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An Exploration of Alternate Design of Automotive Front End Structure for Improving both Pedestrian and Occupant Safety Requirements

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ABSTRACT

Pedestrian protection is one of the key topics safety measures in traffic accidents all over the world. To analyse the relation between the collision site of the vehicle bumper and the severity of the lower extremity injuries, we performed biomechanical experiments. We found that foam materials around the rigid front cross member had a significant effect on the reducing the lower extremity injury risks especially tibia fracture risk against vehicle bumper centre collisions. Because of rapid increase in urban population and hence road traffic, the vehicle-pedestrian crashes are more frequently and have become a major concern in road traffic safety though the bumper of a vehicle plays an important role to protect the vehicle body damage in lower speed impacts, many bumpers particularly in large vehicles are too stiff for pedestrian protection and safety to prevent lower extremity injuries in car-pedestrian collisions, it is important to determine the loadings that car front structures impact on the lower extremities and the mechanism by which the injuries are caused the collision mechanism between a GMT bumper and the legform impactor model is investigated numerically using LS-DYNA software. In this paper the work is concerned with an exploration of alternate designs for improving both pedestrian and occupant safety requirements of automotive design. The front end structure should sufficiently stiff to protect the occupant by absorbing the impact energy generated during frontal collision and at the same time it should not include unduly high impact loads during the pedestrian collision these two requirements conflict each other and there should exist an optimum design solution that meets both the requirements. Considering the peek deceleration extracted from the New Car Assessment Programme (NCAP) crash pulse and the impact force generated on the pedestrian as constrained parameters, the design of bumper facia and bumper beam is studied and alternate design recommendations were proposed and analyzed using explicit finite element analysis.

Keywords *- Wind-Shield Glass, LS-DYNA, Bumper, Crashworthiness, FMVSS.*

1. INTRODUCTION

In recent years automotive crashworthiness design and pedestrian safety are becoming important due to enormous increase in the number of road vehicles, road fatalities and government safety regulations. Road traffic accidents kill more than one million people a year, injuring another thirty-eight million (5 million of them seriously). The present work is focused on exploring alternate designs of the vehicle front end structure that meets both pedestrian and occupant safety requirements. There are various distinct periods in the development history of automotive safety. An early period of safety from the turn of the century to 1935 was a period of genesis, growth, and development to understanding the extremely complex process of vehicle collisions. This period focused on basic improvements such as reduction of tire blowouts to avoid loss of vehicle control; introduction of the self-starter to eliminate injuries associated with engine cranking; incorporation of headlamps to provide for might visibility, installing laminated glass to reduce facial lacerations and adopting an all steel body structure for better occupant protection. In addition, the first full-scale tests were conducted in the early 1930's. These tests involved rollover simulations and car-to-barrier impact. Statisticians estimated that the fatality rate in 1935 was approximately 17 per 100 million vehicle travelled. The next period from 1936 to 1965 was an intermediate safety period. Early in this period, auto manufactures introduced many crash avoidance devices including turn signals, dual windshield wipers, improved headlamps, a test to simulate head impact into the instrument panel, and high penetration-resistant windshield glass. In addition, General Motors conducted the first car-to-barrier frontal crash test, launching a vehicle into a retaining wall. Today, transportation safety efforts focus on crashworthiness, crush avoidance, driver performance, and highway construction. Over the past decade automakers have added many active and passive safety measures to help the occupant avoid a crash, such as anti-lock braking systems, traction control devices and daytime running lamps.

2. CRASHWORTHINESS AND ITS REQUIREMENTS

***Occupant Safety*:** Crashworthiness is the measure of how well a vehicle provides protection to its occupants during a collision. The impact that results from two cars travelling in opposite directions is often severe; therefore there is a need to address the occupant safety crashworthiness requirements during the early design phase of an automotive. In United States of America there are stringent requirements on the part of the vehicle manufacturer to meet the regulations and some specific tests are carried by Global NCAP (New Car Assessment Programme) before launching the new vehicles. Recently the tests were performed on the following cars: Tata Nano, Maruti Suzuki Alto 800, Hyundai i10, Ford Figo and Volkswagen Polo (manufactured in India) by London car safety watchdog global (NCAP) and it was found that all five cars failed the test, landing a zero on a scale of 1-5. The vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling it should minimize high frequency fore-aft vibrations that give rise to harshness.

