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Research Paper

OPTIMIZATION OF BONNET THICKNESS FOR PEDESTRIAN SAFETY BY USING HYPERMESH AND LS-DYNA

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Pedestrian injuries, fatalities, and accessibility continue to be a serious concern in India and across the World. Pedestrian safety is influenced by both human behavior factors and physical environmental factors. Collisions between pedestrians and road vehicles present a main challenge for public health and traffic safety professionals. Adult head and face injuries in car pedestrian accidents is account for 60% of all pedestrian serious injuries, whereas 18% of skull injuries were due to the structure of bonnet. The above values show the essential to think more carefully the role of the bonnet in pedestrian skull safety. Redesigning the bonnet structure to improve pedestrian safety has recently received considerable awareness by automobile industry and institutes. However, there is a lack of research into that considers methods of choosing the most effective thicknesses of bonnet covering and bonnet strengthening with respect to pedestrian safety. This study analyzes the effects of the bonnet skin and bonnet reinforcement thicknesses on pedestrian head injury by performing simulations of headform-impactor-to-bonnet tests according to the Addendum 126, Regulation No. 127, Entry into force November 17, 2012 (US) regulations for different thicknesses. Many spot on the bonnet surface are considered to enhance pedestrian kindliness by using this method. Moreover, a bonnet with the best possible thicknesses is not only pedestrian friendly but also as rigid as possible. Based on the proposed method, this study presents steps for optimizing the bonnet skin and bonnet reinforcement thicknesses using a particular automobile model.

Keywords: Bonnet, Head injury, Optimal design, Pedestrian safety

INTRODUCTION

A pedestrian is a human being travelling on foot, whether jumping, jogging, walking or running. In some communities, those travelling using tiny wheels such as roller skates, skateboards, and scooters, as well as wheelchair users are also included as pedestrians. In modern times, the term mostly refers to someone walking on a road or sidewalk.

The study on adult pedestrian protection currently is focusing mainly on passenger cars and commercial vehicles. This study is an attempt

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to show the sharing of injury patterns focused on the head injury mechanism. The head was found the most injured region. According to the National Highway Traffic Safety Administration (NHTSA), 6745 pedestrians died as a result of automotive-related accidents in the USA in 2009 (Simms, 2008) averaging one fatality every 113 min. Moreover, about 57% of pedestrian fatalities and 75% of pedestrian injuries are attributed to passenger car accidents (Simms, 2008). This shows that automobile industries have to pay more attention on pedestrian safety.

Besides functioning as an engine compartment cover, the bonnet of modern vehicles can also help manage the impact energy of a pedestrian's head in a vehicle-pedestrian impact. However, a bonnet's ability to absorb impact energy may be impeded by the proximity of the bonnet to components packaged inside the engine compartment, i.e., by its underbonnet clearance. For example, for a given bonnet design, the bonnet's ability to absorb impact energy through deformation can be significantly reduced when the bonnet and engine block are in close proximity (Berg *et al.*, xxxx)

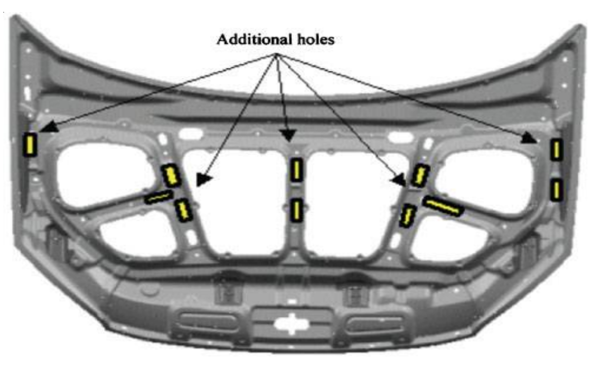
Head and face injuries in car–pedestrian accidents account for 60 per cent of all pedestrian fatal injuries, whereas 17.3% of head injuries were due to the bonnet (FHWA/NHTSA, 2000-2009). The above values show the necessity to consider more carefully the role of the bonnet in pedestrian head safety. Redesigning the bonnet structure to improve pedestrian protection has recently received considerable attention by automobile manufacturers and industry institutes. However, there is a lack of research that considers methods of choosing the most effective thicknesses of bonnet skin and bonnet reinforcement with respect to pedestrian safety.

