsion analysis was done in order to find the torsional stiffness of the hood. The boundary condition for this analysis is as follows,

- Initially all the six degrees of freedom i.e., translation and rotational motion about all the three directions were arrested at Points A, B and C as Shown in figure 7
- At the latch point i.e. point D of the hood only the translation motion UX, UY and UZ were arrested and rotational motions RX, RY and RZ are free.
- A point load of 100N was applied at the Point E.

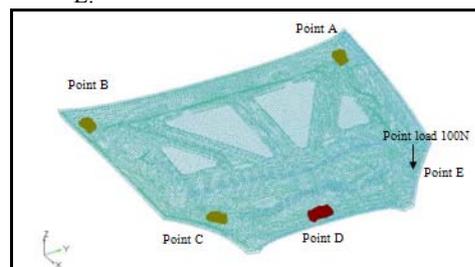


Fig. 7 Boundary conditions and load case for torsion analysis

6. PROBLEM SOLVING

6.1 Introduction

The main objective of the work is to reduce the head injury (HIC) value of pedestrian in the event of pedestrian vehicle collision. The reason for high HIC value is that in the event of collision head of the pedestrian comes in contact with the hood of the car which is stiffer due to the inner reinforcement of the hood providing strength. Thus the stiffness of the present hood was found by structural analysis and a new inner hood reinforcement structure was designed focusing on reduced local stiffness to reduce the head injury of the pedestrian.

6.2 Validation of Head Form

The finite element model of the head form was validated as proposed by EEVC WG17 and Euro NCAP regulation in order to use the head form in head impact analysis on the hood.

6.2.1 Head Form Impactor Test

This impactor test on the adult head form was done as per the proposal of EEVC WG17 regulation. In order to find the head form resultant acceleration in the impactor test a node at the centre of the head form is selected.

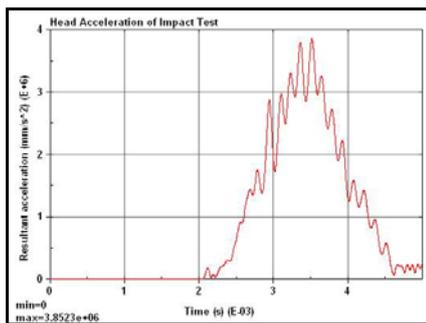


Fig. 8 Head resultant acceleration of impactor test

Figure 8 shows the resultant acceleration at the C.G of the head form and the maximum acceleration is $3.852e6 \text{ mm/s}^2$ which is equal to 392g. According to EEVC WG17 the acceleration of the adult head form with 4.8 kg of mass should be within the limit of 337.5g to 412.5g. Thus the resultant acceleration of the head form lies within the limit.

6.2.2 Head Form Drop Test

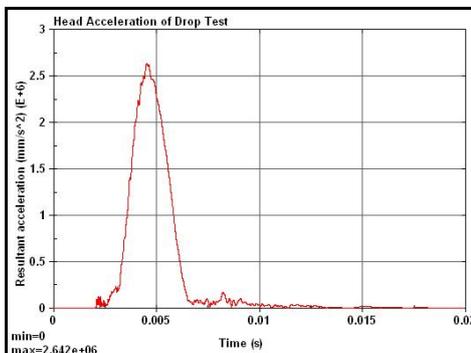


Fig. 9 Head resultant acceleration of drop test

The drop test on the adult head form was done as per the proposal of Euro NCAP regulation. In order to find

the head form resultant acceleration in the drop test a node at the centre of the head form is selected. Figure 9 shows the resultant acceleration at the C.G of the head form and the maximum acceleration is $2.642e6 \text{ mm/s}^2$ which is equal to 269g. According to Euro NCAP proposal the acceleration of the adult head form with 4.8 kg of mass should be within the limit of 225g to 275g and from the above it is evident that the resultant acceleration of the head form lies within the limit.

Thus the adult head form is validated and it can be used for further head impact analysis on the hood for assessing the head injury of the pedestrian.

6.3 Baseline Model Head Impact Analysis

The head impact analysis on the hood for baseline model was done in order to study the response of the head form in the present hood. The impact analysis was performed at two locations on the hood as shown in figure 4. The simulation of the head impact analysis on the hood for the two locations is shown in figure 10 Also it is seen that during the impact of the head form, hood structure deforms in order to absorb the energy produced by head.