In addition, the structure should yield a deceleration pulse that satisfies the following requirements for a range of occupant sizes, ages and crash speed for both genders:

- Deformable, yet stiff front structure with crumple zones to absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and prevents intrusion into the occupant compartment, especially in case of offset crashes and collisions with narrow objects such as trees.
- Deformable rear structure to maintain integrity of the rear passenger compartment and protect the fuel tank.
- Properly designed side structures, B-pillars and doors to minimize intrusion in side impact and prevent doors from opening due to crash loads.
- Strong roof structure that satisfies the crush requirements for roll over protection.
- Properly designed restrained systems that work in harmony with the vehicle structure to provide the occupant with optimal ride down and protection in different interior spaces and trims.
- Accommodate various chassis designs for different power train locations and drive configurations.

Basically, there are two stages in a vehicle frontal impact with a fixed barrier: the primary and secondary impacts. The primary is the collision between the front end structure and the fixed barrier. During the impact mode, the major portion of the crush energy is absorbed by way of structural deformation that produces a crash pulse transmitted to the occupant compartment. The compartment intrusion is largely affected by the extent of the vehicle front end deformation which is, in turn influenced by vehicle package space, the stack up of non-crushable power train components, the vehicle restraint system or the vehicle interior.

The Federal Motor Vehicle Safety Standards (FMVSS) adopts the frontal rigid barrier collision test as a standard to evaluate the crashworthiness for occupant safety. This specifies performance standards for the vehicle occupant and the severity of injuries on the roads. This is accomplished by specifying vehicle crashworthiness requirements in terms of force and deceleration measurements on a 50^{th} percentile Hybrid III dummy as a human surrogate in crash tests and by specifying active and passive restraint requirements.

***Pedestrian safety*:** The design of vehicle front structures is important for decreasing the pedestrian injuries. However, the protection of the pedestrians has received less attention. The Bumper of a vehicle plays a major role to protect the vehicle body damage in low speed impacts. Many bumpers, particularly in large vehicles are too stiff for pedestrian protection. In design of a new bumper for an automobile, pedestrian protection is as important as bumpers energy absorption in low speed collision and the efforts focused for designing an optimum bumper. Analysis of vehicle in frontal crash event, in general consists of studies of the vehicle response and occupant response. In the European Union more than 7000 pedestrians and 2000 pedal cyclists are killed every year in road accidents, while several hundred thousands are injured. Serious or fatal injuries can be sustained at relatively low speeds between 25 and 50 km/h.

In recent years there have been proposals in Europe to legislate requirements in this area and therefore considerable effort has been focused on developing a vehicle performance requirement. The (EEVC) has proposed a test procedure to assess the protection vehicles provide to pedestrians during a collision. In EEVC/WG17, pedestrian protection test consists of three impact tests:

- The head form impactor to bonnet top test.
- The legform impactor to bumper test.

•The upper legform impactor to bonnet leading edge test.

As leg injuries from the bumper are the most common injuries in nonfatal pedestrian accidents (38%), current investigations focus on the accident conditions in vehicle bumper-pedestrian leg injuries. This procedure utilizes a legform impactor developed by the Transport Research Laboratory (TRL). The goal of this study is to establish a methodology to understand injury mechanisms of both ligament damages and bone fractures in car-pedestrian accidents. A pedestrian legform impactor is a tool for the evaluation of car front bumper aggressiveness when simulating a pedestrian leg hit by a car. Impact is imposed to the bumper at 40km/h velocity parallel to the longitudinal axis of the vehicle on at least three points where injuries or shape changes may result. The lower leg acceleration, knee shearing displacement and knee bending angle are measured. The lower leg acceleration is used to evaluate tibia fracture risk, and the shear displacement and bending angle are used to evaluate cruciate and collateral ligaments injury risks, respectively. The maximum dynamic knee bending angle shall not exceed 15°, the maximum dynamic knee shearing displacement shall not exceed 6mm, and the acceleration measured at the upper end of the tibia shall not exceed 150 G.