The aim of these tests was to compare the general pedestrian friendliness of steel and aluminium, used as hood material. The tests were conducted on a car that is still available on the market with either a steel or aluminium hood, both having the same design. Knowing that the hood design was not developed to meet pedestrian safety requirements, the results compare the application of both steel and aluminium to assess which hood material is favorable for pedestrian protection.

REDESIGNING THE BONNET FOR PEDESTRIAN SAFETY

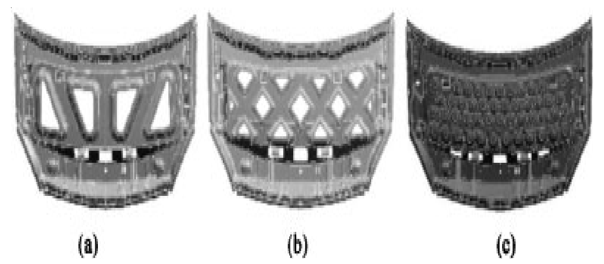
Redesigning the structure of the bonnet to improve pedestrian protection has recently received considerable attention by automobile manufacturers and industry, institutes. Figure 1 illustrates a method of protecting pedestrians by creating more holes in the ribs of reinforcement to reduce the bonnet stiffness (Han, 2003). Previous research on improving pedestrian safety also increased the number of ribs to create a bonnet surface with more uniform stiffness (Simms, 2008). Figure 2 shows the reinforcement structure developed to protect pedestrians in accidents. Currently, some automobiles use a multi-cone

Figure 1: Pedestrian Protection by the Modified Original Reinforcement Structure [4]



structure (Figure 2) instead of a rib structure for bonnet reinforcement.

Figure 2: The Solution of an Alternative Design for Protection of the Pedestrian Head [5]: (a) traditional design; (b) increased number of ribs; (c) multi-cone design



It is very important to select the most helpful thicknesses of the bonnet skin and bonnet reinforcement for each bonnet structure. Kalliske and Friesen (2001) reduced the bonnet stiffness and mass by reducing the bonnet skin thickness to protect the pedestrian head. However, this research did not expose the basis for selecting the bonnet skin thickness. This research has simply reduced the bonnet skin thickness rather than seeking a basis for optimizing the values. Moreover, the bonnet stiffness must be systematically optimized because some components within the engine compartment can often be very close to the bonnet surface and these components can damage the skull of human head when collision occurs.

If the bonnet has poor stiffness, there is a risk that components within the engine compartment may strike the bonnet during collision, increasing the danger to the pedestrian and negating the benefits of the reduced stiffness. Therefore, bonnet redesign not only must simply reduce the bonnet stiffness and mass but also should consider the bonnet deflection during collision. Presently there are two methods for evaluating pedestrian injury. The first method uses pedestrian impactors to evaluate corresponding areas on the vehicle. The second method uses a complete dummy to evaluate the vehicle's frontal structure. Both the complete dummy and the pedestrian impactor methods require complicated physical testing systems. Furthermore, the pedestrian impactors must pass a series of tests to obtain certification. Testing the material properties of pedestrian impactors is time consuming. Numerical simulation offers another reliable method of solving the above problems. One advantage of this method is its ability to solve optimization problems. While mathematical analysis is not an easy method of solving optimization problems, analysis of simulation results is relatively simple and effective. Because of the above advantages, all pedestrian-head-to-bonnet-top tests in this study will be performed using numerical simulation.

This study analyses the effects of the bonnet skin and bonnet reinforcement thickness on pedestrian head injury by performing number of simulation of head form impactor to bonnet top test as per Addendum 126, Regulation No. 127, Entry into force 17 November 2012 (US) regulations using different thicknesses. Many points on the bonnet surface will be considered to enhance pedestrian friendliness by using this method. A bonnet with the optimal thicknesses not only is pedestrian friendly but also is as stiff as possible. Based on the proposed method, this study presents steps for optimizing the bonnet skin and bonnet reinforcement thicknesses for a particular automobile model.

