REDESIGN OF REAR END OF A CAR TO MINIMISE WHIPLASH INJURY

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Abstract

Among automobile related injuries, whiplash injury is very common. Its occurrence is quite common as this can be caused even by collisions at very low speeds. It does not get as much attention as the injuries sustained during frontal collision even though these can be quite debilitating and have long term effects. In this project , with an aim to minimise the severity of whiplash injury to the occupants during rear end collisions, rear end of a car has been redesigned. Parts of rear end structure of a popular car have been redesigned to manage crash energy better during rear end collisions.

In the current project work, first a rear end collision between two models of Geo Metro, a popular automobile was simulated using explicit dynamic simulation. From the results of this simulation crash pulse, deceleration experienced by the car hit from behind, was obtained. This was used as "load' in the multibody simulation of a sled test to assess the effect of collision on the physiology of the occupant and resulting injury levels. The simulation also provided in insight into the crash energy management of the components in the rear end. Designs of components of rear end structure for better energy management and reduced injuries to the occupants were developed and analysed. From among many designs, some designs were successful in bringing down the injury levels to the occupants within acceptable levels. This was checked for three very common types of rear end collisions – full width, 50% offset and 30º oblique conditions.

Keywords: Torque Converter, CFD Analysis, Speed Ratio, Flow Separation Region

Nomenclature

a_x	Head CG acceleration in x-direction, m/s^2
a_{rel}	Relative Acceleration, m/s^2
a_x (T1)	First thoracic vertibra acceleration in x-direction, m/s^2
v_{rel}	Relative Velocity, m/s

Abbreviations

CAD	Computer Aided Design
CAE	Computer Aided Engineering
CFC	Channal Frequencies Class
IIHS	Insurance Institute for Highway Safety
NIC	Neck Injury Criteria

1. INTRODUCTION

Rear end collision (Figure 1) is a common accidents seen in western countries with less or no injury to the occupants neck by spending huge amount of societal amount by the insurance companies to this kind of collision. The occupants have an influence by this type of collision causing the neck to hyper extension and hyper flexion of the neck. Injury can be seen at the time of impact or after a day. The severity of the injury starts from short term to long term which can cure for 1 day or it may take several years. Real-life crash statistics shows that, even at relatively low speeds, neck injuries are one of the most common injuries during rear end collision. This kind of collision leads to no or less structural damage to the car.

Fig. 1 Rear end collision scenario

Occupant safety is also the important considerations during the assessment of new car rating. Due to an increase in this type of collisions globally the importance is being given to the occupant safety. The insurance company is funding for this type of collision conditions to identify the reason and to reduce the severity for minimising the amount spent about this minor injury (IIHS-Insurance Institute for Highway Safety).

The societal amount spent by the insurance company for this type of collision condition are as follows: In UK the amount spent is around 3.1 billion € every year for this type of injury, as well as even though the accidents record shows reduction in accidents from 2006 but there has been increase in this type of collision 1600 every day [7,8].

The study is focused on the hatch back car based on the obtained injury levels for this segment. In India the commonly used car segment is hatch back hence the study is focused on this segment for the rear end collision performance with occupant whiplash injury level.

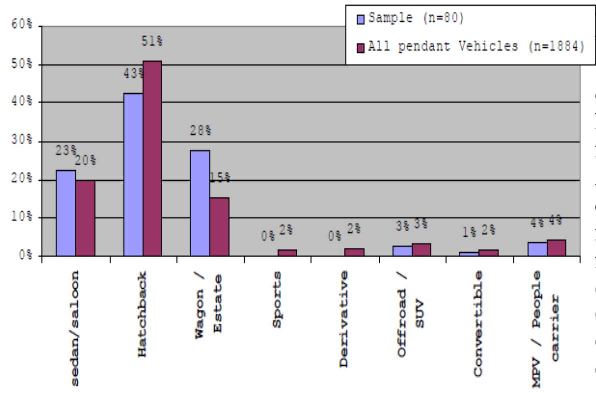


Fig. 2 Injury level for different car segments

By considering the accident data the most commonly seen collision is rear end collision and the affected is the hatch back segment cars. hence the study is focused on the redesigning of the rear end of an hatch back segment car i.e., Geo Metro. Also considering the Indian market scenario the most owned car are the hatch back segments (Figure 2).

Whiplash injury is most common found during rear end collision, it's a soft tissue neck injury occurs with relative head and neck movement. The mechanism of the injury (Figure 3) starts form the normal position, it extends back (hyper extension) and it moves forward (hyper flexion).

