

Influence of Vehicle Front End Design on Pedestrian Lower Leg Performance for SUV Class Vehicle

2011-01-0084

Published
04/12/2011

Milind Bhagat, Sujit Chalipat and Amod Ranade
Tata Technologies Ltd.

Copyright © 2011 SAE International

doi:10.4271/2011-01-0084

ABSTRACT

Accident statistics shows pedestrian accident fatalities as one of the important concerns globally. In view of this, new test protocols for pedestrian safety have been drafted in regulation as well as in consumer group. Also as per new ENCAP requirements, pedestrian safety assessment is used as one of the four assessment criteria's (Adult protection, child safety, pedestrian safety, safety assist) in deciding the overall vehicle safety. Hence today importance of pedestrian safety is perceived as never before in vehicle development program.

Basically pedestrian safety evaluation involves subsystem level (head form, upper leg form and lower leg form) impact tests representing human body parts, at specific region on test vehicle with injury limits to decide the severity of impact. In general these injuries are governed by vehicle styling, vehicle stiffness, hard points clearances from vehicle exterior like bonnet, bumper etc. For head impact, design parameter that mainly control the injury, like bonnet top stiffness design and under bonnet clearances remain valid for both passenger cars as well as for SUV's (Sport Utility Vehicles). Upper leg form impact test is not mandatory to be met in regulation and also difficult to meet in SUV class type vehicles as the location of impact is guided by bonnet leading edge which are quite high in case of SUV's because of vehicle stance. In case of lower leg test, injuries are mainly guided by front styling and bumper to hard point clearance. In SUV's as compared to passenger cars as the ground clearance from the ground is generally higher and vehicle styling is aggressive, controlling the injuries within the limits are quite challenging.

This paper specifically discusses important design aspects on controlling the injuries of lower leg form for a SUV type vehicle to meet target requirements. This paper attempt to demonstrate the importance of vehicle front end styling,

bumper system design, location of energy absorber, bumper profile, front end stiffness and limitation of bumper to hard point clearance in meeting the lower leg injuries.

INTRODUCTION

Almost two-thirds of the 1.2 million people killed in road traffic crashes worldwide are pedestrians^[1]. Despite the magnitude of the problem, most attempts at reducing pedestrian deaths were focused solely on education and traffic regulation. However, in recent years car manufacturer have begun to use vehicle design concepts that reduce the risk of injuries to pedestrians in the event of a car-pedestrian crash. These involve designing the bumper, hood (bonnet), windshield and the pillars to be energy absorbing without compromising the structural integrity of the car.

Analysis of pedestrian kinematics shows that the bumper typically strikes the lower limbs first followed by hip region hitting the bonnet leading edge. Head impact subsequently occurs with either the bonnet top or the windscreen area. Based on the accident data, various regulatory as well as consumer group protocols, such as ECE regulation^[2], Euro NCAP^[3], Australian NCAP^[4], Japan NCAP^[5], have been drafted to cater the Pedestrian safety requirements. In order to have consistency and uniformity, pedestrian test on vehicle front end is evaluated based on different subsystem level (head form, upper leg form and lower leg form) impact tests at different vehicle regions, instead of having a complete pedestrian dummy. Vehicle assessment for pedestrian safety is done by impacting lower leg-form on the bumper, upper leg-form on the bonnet leading edge while child and adult head form test is done on the bonnet and windscreen based on vehicle type and geometry. Figure 1 shows the brief description of test requirements.

In this paper various parameters which influence pedestrian lower leg performance and solutions to mitigate them are explained exclusively in relevance to SUV's (Sport Utility Vehicles). First part of the paper covers the conventional vehicle front end design approach and its limitations for SUV class vehicles. For such cases various design changes in vehicle front end design to meet Pedestrian lower leg performance targets are presented. Second part of the paper covers the sensitivity study carried out on various design parameters influencing lower leg performance to have robust design. CAE tool is used for this study as it provides effective and efficient way to do design feasibilities.