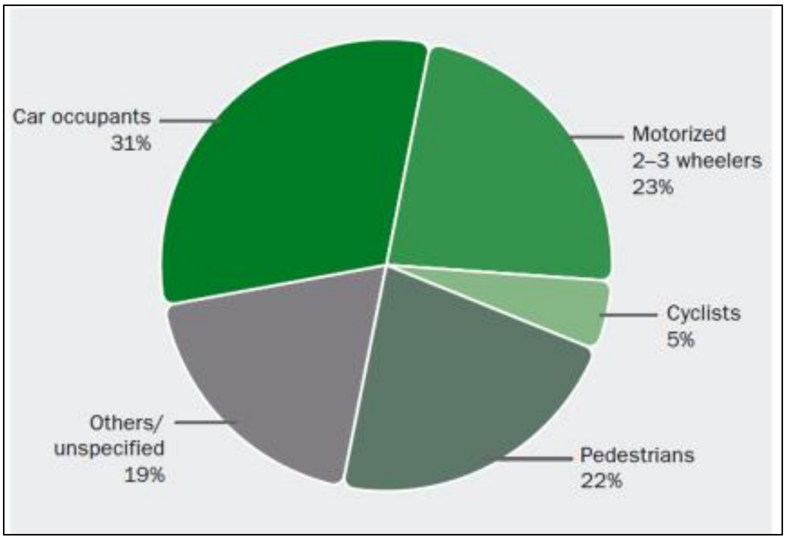

Fig 1: Distribution of Road Traffic Deaths by Type of Road User, GLOBAL (2010)

2.1 Automotive Safety Requirements

There are low speed and high speed impact test requirements that a vehicle need to meet. The following are the current norms that are followed in USA.

- Low speed impact test at 4 km/h with no damage to the bumper (after the test, any damage to the bumper visual and functional should not occur).
- High speed impact test, here the bumper system has to absorb enough energy to meet the bumper standard in design stage. No bumper damage or yielding after 8 km/h frontal impact into a flat, rigid barrier.
- Pedestrian impact test, the bumper system requires elastic energy absorption before any plastic yielding of the bumper beam takes place.
- The accelerations on the occupant should not exceed 41G during a frontal collision, when the vehicle hits a rigid barrier with a speed of 35 miles/hour (FMVSS 208).

Crash tests to be mandatory for all new cars from October 2017. Passing minimum frontal and side crash tests will be mandatory for all new cars from October 2017 while for new vehicles of existing models the deadline will be October 2019.

2.2 Vehicle Front End Components Under Study

2.2.1 Bumper Beam

A bumper is a structural component which mounted on the front and rear of a passenger car ostensibly designed to allow the car to sustain an impact without damage to the vehicle's safety systems. When a low speed collision occurs, the boomer system absorbs the shock to prevent or reduce the damage to the car. Dampers are designed to protect the hood, trunk, fuel, exhaust and cooling system.

2.2.2 Bumper Fascia

The fascia is designed with aerodynamic form and also it works as bearing for spring system. Twenty five numbers of helical springs are attached to fascia which works as a mechanical energy absorber.

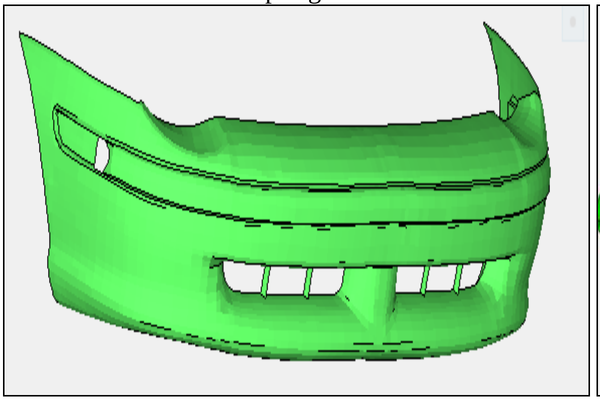

Fig 2: Bumper Fascia.

