A Comparative Study of European and Indian Pedestrian Safety Standards: A Systematic Review

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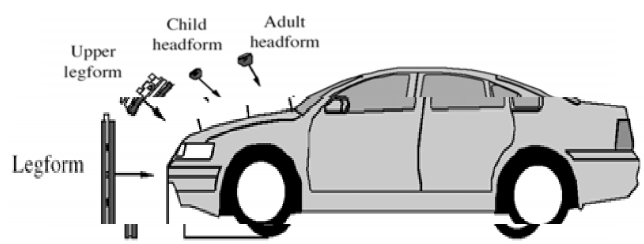
Abstract
A total of 1.2 million people died in road traffic crashes worldwide and almost two-thirds of them are pedestrians. The number in itself is quite significant. Focus by the government agencies is to educate and provide traffic regulation / rules to the vehicle users. Not much attempt has been made at reducing pedestrian deaths through the use of available modern technology. Crash engineers in recent years have made significant progress by applying vehicle design concepts that can mitigate or reduce injuries to pedestrians in the event of a car-pedestrian crash. These involve redesigning the bumper, hood (bonnet), windshield and Pillar (car) to be energy absorbing (softer) without compromising the structural integrity of the car. There was European Directive for the design of the vehicle front protection system to lessen the jeopardous injuries to a pedestrian in a crash. The present paper compares the European Directive in context to the Indian conditions and proposes certain requirements that the Indian manufactures needs to address for frontal protection systems in any vehicle. Also certain technologies for pedestrian safety that are being in the initial stages of development are analyzed and discussed in the paper.

Introduction
From the emergence of concept of vehicle safety most of the research had been done for occupants of the vehicle, which was generally accepted till 1960`s. A minimal approach towards pedestrian safety was concerned till then but, just by reducing the additional trim and the sharp protruding parts on the exterior of body. Transport Research Laboratory of United Kingdom have estimate 8% of all fatalities related to pedestrian in an accident and 21% of serious injuries caused in a crash can be eliminated through improving a design of vehicle. An estimated statistics by following the above data suggests improved vehicle design for pedestrian protection can save between 1% and 2% of all road fatalities in developed nations [1]. The data estimated above results in benefit to cost ratio of 7:1. With the development of automotive technologies and better engines, speed of the vehicle has also moved up. This has given rise to a condition that if the vehicle in any circumstances goes out of control the results can be devastating. The vehicle crashes are dangerous for human life both for the occupant and the pedestrian. In general the pedestrian road accident statistics among developed nations can be conceded to 4.8 per million in the Japan to 5.6 per million in the Australia. The average in European Nations is 13.8 per million and the range in United Kingdom and United States of America is 11.6 per million while in India it is 19.5 per million [2]. Also road accident data with parameters is shown in table 1. The criteria for road accidents related to pedestrian safety is shown in figure 1.

Table 1 Road Accident Parameter 2012-2013

Parameters	2012	2013	Change %age
Accident	4,90,383	4,86,476	-0.8
Person killed	1,38,258	1,34,572	-0.5
Person injured	5,09,667	4,94,893	-2.9
Accident severity	28.2	28.3	0.3

Figure 1 Design criteria for vehicle for different pedestrian accident



This data indicates the need of more stringent regulations for pedestrian safety. During the calendar year 2013-2014, there was a decline in the number of road accidents and also in the number of persons killed and injured in road accidents (Table 1). With a decline of 2.9%, the reduction in the number of persons injured in road accidents during 2013 was the most pronounced. Despite the reduction in the number of persons killed during 2013, the accident severity (number of persons killed per 100 accidents) increased as compared to the previous year [2].
In this paper a brief review of the regulation for vehicle design is provided in relation to protection of a pedestrian in the event of a collision. An overview of European and Japanese regulations is given first and finally the report concludes with the regulation of the design of vehicle frontal protection systems. Detailed description of the European Directive to reduce the risk of injury of pedestrian in a collision is provided in the paper. A comparison of these proposed requirements with the Indian Standard for vehicle protection systems for frontal collision is also made. Indian directives which are in the initial stages of developments are also discussed in detail in the paper.

Pedestrian Protection
The Pedestrian Protection score is determined from tests to the most important vehicle front-end structures such as the bonnet and windshield, the bonnet leading edge and the bumper. In these tests, the potential risk at injuries to pedestrian head, pelvis, upper and lower leg are assessed. Cars which perform well can gain additional points if they have an autonomous emergency braking (AEB) system which recognises pedestrians.