HEAD INJURY CRITERIA AND MASS OF HUMAN HEAD

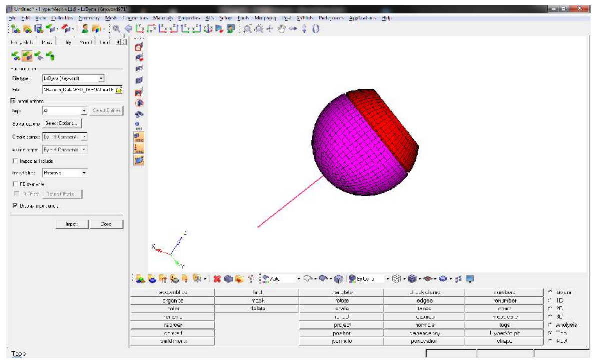
Head injury criteria can be calculated by using the formula

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} \right\} \max$$

where t1 and t2 are the initial and final times (expressed in seconds) of the interval during which the HIC attains a maximum value and a (t) is the resultant acceleration (expressed in G) measured at the head CG (Philomin, 2000). The time duration (t1 – t2) used in the calculation should be taken as the contact time for the impact, however, this is often very difficult to ascertain in physical evaluations using crash test dummies or head form simulators. In using HIC for assessing the potential of concussion then a maximum time duration of 15 m s should be used, which was the maximum time duration for which the original tolerance curve was developed. Longer contact time durations can be used to predict skull fracture. The highest acceleration, independent of location or direction, should be used in the Head Injury Criterion, which will therefore be the resultant acceleration measured at the heads centre of gravity.

The headform model as shown in Figure 3 consists of 28,696 nodes, 22,240 solid, 3,712 shell. A typical headform impactor has three main parts: a steel base mounted with an accelerometer, a spherical aluminium core, and a PVC skin which shall cover at least half of the sphere. The skin is 12 mm thick for the child headform and 14 mm thick for the adult headform. The adult headform has a weight of 4.5 kg simulating a 50th percentile male and the child headform, simulating a 6 year old child weights

Figure 3: FEA Model of Adult Headform



3.5 kg. The diameter is 165 mm for both headform impactors. The adult headform had earlier, according to regulations, a weight of 4.8 kg and this headform is still used sometimes. The impactors are equipped with a damped triaxial accelerometer, with seismic masses within the maximum tolerated distance from their centre of gravity. The x, y, and z component accelerations acquired by this accelerometer are used to calculate a resultant acceleration vs. time trace, which is used to calculate Head Injury Criterion (HIC) from the impact.

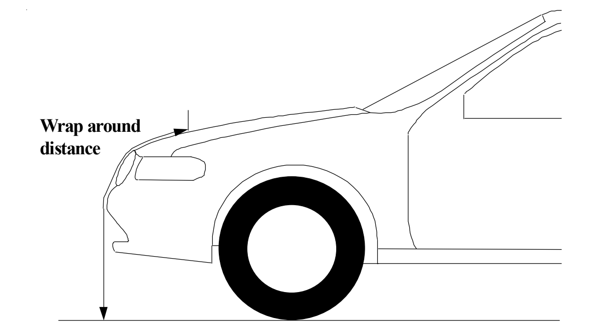
EXPERIMENTAL SET UP ACCORDING TO REGULATIONS

Experimental set up prepared according to Addendum 126, Regulation No. 127, Entry into force November 17, 2012, Uniform provisions concerning the approval of motor vehicles with regard to their pedestrian safety performance, US, E/ECE/324/Rev.2/Add.126"E/ECE/TRANS/505/ Rev.2/Add.126, 7 January 2013.

This procedure shall be followed, using alternative tapes of appropriate lengths, to describe wrap around distances of 1,000 mm (WAD1000), of 1,700 mm (WAD1700) and of 2,100 mm (WAD2100) (Figure 4).