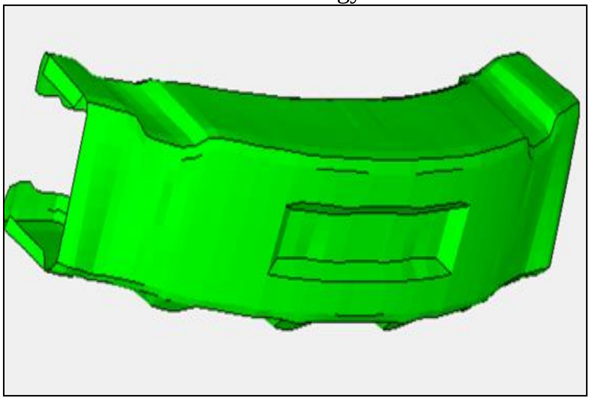

Fig 3: Bumper Beam.

3. METHODOLOGY

Initially base line Finite element model of Dodge Neon is extracted from NCAC website (National crash analysis center) [12] and the FE model was calibrated, various alternative designs were explored and introduced between the bumper and bumper facia for getting improvement in energy absorption. Analysis was then performed on these conceptual designs to identify the best performing design.

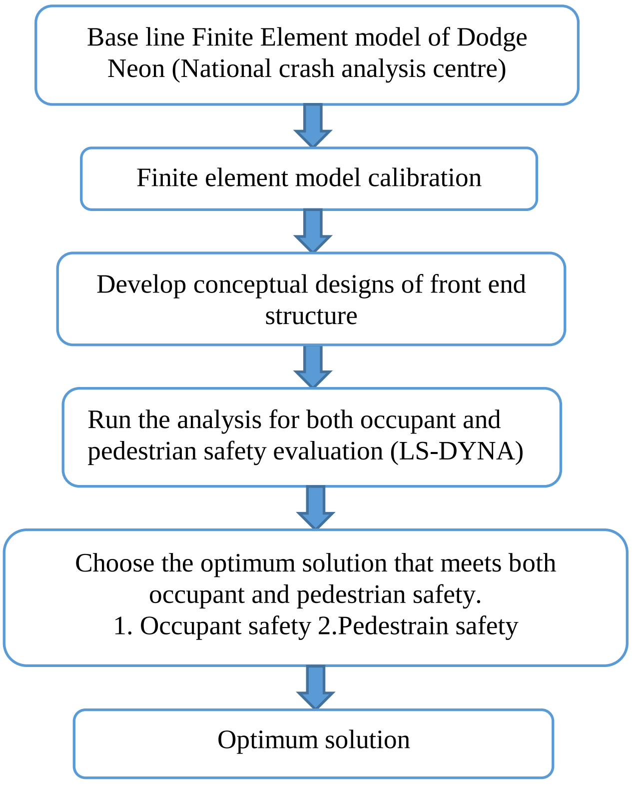

Fig 4: Flow Chart of the Methodology.

5. RESULTS AND DISCUSSIONS

5.1 Material Properties Used For Envelope:

Material Properties	Polypropylene	Foam
Young's Modulus (E), MPa	1400	50
Poisson's Ratio (υ)	0.3	0.35
Density (ρ), ton/mm^3	1.0 e^{-9}	6.0 e^{-11}
Yield Strength (σ), MPa	30	10

Table 1: Material Properties of Polypropylene and Foam.

5.2 Concept 1: Letter 'W' Shape

Fig 5 shows the details of the front end energy absorption component that are assembled in between Bumper fascia and Bumper beam. Foam is embedded in a closed envelope made up of polypropylene. Reinforcement of Letter W Shape is placed at regular intervals and is enclosed inside the low density polyurethane foam. This envelope assembly is bolted to the bumper beam.