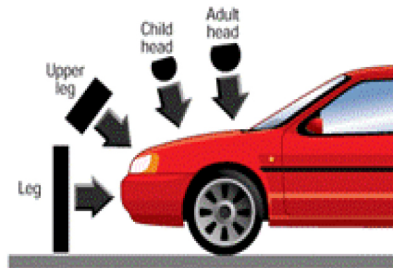


Figure 1. Pedestrian impactor and their position of impact.^[6]

PEDESTRIAN LOWER LEG KINEMATICS

Lower leg Impactor (TRL - Lower leg form) consists of two cylindrical masses with top cylinder representing the femur while lower part as tibia of a human leg. These two cylinders are connected through a joint representing the knee so that two cylinders under load can move relative to each other. Refer [figure 2](#) for more details. Lower leg injuries are monitored through accelerations measured at tibia top, Knee bending and shear measured in the knee area.

Lower leg performance is mainly governed by clearance behind the bumper so as to absorb the energy through cushioning methods (energy absorbers) while keeping the acceleration within the defined limits. Such cushioning parts are usually placed so as to help in supporting the femur.

Along with the support for the femur it is also beneficial to just smoothly stop the lower part (tibia) of the leg preferably below the C.G of the tibia to effectively control the lower leg kinematics. This will help in giving it a good rebound in order to avoid lower part of the leg getting trapped under bumper and allowing it to move along with upper part (femur) of the leg thus reducing bending and shear^[7]. Such a provision can be done by providing secondary support (lower stiffener) close to the lower chin of the bumper. Also if the relative stiffness of the bumper front end system is not uniform then there is a likely chance of relative movement of

the upper part (femur) of the leg with respect to lower part (tibia). This will result in bending moments in case of unsupported tibia and can cause extensive bending and shear displacement. From this point of view front end styling of vehicle plays an important role in limiting the bend angle and shear displacement of the pedestrian lower leg. Ideally a styling which can provide good support to femur and tibia can help in controlling lower leg performance.

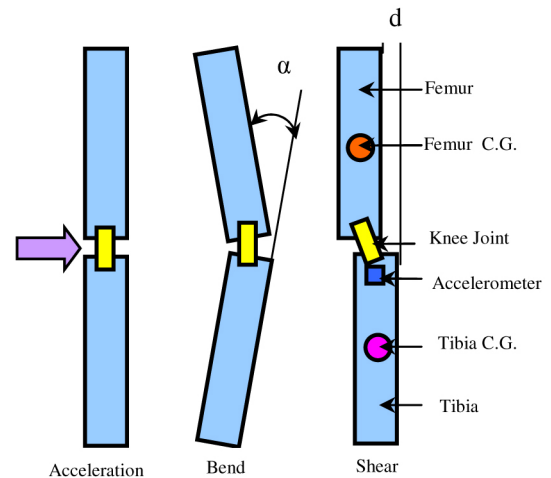
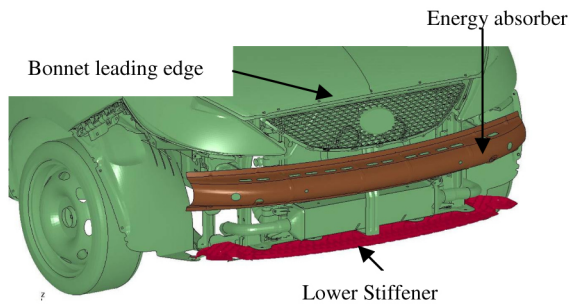


Figure 2. Pedestrian lower leg impactor (TRL - Lower leg form) kinematics

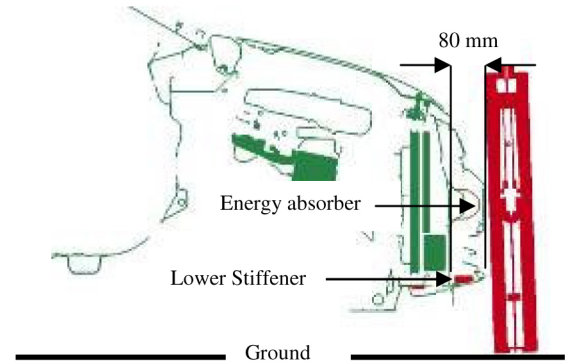
CONVENTIONAL APPROACH (FOR PASSENGER CARS)