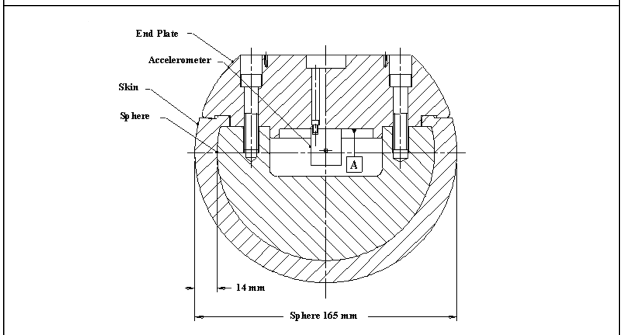
For adult head form the WAD is taken as 1700 – 2100 mm as per regulation.

Figure 4: Wrap Around Distance Measurement



The mass shall be 4.5 ± 0.1 kg, the overall diameter is 165 ± 1 mm. Headform impactor parts use solid elements. The adult headform impactor model consists of 3,713 nodes and 13,783 solid elements. The vinyl skin is modelled using viscoelastic material and a steel core with elastic material. The structure of adult head form is shown in Figure 5.

Figure 5: Adult Headform Impactor



As per regulation the headform velocity at the time of impact shall be 9.7 ± 0.2 m/s.The direction of impact shall be in the longitudinal vertical plane of the vehicle to be tested at an angle of 65 ± 2° to the horizontal as shown in Figure 6.

In India there is no such regulation for vehicle manufacturing. The adult headform impactor is used to test the points lying on boundaries described by a WAD of 1500 mm and the rear of the bonnet top, or a WAD of 2100 mm for a long bonnet. Each section is divided into three parts, as illustrated in Figure 7.

Figure 6: Pedestrian Protection Concept Proposed by the US Regulation

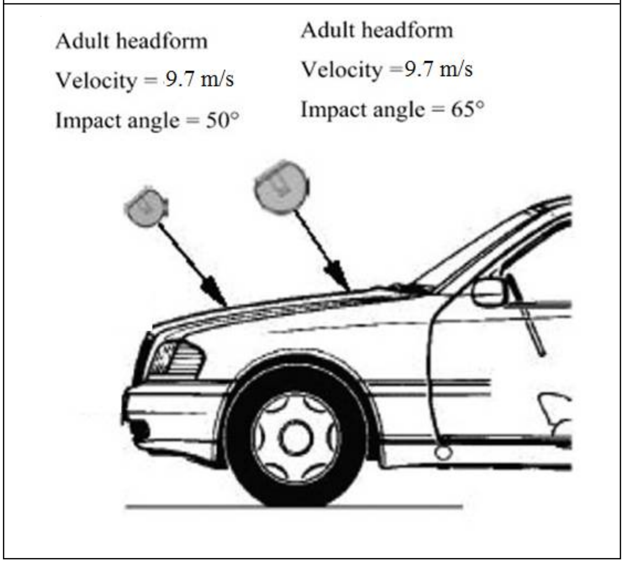
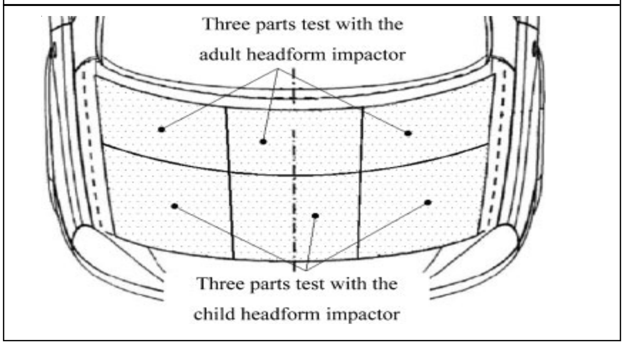


Figure 7: Description of the Impact Area for Pedestrian headform-impactor-to-bonnet-top Tests



In each part, a minimum of three tests is carryout at spots with high injury risk. Test points should vary according to the types of structure, which vary throughout the assessment area.

FINITE ELEMENT MODEL AND SIMULATION

In Finite element the model of vehicle and adult headform is crated. This study analyses the effect of the bonnet skin and bonnet reinforcement thicknesses on pedestrian head injury by performing headform impactor simulations of the US regulations using different thicknesses.

The Reduced Car Model is at the same level when the Full Vehicle is standing on the level floor shown in Figure 8. All translational and rotational degrees of freedoms are fixed (arrested) at the cutting location of BIW. Head is positioned as per Adult Head Impact Zone at 65^0 to horizontal. The Head is impacted with initial velocity of 9.7 m/s. Head accelerations are measured from the accelerometer fitted in Headform.