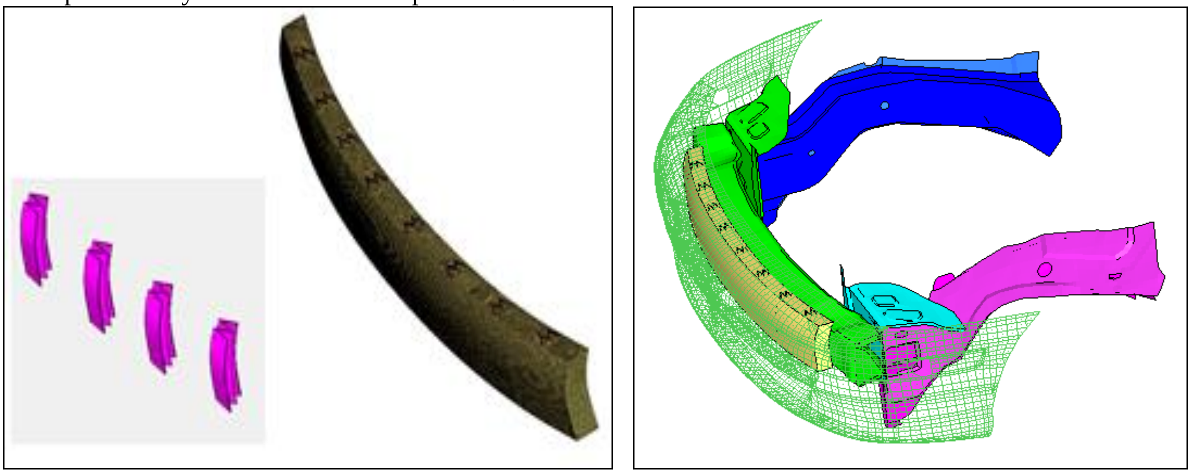

Fig 5: W Shape Front End Energy Absorption Component.

5.3 Concept 2: Circular Tubes

Fig 6 shows the details of the front end energy absorption component that are assembled in between Bumper fascia and Bumper beam. Foam is embedded in a closed envelope made up of polypropylene. Reinforcement of Circular Tubes is placed at regular intervals and is enclosed inside the low density polyurethane foam. This envelope assembly is bolted to the bumper beam.

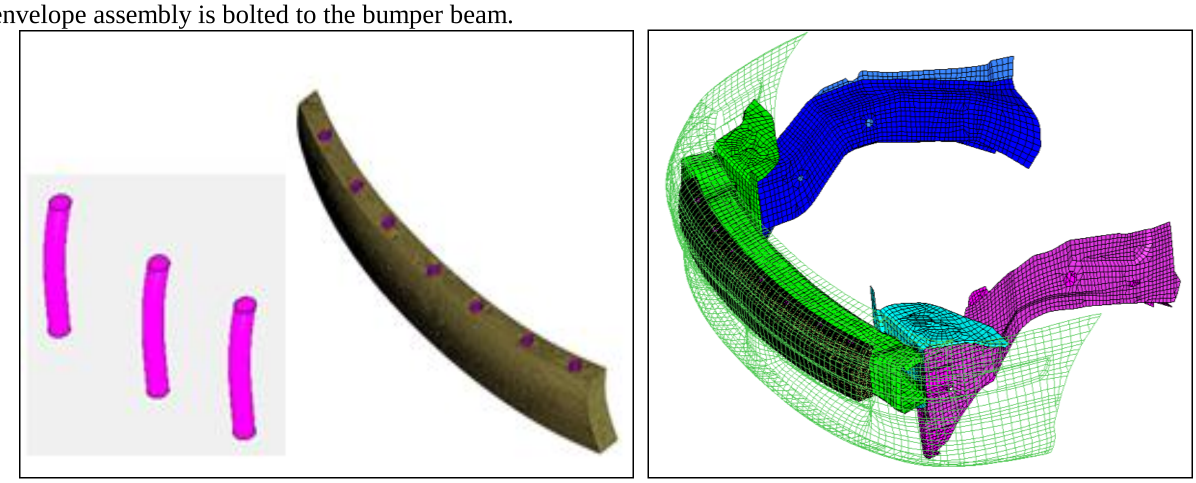

Fig 6: Circular Tube Front End Energy Absorption Component.

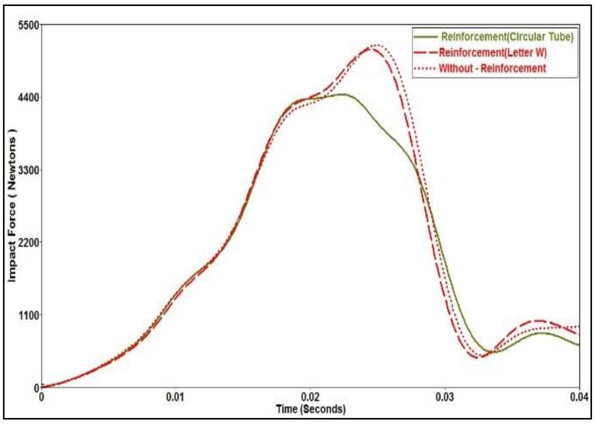

Fig 7: Impact Force v/s Time plot.