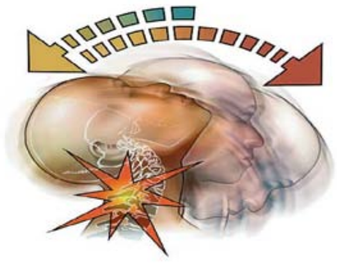


Fig. 3 Whiplash injury mechanism

A number of research has been done based on the rear end collision in order to minimise injury level as well as the amount spent for this type of minor injury. And the researchers studied only on the seat design and recliner design to minimise the injury level during rear end collision. The focus of study on the structural modification has not been carried out, hence the gap was filled by conducting the study on structural modification to minimise the injury level. The rear end of a vehicle has less or short crumple zone. Bumper system is predominant system of energy absorption between impact and occupant. During rear end collision the affected is struck car occupants. Impact energy management within the vehicle to prevent injury requires improved occupant protection with high elastic behavior of the vehicle frame. Due to high incident rate the current bumper system should be re-evaluated for rear end collision condition. Martine [1] the risk of whiplash injuries in rear end collision is twice higher than frontal collision. Anita Berglund et al. [3] crash related factors such as age, gender; seating position influences the risk of whiplash. Also reported that females were the highest affected during rear end collision. Krafft et al. [2] mean acceleration influences the risk of whiplash injury. According to various studies the velocity of the vehicle below 20 km/h is the major concern to the whiplash injury during rear end collision. Hambali [5] various design for the bumper beams includes hollow tube, D-shape, hat box, x-ribbon etc. Avery et al [6] bumper beam was the key feature in determining the severity of the damage to the vehicles in low speed impacts. Bostrom et al.[4] reported the filters used according to channel frequencies class (CFC) for different digital output signals filtered at CFC 60, occupants head acceleration signals is filtered at CFC 1000 and the sled acceleration signals is filtered at CFC 60.

2. GEOMETRIC MODEL

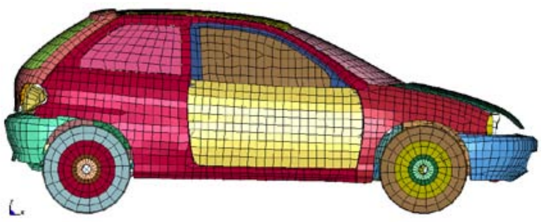


Fig. 4 Geo Metro car model [9]

The finite element model is obtained from national highway traffic safety administration (NHTSA). The car model is an hatch back segment Geo Metro (Figure 4) and modelled for different impact conditions using LS-Dyna. The sled test setup is built using plane method in XMADgic based on the standard seat measurement. The human kinematics is studied using ellipsoid Hybrid III 50th percentile male dummy using Multibody dynamics. The critical components is modelled using CAD software. To optimize the results parametric study was carried using CAD, CAE. The redesigned component is dynamically tested for different impact conditions and conventional materials (aluminium and steel).

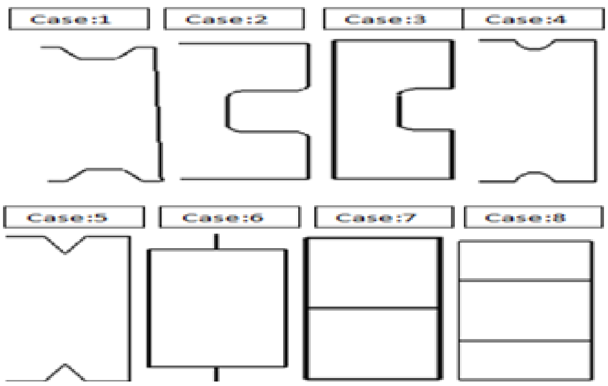


Fig. 5 Various cross sections used to study the performance

The cross sections of the bumper beam has been designed to absorb energy to minimise the injury to the occupents. The cross sections studied to know the performance of the occupents are crush tube, double c channel, tyre tread, semi circular notch, v notch, hat, double rectangular and tripple rectangulat sections (Figure 5).