Head impact
Most of the road fatalities are pedestrians, with children and the elderly being at greatest risk. Pedestrians comprise one of the main categories of vulnerable road users, which also include cyclists and motorcyclists. Most pedestrian accidents occur within city areas where speeds are moderate. The head, the lower body and the legs are amongst the most frequently injured body regions. To estimate the potential risk of head injury in the event of a vehicle striking an adult or a child, a series of impact tests is carried out as shown in figure 2 at 40 km/h using an adult or child head form impactor. Impact sites are then assessed and the protection offered is rated as good, adequate, marginal, weak or poor. The procedure promotes energy absorbing structures, deformation clearance and deployable protection systems such as pop-up bonnets and external airbags.

Figure 2 Position of head Impact of pedestrian in the form of dummy

Upper Leg Impact

The shape of the hood or bonnet leading edge can play a critical role in the outcome of a vehicle impact with a pedestrian and contribute to injuries to the pelvis and femur. To estimate the potential risk of pelvis and upper leg injuries in the event of a vehicle striking an adult, a series of impact tests is carried out at 40 km/h using an adult upper leg form impactor as shown in the figure 3. Impact sites are then assessed and the protection offered is rated as good, adequate, marginal, weak or poor. The procedure promotes energy absorbing structures and a more forgiving geometry that mitigates injuries.

Figure 3 Position of upper leg Impact of pedestrian in the form of dummy

Lower Leg Impact

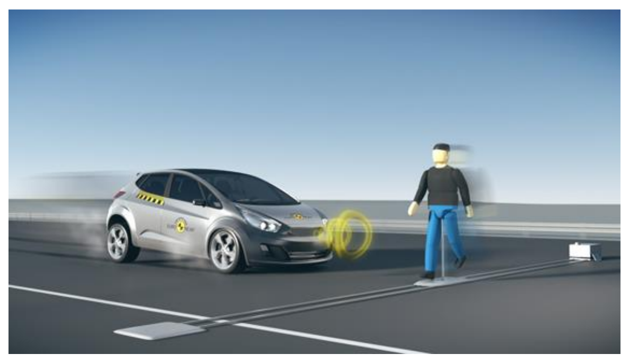
Typical injuries resulting from leg to bumper impacts include fractures to the leg, knee and ligaments. These leg injuries are rarely fatal however are often associated with permanent medical impairment. To estimate the potential risk of leg injuries in the event of a vehicle striking an adult, a series of impact tests is carried out at 40 km/h using an adult leg form impactor as shown in the figure 4. Impact sites are then assessed and the protection offered is rated as good, adequate, marginal, weak or poor. The procedure promotes energy absorbing structures and a more forgiving geometry that mitigates injuries to the leg.

Figure 4 Position of lower leg Impact of pedestrian in the form of dummy

AEB (Autonomous emergency braking) Pedestrian

One major factor that influences pedestrian injury outcome during a collision is the vehicle speed at the point of impact. An increasing number of vehicle manufacturers are offering systems which are able to bring the car to a safe halt before a pedestrian is struck or which can at least reduce the speed of the collision. Euro NCAP tests three crossing scenarios, all of which would result in a fatal collision between the car and the pedestrian if the AEB system did not intervene: an adult runs from the driver's side of the vehicle; an adult walks from the passenger's side (two tests are done for this scenario) as shown in figure 5; and a child runs from between parked cars on the passenger's side. These tests represent critical situations that often result in pedestrian casualties in the real world. Cars that perform well can be expected to have a significantly reduced risk of pedestrian accidents in real world driving. In many instances, AEB Pedestrian technology may not be able to completely avoid the collision. For this reason, Euro NCAP only rewards the technology if the pedestrian impact tests show that the car has a forgiving front design.

Figure 5: Position of pedestrian when an adult walks from the passenger's side of vehicle



Agencies involved in the framing regulations in Vehicle Design for Pedestrian Safety

Basically five groups had been working on the development of test procedures for assessing the degree of pedestrian protection. They are:

i. United States National Highway Traffic Safety Administration (NHTSA):

In 1980s the United States National Highway Traffic Safety Administration (NHTSA) was involved in the development of vehicle impact test methods for pedestrian protection [3]. Proposed rules were prepared up till 1992. At present research being conducted by NHTSA on the United States Government's contribution and is known by the name as International Harmonized Research Activities Pedestrian Safety Working Group (IHRA PS).