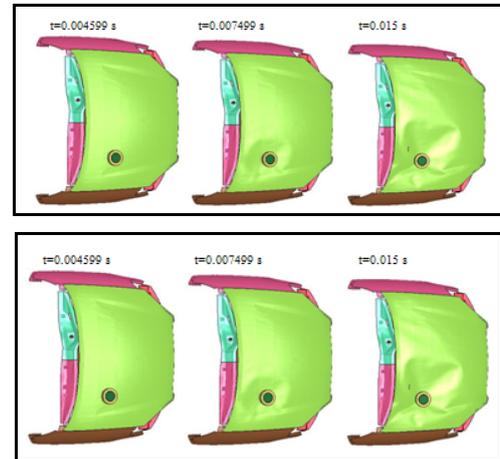


Fig. 10 Head impact simulation at various timestep for baseline model position 1 and position 2

Table. 2 Acceleration and HIC values for baseline model

Head Form Position	Acceleration (g)	HIC Obtained	HIC Required
Position 1	409	2144	< 1000
Position 2	368	2400	< 1000

6.4 Baseline Structural and Modal Analysis

The structural analysis for the baseline hood assembly model was done in order to find out the local, global, torsional stiffness values and natural frequencies of the present hood.

Table. 3 Displacement and Stress values of baseline model for various load cases

SI No	Type of Analysis	Displacement (mm)	von Mises Stress (MPa)
1	Oil Canning	0.107	16.41
2	Self Weight	0.047	6.09
3	Torsion	0.36	31.5

Thus the deformation and stress values of the baseline model analysis are taken as the benchmark for further design of the hood inner panel. From oil canning analysis it is seen that the deflection of the hood is 0.107 mm for the load of 50N and thus the local stiffness of the hood is 467.2 N/mm.

6.5 Design and Selection of Modified Hood Inner Panel

The HIC value is directly proportional to stiffness and inversely proportional to the deformation of the hood. Thus in order to design the hood for pedestrian friendliness the inner panel of the hood which provides reinforcement to the outer hood panel is redesigned focusing on reducing the local stiffness of the hood and thereby increasing the deformation of the hood.

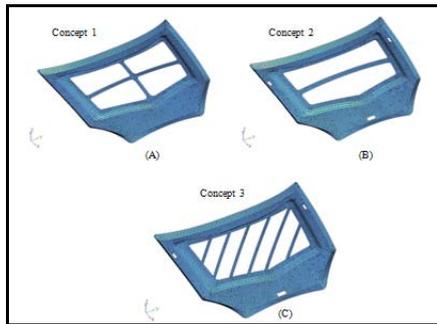


Fig. 11 New design hood inner panels A, B and C

Stiffness of the component varies either by changing the geometry of the component or by changing the material properties of the component. In this work the stiffness of the hood was varied by changing the geometry of the hood. Figure 11 shows three designs of the hood inner panel which has smaller cross section ribs in the area of head impact. The model was created in CATIA V5 as a surface model and was meshed in Hypermesh.

In order to finalise the new design of hood inner panel from the above three again the structural and modal analysis for the three concepts were performed and results of the three concepts namely local stiffness, global stiffness, torsional stiffness and the modal frequencies is compared with the benchmarked baseline model.

7. RESULTS AND DISCUSSION

7.1 Structural and Modal Analysis of Modified Hood

Structural Analysis of the modified hood assembly for the three concepts was done to find out the local, global, torsional and natural frequencies of the modified hood structures. From that, the hood inner panel concept which has lower local stiffness and similar global, torsional stiffness was selected.

7.2 Results of Modified Hood Inner Panel

The Summary of the results for the structural analysis of the modified hood inner panel concepts are shown in table 3. From Table 3 and 4 it is evident that the modified hood inner panel concept 2 has less local stiffness when compared to the others and the global and torsional stiffness values of this model is almost similar to that of the baseline hood model. The natural

frequencies of this concept 2 are also similar to the baseline model. Thus the concept 2 was finalized for head impact analysis to analyze the head form acceleration at different locations.