2.1 Details of the Numerical Model

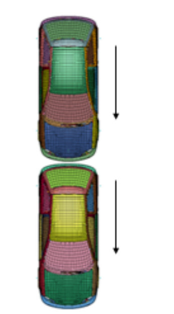
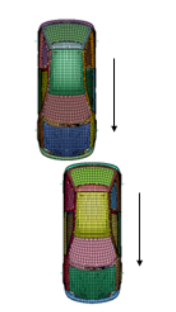
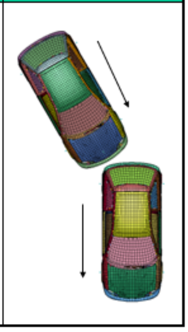
The study is focused on explicit solution this method can readily analyse problems involving complex contact interaction between many independent bodies. The explicit finite element analysis is simulated using LS-Dyna pre-post. boundary conditions and initial parameters has been assigned based on the impact condition. For rear end collision condition the initial velocity of the bullet car is 15 km/h with automatic single surface contact between the target and bullet car. The simulation time is considered as 150 mille-sec. After completion of the simulation results are obtained which is obtained through LS-Dyna post process.

And the obtained result (pulse data) is feed to the multibody dynamics to study the performance of the human neck during rear end collision.

The sled test setup is built using MADYMO (Multibody dynamics) and the dummy used to study the performance is Hybrid III which is positioned to the seat built with all the restraint systems to study the behavior of the dummy during rear end collision and to study the injury level. the simulation time for the sled test is also same as the explicit simulation time.

Different impact conditions studied were modeled using LS-Dyna (Table 1).

Table 1. Different impact conditions studied during rear end collison

Full width	Offset	Oblique
		

Occupents kinamatics is observed from the Hybrid III 50th percentile male dummy, which mimmics the human behavour during the collision conditions. Based on its flexibility during different impact conditions, hence Hybrid III dummy is used to study the performance. The dummy is possitioned on the sled built using multibody dynamic software package (XMADgic) and required restraint systems, sensors has to be mounted to the first thoracic vertibre (Figure 6, 7) and the output signals is created for the rear end collision condition.

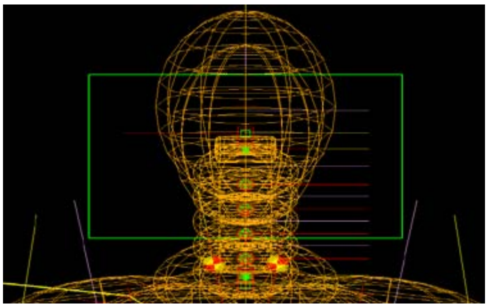


Fig. 6 Output sensors mounted at the first thoracic vertibre

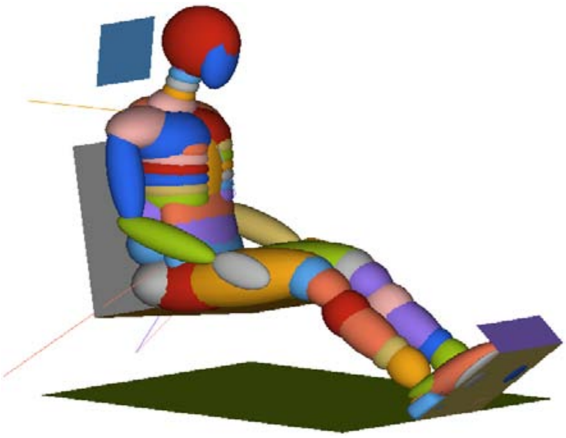


Fig. 7 Dummy positioned with all the restraint system

2.2 Solution Procedure

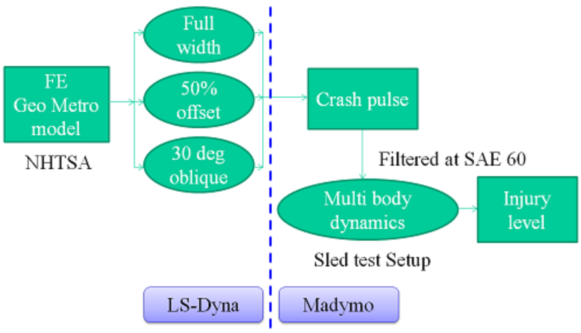


Fig. 8 Flow chart

The study of rear end collision and occupant safety performance is represented with the flow chat (Figure 8). Firstly the bench mark solution is conducted, the performance of vehicle and occupants reviles the need to redesign. Hence redesign process has been carried out which is represented with the flow chart (Figure 9) to minimise the whiplash injury.