For meeting the lower leg performance, generally the front end designs of modern vehicles include cushioning part (primary load path) to absorb energy and a supporting member acting as a secondary load path. The most common method used for cushioning the lower limb and controlling the deceleration levels are through energy absorbers. Energy absorbers are usually attached to the front of semi rigid bumper beam behind the bumper fascia and are made of thin steel panels, plastics, foams or composites. For secondary load path the most common method used is a support at tibia bottom known as lower stiffener. This helps to control knee bend and shear. Lower stiffeners are usually made up of Foam or plastic which are supported rigidly from engine under tray, cooling module bottom support or front end module.

Typical energy absorber mounting on bumper beam and lower stiffener mounting on cooling module is shown in [figure 3](#). Based on mathematical calculations it is observed that a minimum gap of an around 80 mm^[7] is observed between the bumper front fascia and the bumper beam to absorb energy through energy absorber and to control lower leg injuries within required limits.



a) Full vehicle



b) Section view

Figure 3. Conventional design for pedestrian safety.

SUV DESIGN FOR PEDESTRIAN LOWER LEG SAFETY

As a part of new vehicle development program it was required to develop a SUV with body over chassis design which would meet European target requirements along with pedestrian safety. Based on target strategy for pedestrian safety, it was vital to meet the requirements in both headform and lower leg region as meeting the upper legform requirements was quite difficult for such vehicle. With proper bonnet stiffness and clearance below the bonnet it was quite possible to meet the headform requirements. However, the challenge was to meet the target requirements for the lower leg area.

Typically for SUV class vehicle, requirements like having sufficient clearance behind the bumper fascia to have energy absorber and a secondary support at the bumper lower chin may not come as complementary compared to passenger cars. This is because of the aggressive styling requirements, packaging constraints due to large size engine, higher ground clearances and greater approach angle requirements as compared to passenger cars. This is in addition to the crash requirements to meet high speed test requirements along with low speed insurance test requirements.

Similar to the challenges and constraints as explained above, SUV to be designed to meet lower leg requirements was confronted with following challenges based on given packaging and styling:

- i. Clearance between chassis frame cross member and bumper grill was as low as 30 mm at the corners and 50 mm at the center of the vehicle. Please refer [figure 4](#) for detail.
- ii. Being a body over chassis design, the static clearance requirement between the frame front cross member and body mounted bumpers was around 20 mm. These requirements were based on higher relative motion observed between body and frame in such vehicles as compared to monocoque design.

iii. In conventional method, purpose of energy absorber is to absorb energy and control accelerations within the specified limits. With the above two constraints, the available package space for energy absorber was only around 10 to 30 mm which was insufficient for energy absorption and to prevent secondary contact with frame front cross member.

iv. Also the location of the energy absorber was critical. Mounting of the energy absorber on frame front cross member as per conventional design approach would have required to make it stiffer so as to avoid the secondary impact of lower leg with chassis frame cross member. But as a consequence this would have also resulted in accelerations higher than the limiting value.

v. As per conventional design approach, lower stiffener is required to be positioned at the bottom end (close to tibia C.G) of the bumper so as to get proper support in order to avoid bending. This support is in the form of lower stiffener which is connected to the BIW (Body In White) through rigid connections to obtain proper reaction for tibia so as to move it along with upper part (femur) of the leg. In the case of mentioned SUV, such an arrangement was not feasible due to higher relative motion observed between body and frame in comparison to passenger cars.

vi. Also as the approach angle for SUV was relatively higher as compared to passenger cars supporting connections for the lower stiffener were not possible.

vii. Based on above two constraints (point v and vi) controlling the lower leg knee bend angle and knee shear was a complex issue.

In order to overcome above challenges and to meet pedestrian safety requirements following design modifications were implemented on the SUV design. Please refer [figure 4](#) and [5](#) shows the below mentioned modifications.