Table. 3 Comparison of structural analysis results of modified hood with baseline

Sl No	Type of Analysis	Model	Displacement (mm)	vonMises Stress (MPa)
1	Oil Canning (Local Stiffness)	Baseline	0.107	16.41
		Concept 1	0.16	29.79
		Concept 2	0.22	55.51
		Concept 3	0.179	12.65
2	Self Weight (Global Stiffness)	Baseline	0.047	6.09
		Concept 1	0.051	4.66
		Concept 2	0.05	4.63
		Concept 3	0.044	4.614
3	Torsion (Torsional Stiffness)	Baseline	0.36	31.5
		Concept 1	0.31	25.24
		Concept 2	0.36	52.1
		Concept 3	0.39	92.62

Table. 4 Comparison of natural frequencies of baseline and modified model

Set No	Frequency (Hz)	
	Baseline Model	Concept 2
1	39.27	37.42
2	52.96	63.05
3	82.05	92.4
4	96.7	107.16
5	99.02	126.74

7.3 Modified Hood Model Head Impact Analysis

Head impact analysis for the modified hood was done and the results of the head acceleration for the modified hood were compared with baseline model.

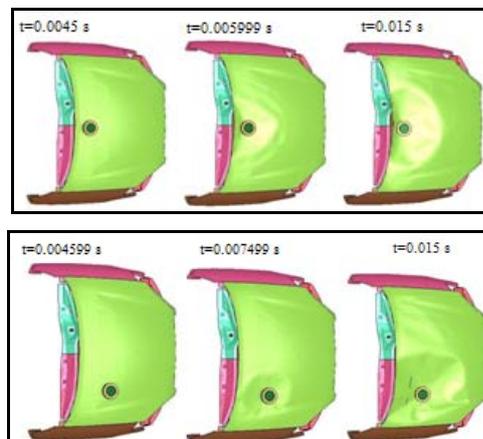


Fig. 12 Head impact simulation at various time step for concept 2 at position 1 and position 2

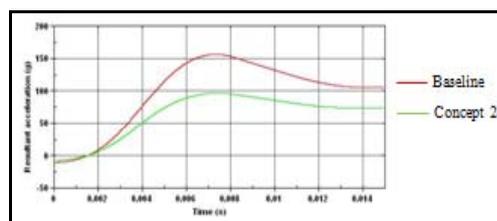


Fig. 13 Comparison of HIC for concept 2 and baseline hood model at position 1

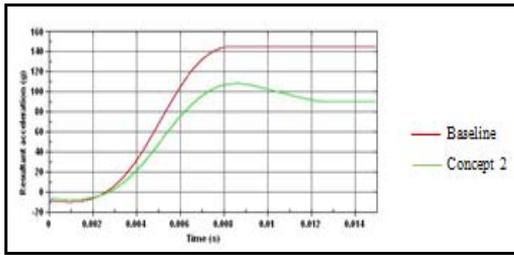


Fig. 14 Comparison of HIC for concept 2 and baseline hood model at position 2

Figure 13 and 14 shows the comparison of HIC values and it was seen that the acceleration of the head form was reduced when compared to that of the baseline model. This is because the stiffness of the hood in the impact area was reduced and the deformation of the hood was more thereby absorbing more amount of impact energy. Also there is no secondary acceleration of the head due to components underneath the hood because of more clearance between the hood and the engine components.

Table. 5 Comparison of HIC of head for baseline and concept 2 hood model

SI No	Description	Position 1		Position 2	
		Baseline	Concept 2	Baseline	Concept 2
1	HIC	2144	706	2400	948
2	Acceleration	409	219	368	283

Table 5 shows the comparison of HIC value and the head acceleration of the baseline and concept 2 hood model. It was seen that due to lower local stiffness of the concept 2 hood model the HIC value and the resultant head acceleration has been reduced. HIC values for the concept 2 hood model at two different positions are 706 and 948 respectively which are well within 1000 as proposed by EEVC WG17 for the safety of the pedestrian and thus the modified hood inner panel concept 2 of the sedan car is pedestrian friendly.

8. CONCLUSIONS

Head impact analysis was simulated in present hood and the hic value was found to be 2144 and 2400 at two locations. These values exceed the adult head form limitation of 1000. redesign of the hood inner panel was carried out considering the hood design requirements. Head impact analysis with modified hood was simulated and the hic values are found to be 760 and 948 at two locations which are within the target value. Thus the new design of the hood is pedestrian friendly, considerably maintaining the overall global stiffness of the hood.

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