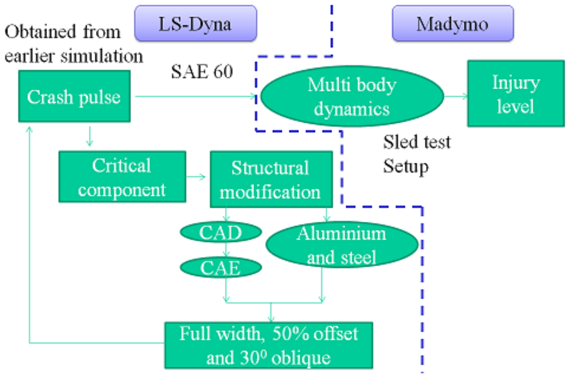


Fig. 9 Redesign flow chart

3. VALIDATION

In order to know the performance of simulation in the dynamic testing the results obtained is validated with the obtained literatures. Gert [1] reported the limit for the vehicle dynamic response i.e.,11 to 30 g's also the human lower neck response is around 7 g's. After successful completion of simulation it shows that the obtained crash pulse is within that range, hence the results are validating (Figure 10).

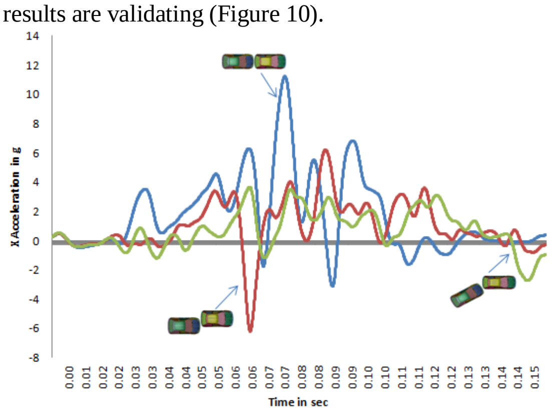


Fig. 10 Crash pulse for different impact conditions

4. NECK INJURY CRITERIA, NIC [10]

To determine whiplash injury level during rear end collision NIC is an important criterion considered to study the performance of the human kinematics to minimise whiplash injury. NIC is expressed by the relative acceleration between upper (head) and lower neck (thorax) acceleration. It measures the neck load before contact with the head restraint [10].

$$NIC = (0.2 * a_{rel} + V_{rel}^2)$$

$$a_{rel} = a_x(T1) - a_x(Head)$$

$$V_{rel} = \int a_{rel}\,dt$$

Where,

$a_x(T1)$	First thoracic vertebra acceleration in x-direction (m/s^2)
a_x (Head)	Head C. G acceleration in x-direction (m/s^2)
a_{rel}	Relative Acceleration (m/s^2)
V_{rel}	Relative velocity (m/s)

5. RESULTS AND DISCUSSIONS

During rear end collision the injury criteria considered is NIC in order to study the severity of the injury during rear end collision. The curve deceleration verses time (Figure 11) shows the response of a car during dynamic full width collision condition. The critical component can be identified at the high-low-high profile of the curve obtained through accelerometer sensor (crash pulse).

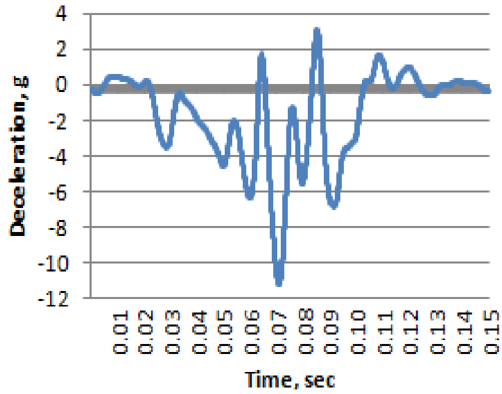


Fig. 11 Deceleration verses time plot for full width impact condition

In rear end collision, there is less space to manage energy absorption, rear bumper system has to be managed hence to design the structural component to absorb energy different cross section of bumper beam has been studied including materials and impact conditions. From (Figure 12) it can be observed that design 7 and 8 is absorbing maximum amount of energy during collision considering all the conditions.

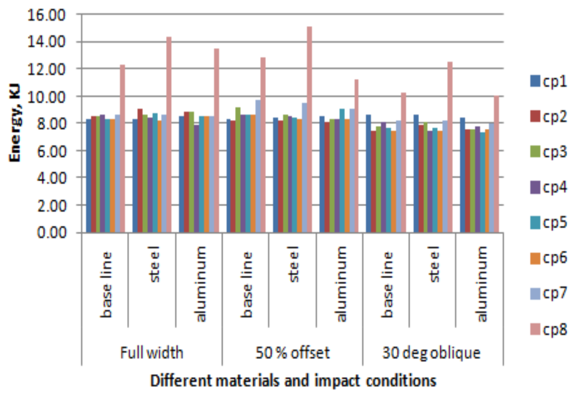


Fig. 12 Energy absorbed by different concepts for different materials and impact conditions

The displacement of the structural component is observed to be good in 7th design when compared to other design consedering all the conditions (Figure 13).