Figure 8: FE Original Model and Reduced Model

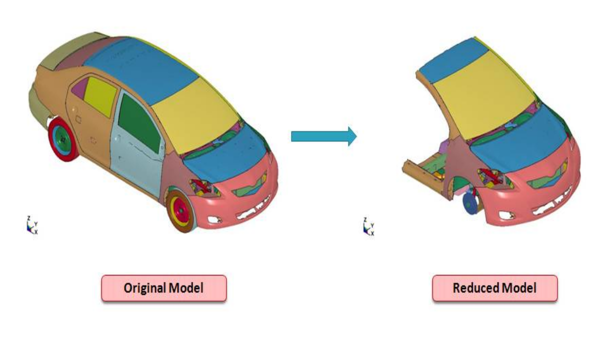


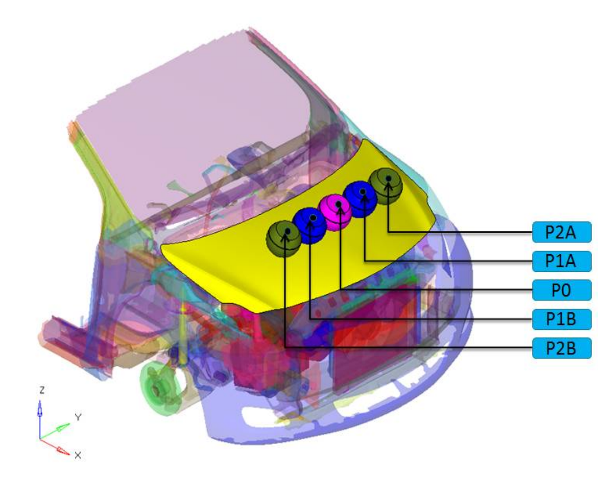
Table 1 lists proposed HIC tolerance levels correlated with brain injury and skull fracture (Philomin, 2000). Based on this tolerance, the level of 1800 represents the maximum allowable HIC value, and an HIC value less than 650 represents the best pedestrian protection, which is the level of zero injury.

Table 1: Proposed HIC Tolerance Levels

HIC range	Brain injury	Skull fracture	Euro-NCAP
< 150	No concussion	No fracture	< 650, green
150–500	Mild concussion, less than 1 h	No fracture	< 650, green
500–900	Severe concussion, 1–24 h	Minor fracture	< 650, green 650–767, yellow 767–883, orange
900–1800	Severe concussion, 1–24 h	Major fracture	883–1000, brown > 1000, red
> 1800	Life threatening	Life threatening	> 1000, red

Bonnet-top simulations are performed using the adult headform impactors simulations of the headform-to-bonnet-top test are performed using the finite element models of the headform impactor mentioned above. The test point are selected are shown in Figure 9. In the engine compartment, components that are close to the bonnet top include the oil cap and the battery. This study does not consider the effect of the engine compartment arrangement on the HIC value. Therefore, all parts in the engine compartment that are close to the bonnet are moved down to ensure that the bonnet does not impact any parts in the engine compartment during simulation.

Figure 9: Impact on Different Location of Bonnet



CONCLUSION

In this way we can simulate the bonnet to head impact test. By using simulation technique the result is obtained which is approximating same to the real test results. By using simulation we can save the time cost of the test. This study shows that the interdependence of the HIC value, the bonnet reinforcement thickness, and the bonnet skin thickness is very complicated. This study analyzes and proposes a method of identifying the most useful values for the bonnet reinforcement thickness and the bonnet skin thicknesses to defend pedestrians while maximizing the bonnet stiffness. The method presented in this study uses the regression technique to design constraints for the optimization problem. The proposed algorithm identifies numerous critical positions on the bonnet surface with respect to pedestrian safety. The algorithm used to optimize the thicknesses is solved by combining LS-DYNA to simulate and analyze the simulation results. Compared with the original bonnet, the optimal bonnet is more pedestrian friendly but somewhat less stiff than the original bonnet.

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