ii. International Harmonized Research Activities

(IHRA):

The proposal of International Harmonized Research Activities program was cited at the 15th International Technical Conference on the Enhanced Safety of Vehicles held in Melbourne in 1996 [4]. The primary tasks assigned to the Pedestrian Safety Working Group were:

- To examine and to study the latest pedestrian accidents in the IHRA member countries.
- To practice harmonized test procedures that would redirect circumstances typical of the pedestrian accident situation and would include automobile assemblies.
- To reassure the use of the research results as the basis for future harmonized technical pedestrian safety regulations.

iii. European Experimental Vehicles Committee (EEVC):

The European Experimental Vehicles Committee (EEVC, now re-named the European Enhanced Vehicle-safety Committee) has played the major role in the development of pedestrian impact test procedures through its Working Groups (WG) 7, 10 and 17.

a. EEVC Work Group 7 “Pedestrians” was set up in 1982 to examine how car design could take into consideration pedestrian accidents in European countries [5].
b. EEVC Working Group 10 “Pedestrian Protection” was established in 1987 to determine test methods and acceptance levels for assessing the protection afforded to pedestrians by the fronts of cars in an accident [6].
c. EEVC Working Group 17 “Pedestrian Safety” was established in 1997 for two main tasks:
   - Review of the EEVC WG10 test methods (final report 1994) and propose possible adjustments taking into account new and existing data in the field of accident statistics, biomechanics and test results.
   - Prepare the EEVC contribution to the IHRA working group on pedestrian safety [7].

iv. International Standards Organization (ISO):

In 1983 the International Standards Organization’s (ISO) Technical Committee on Road Vehicles formed a Working Group to “Develop a method for discrimination between passenger car front ends as to their relative friendliness when impacting a pedestrian”. (ISO/TC22/SC10, Document N173, 1983) The Working Group (WG2) met for the first time in 1988. The secretariat is based at the Japan Society of Automotive Engineers. There was substantial common membership with EEVC Working Group 10 [5].The methodology behind the working of each group is to achieve the task of designing a vehicle in its class for pedestrian safety by developing system, sub-system, components and there tests [5]. This is done mainly due to following reasons:

- Obdurate problems in repeatability of full scale collisions between a dummy (as a pedestrian) and the vehicle,
- The need for a family of dummies to represent the pedestrian population (ranging from a child to adult) [5].

v. NCAP pedestrian impact test procedures:

a. Euro and Australian NCAP: New Car Assessment Programs (NCAP) conducting pedestrian impact tests consists of Euro NCAP, Australian NCAP (ANCAP) and Japan NCAP (JNCAP). Euro NCAP test procedures are based on those developed by EEVC and ANCAP pedestrian test procedures are identical to those of Euro NCAP. However, because many, or possibly most, current vehicles have not been designed to comply with the EEVC criteria the Euro NCAP consortium introduced the assessment changes with the current level of pedestrian protection provided by car fronts, it would be optimistic to expect protection levels to exceed those proposed by the EEVC. In order to discriminate between cars which more nearly meet the EEVC requirements from those which greatly exceed them, a lower limit has been set. This has been derived from experience gained in the early phases of Euro NCAP tests conducted at 40kmph.

b. Japan NCAP: JNCAP test procedures are limited to child and adult head form tests which are similar to the Japan Standard except that the head form impact velocity has been increased from 32 kmph to 35 kmph.

Methodology of Tests Performed

Euro-NCAP has been assessing pedestrian impact protection of popular vehicle models since the NCAP test program began in 1997. The EU has just decided to proceed with a directive requiring vehicles to meet minimum pedestrian protection requirements which (in phase-I) are the same as those applied by Euro-NCAP [6]. The Japanese automotive consumer organization OSA plans to introduce Euro-NCAP style pedestrian impact tests. Australian NCAP is also likely to introduce these tests into its assessment of new vehicles. The situation is less clear in the USA but research is underway into test methods and equipment. There have been efforts to develop full dummy impact tests with varying (usually limited) levels of success. Honda Motor Company made public for the first time details of its POLAR dummy for the purpose of conducting full scale pedestrian impact tests. Verification work at this stage is primarily aimed at matching the dummy kinematics with those of computer models and cadaver tests. Given the inherent repeatability problems with a full dummy test European Experimental Vehicles Committee (EEVC) developed three sub-system tests: head, upper legs and knee/lower legs. It was stressed several times that any assessment must be based on all three tests because the design of a vehicle simply to meet one of the requirements could lead to a degradation of protection for another area (for example changes to a bumper design to improve knee protection could result in increased head to bonnet impact velocity). The EU decided to proceed with this measure irrespective of the benefit cost calculations. The test procedures are described in more detail below:

Test Procedures

Head impact test

A head form in free-flight is "fired" at representative areas of the bonnet (US="hood") at a prescribed angle and speed. These prescribed values vary according to the geometry of the front of the vehicle - in particular the bumper "lead" and the height of the "bonnet leading edge" (the latter can be quite complicated to determine in the case of a smoothly contoured vehicle). Two head forms are used - in essence a child head form is fired at the front half of the bonnet and an adult head form is fired at the rear half of the bonnet. Six tests are conducted with each head form - at present the test organization is at liberty to choose the locations with the intention that the "worst" locations are covered.

The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. The HIC can be used to assess safety related to vehicles, personal protective gear, and sport equipment. Normally the variable is derived from the measurements of an accelerometer mounted at the centre of gravity of a crash test dummy’s head, when the dummy is exposed to crash forces.

It is defined as: $HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$ where t_1 and t_2 are the initial and final times (in seconds) of the interval during which HIC attains a maximum value, and acceleration a is measured in gs (standard gravity acceleration). The maximum time duration of HIC, $t_2 - t_1$, is limited to a specific value between 3 and 36 ms,[1] usually 15 ms. This means that the HIC includes the effects of head acceleration and the duration of the acceleration. Large accelerations may be tolerated for very short times. At a HIC of 1000, there is an 18% probability of a severe head injury, a 55% probability of a serious injury and a 90% probability of a moderate head injury to the average adult.

Decelerometers in the head form are used to determine HIC (spike was only about 8ms so is doesn't really matter whether it is reported as HIC15 or HIC36). Euro-NCAP assigns a red (poor) rating if the test results in a HIC of 1,500 or more.

The motor industry has expressed concern about the manner in which test locations are chosen. This is particularly important where repeat tests are conducted - for example, if the test is called up in a regulation then any conformance (audit) tests must be carried out in the same locations as the original compliance test. One alternative to consider is to prescribe, say, 50 geometric locations on the bonnet and for the 12 test locations to be chosen by random number selection. This might mean that a test did not cover the "worst" location on the bonnet and therefore an undesirable design might "slip through". However, the manufacturers would need to ensure that at least all 50 locations meet the requirement and this would be a great advantage to pedestrians. A random selection process might not be as appropriate for consumer testing, which assigns a score to the test results, rather than just pass/fail. On the other hand, the "expert" selection method currently used is also likely to be fallible.

Upper legform test

A test device has been developed to simulate the adult human femur. The test therefore gives an indication of the likelihood of femur fracture. It consists of an instrumented aluminum tube with substantial padding on one side. It is fired at the leading edge of the bonnet at a prescribed angle and energy (or mass and speed), based on similar criteria to those of the headform test. The procedures have a minimum energy level at which a test is required and it is possible (but probably unlikely) that a vehicle can be designed so that it does not require the upper legform test (for example a BLE height under 650mm and bumper lead of 100mm). Bending moments and resultant forces are measured. Euro-NCAP assigns a red (poor) rating if the bending moment exceeds 400Nm or the resultant force exceeds 7kN. Now that the prescribed energy levels for the test have been reduced there do not appear to be any major objections to the test procedures and assessment criteria.

Legform test

A test device has been developed to simulate the human knee and main bones. An impact side-on to the plane of articulation of the knee is assumed. The angular movement of the knee joint at right angles to the axis of articulation is measured. Tibia deceleration and knee shear displacement are also measured. Euro-NCAP assigns a red (poor) rating if the tibia acceleration exceeds 230g, the knee shear exceeds 7.5mm or the knee bending angle exceeds 30 degrees (which is the physical limit of the device). The Japanese motor industry appears to be concerned about the bio-fidelity (accuracy of simulation of real human body parts) of the knee shear mechanism. NHTSA appears to be concerned that the test device contains frangible elements which need to be replaced after each test (*on principle*, they want a test device that can be calibrated after a test [6]. Research is being carried out on an alternative device which uses friction plates but this seems, to me, to be vulnerable to repeatability problems - maybe the "principle" should be reviewed.