The study is focused to minimise whiplash injury, in rear end collision (NIC) neck injury criteria is one of the important consideration considered to study the performance of the dummy. From the results obtained for different designs considering all the conditions design 7 is found to be the minimum value (Figure 14).

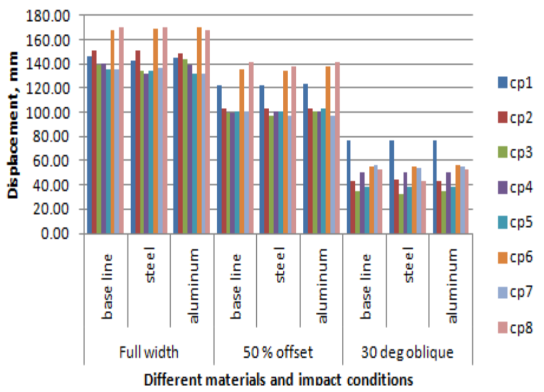


Fig. 13 Displacement of differnt concepts for different materials and impact conditions

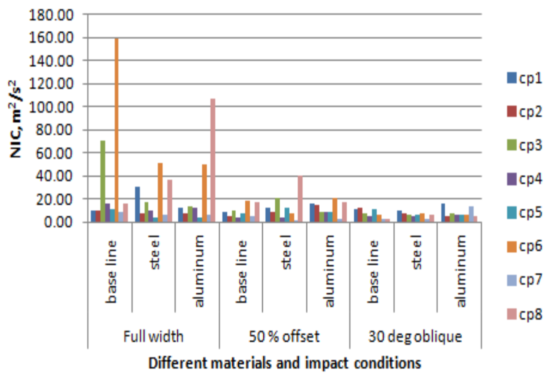


Fig. 14 Neck injury critera value for different materials and impact conditions

5.1 Comparison Study

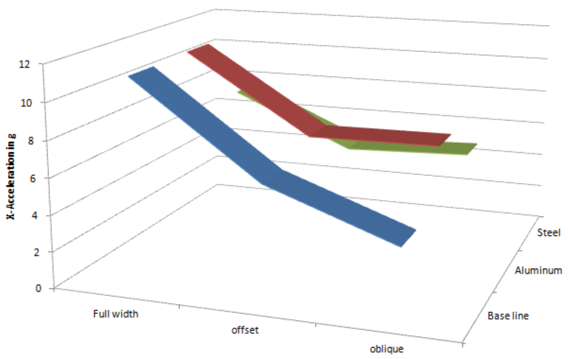


Fig. 15 Vehicle performance (baseline design)

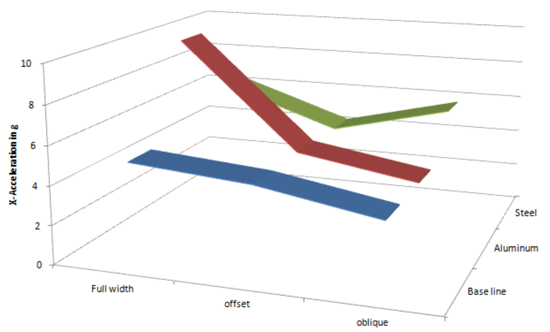


Fig. 15 Vehicle performance (new design)

It can be observed that the vehicle dynamic performance has been reduced by implimenting new design modification to the Geo Metro car model (Figure 14 and 15).

6. CONCLUSIONS

The Geo metro (hatchback segment) rear end bumper system has been redesigned with improved occupant safety without sacrificing its crash worthy requirements.

From the study the following conclusions were made

- Physical shape of bumper beam is the issue that was investigated in order to choose the best shape or geometry of bumper beam because it gives a significant role in overall bumper performance.
- In full width impact collision the vehicle accelerations are higher compared to other two collisions.
- Material selection for the bumper beam should be based on its application. From study the steel is the best alternative compared to other materials.
- Multi section beam provides better performance compared to single section beam.
- Bumper beam has to absorb maximum energy in order to protect the occupant.
- Bumper beam has to satisfy all the impact collisions in order to protect the occupant from injury.
- From the study it was observed that design 7 is meeting the required occupant safety conditions.
- The final design can be produced with extrusion process.

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