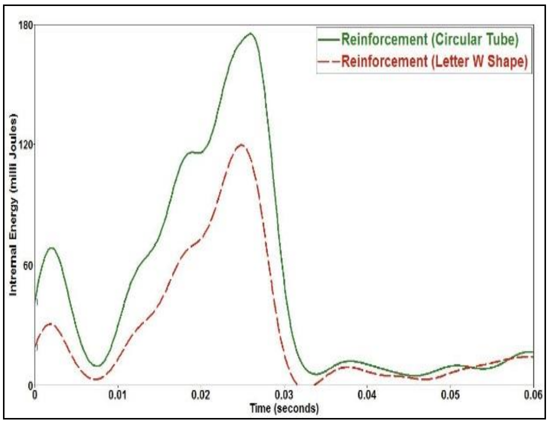

Fig 8: Internal Energy v/s Time plot.

6. CONCLUSION

The following concepts are generated in the present study and explained briefly as follows:

• It is noted from fig 7, that the impact force is reduced by nearly 15% in case of circular reinforcement (concept 2) in comparison with other concepts.

• The G level experienced by the occupant is found to be same for all the concepts.

• It is shown in fig 8, that the circular tube absorb more energy compared to Letter W Shape design, which resulted in generation of lesser impact force in the circular reinforcement design.

REFERENCES

1. Development of a New Model of EEVC/WG17 lower Legform for Pedestrian Safety by Alireza Noorpoor et al.
2. Development process of new bumper beam for passenger car: A review by M.M. Davoodi et al.
3. Smart bumper for pedestrian protection by Alessandro Zanella et al.
4. Severity of vehicle bumper location in vehicle-to-pedestrian impact accidents by Yasuhiro Matsui et al.
5. C.P-Y. Rohan et al, "*Biomechanical response of varicose veins to elastic compression: A numerical study*".
6. Robert P. Kaufman, Randal P. Ching, Margaret M. Willis, Christopher D Mack, "*Burst fractures of the lumbar spine in frontal crashes*", Accident Analysis and Prevention 59(2013) 153-163
7. Francis Denis, "*The three column spine and its significance in the classification of acute thoracolumbar spinal injuries*", Spine, Volume 8 , Number 8,1983
8. Nicolas V. Jaumard, William C. Welch, Beth A. Winkelstein, "*Spinal facet joint biomechanics and mechanotransduction in normal, injury and degenerative conditions*", Journal of Biomechanical Engineering, JULY 2011, Vol. 133/071010-1.
9. S-J Hsieh, S-W Yang, "*Dynamics Finite Element Analysis of the lumbar spine injury on collision*", Y-Y Chien Poster session 2/Rehabilitation 14:10-15:10, Room 103& Alley Area Poster 248
10. Sean Gallagher, William S. Marras, "*Tolerance of the lumbar spine to shear: A review and recommended exposure limits*", Clinical Biomechanics 27 (2012) 973–978.
11. Alison C.Jones, Ruth K.Wilcox, "*Finite element analysis of the spine: towards a framework of verification, validation and sensitivity analysis*", Medical engineering and physics 30(2008) 1287-1304.
12. http://www.ncac.gwu.edu/vml/models.html
13. http://www.ncac.gwu.edu/vml/archive/ncac/vehicle/neon-0.7.pdf.
14. Times of India Newspaper article clipping, dated 1st March 2015.
15. Pedestrian safety: A road safety manual for decision-makers and practitioners by World Health Organization 2013.
16. Deb A, Gunti R, chou,c, and Dutta,U, "*Use of Truncated Finite Element Modeling for Efficient Design Optimization of an Automotive Front End Structure*", SAE technical paper2015-01-0496, 2015, doi:10.4271/2015-01-0496
17. Development of practical multi-disciplinary design optimization (MDO) algorithm for vehicle body design by Anindya Deb.