Figure 6 Crash test for getting the data for occupant safety

Figure 7 Crash test for getting the data for occupant safety

Indian Directives

Bharat New Vehicle Safety Assessment Program

After the popular Indian small cars failed the crash tests figure 6 & 7 (Suzuki Swift & Datsun Go failed NCAP Tests) spectacularly one after the other, the government has finally started working on ways to improve the vehicular safety in the country. The minimum requirement for every car could include frontal and rear collision tests at 56 km/h According to a report in Economic Times, CMVR-TCS, CMVR-TCS which is the apex advisory committee that answers to the Road Transport Ministry in matters of safety and all issues that are related to the motoring industry the is gearing up to determine the minimum test requirements and safety features that every new car in India should have in the years to come. Many prominent Auto manufacturers oppose the move to make safety equipment mandatory since it would shoot the costs up to 30% depending on the model. The CMVR-TCS committee which has representatives from various concerned organizations including the ministry of heavy industries, Bureau of Indian Standards (BIS), Automotive Research Association of India (ARAI) would take a final call on the new automotive safety standards in India.

Safer cars for India by Global NCAP (Results 2013) Star rating on a scale of 5 (Source http://www.indiancarsbikes.in/wp-content/uploads/2014/07/Chart-NCAP-Reviewed.jpg?3a87fd)			
Car Name	Side	Front	Rear
Volkswagon POLO	2	4	3
Maruti Suzuki 800	0	0	2
Ford Figo	0	0	2
Hyundai i10	0	0	1
Tata Nano	0	0	0

Feature	Euro Norms	Indian Norms
Airbags	Mandatory	Not Mandatory only in the higher versions
Anti-Lock Braking System (ABS)	Mandatory	Not Mandatory only in the higher versions
Electronic Brake Distribution	Mandatory	Not Mandatory only in the higher versions
Electronic Stability Control	Mandatory	Not Mandatory only in the higher versions
Seat Belt Reminder	Mandatory	Not Mandatory only in the higher versions
Child lock functionality check	Mandatory	Not Mandatory only in the higher versions

Once the safety standards are finalized, the minimum required standard would be notified under the Bharat New Vehicle Safety Assessment Program (BNVSAP) which will be the Indian equivalent of the Euro-NCAP. While it will be voluntary for car makers to comply with the BNVSAP norms initially, it will be made mandatory for the new cars from October 2017. The existing models would be given an additional time of one year (till October 2018) to adopt the safety requirements. Hence it is recommended for the policy makers for Bharat New Vehicle Safety Assessment Programme (BNVSAP) that the above mentioned five features should be made mandatory even in the lowest versions.

Even as most of the OEMs oppose the idea of making safety equipment like airbags, ABS, EBD, ESP mandatory due to the fear of increased price tag (some small cars would see an increment of up to 30%), but the Government wants no compromise on safety regulations. He added that the minimum standard for occupant safety would see frontal and rear crash tests at 56 km/h that every car must pass in order to be eligible for the market. Moreover, like the international NCAPs, there would be star rating based on the safety features. The BNVSAP will get an administrative body which will have the power to choose the new vehicle variants to be assessed for safety compliance.

The Automotive Research Association of India (ARAI) is building the testing equipment and facilities needed for compliance of the new regulations of the 'Road map of Passive Safety' implemented in India in 2013. It will be an upgrade of its existing testing facilities and will include a fully equipped crash track with electric drive, a facility for pedestrian testing, as well as high-speed cameras and test dummies, among other technologies. The facility will come under the National Automotive Testing, Research and Development Project (NATRiP). ARAI has a fully-fledged crash test facility at Chakan in Pune (Maharashtra) to cater the Western auto hub with NATRiP, while NATRiP is building its own crash testing facilities at the iCAT (International Centre for Automotive Technology) Manesar (Haryana) in North and G-ARC (Global Automotive Research Centre) in down South in Chennai.

The crash test facilities are being built under the NATRiP project. The passive safety facilities are part of these and they are being built at Manesar, Chennai and Pune. The facilities at Manesar and Pune are mainly for regulatory requirements, whereas the facility at Chennai is for both regulatory and development work.

Overall impressions of the EEVC/Euro-NCAP procedures

The three sub-system tests appear to be a suitable way to get started at improving pedestrian safety through improved vehicle frontal design. Ultimately full scale dummy tests will probably be developed and these may supersede the sub-system tests. It is evident however, that major advances can be achieved by immediately implementing the EEVC procedures [5]. It is important that all three tests are adopted so that vehicle designs are not unintentionally "driven" in a direction that could reduce protection in other areas [8].

Suggested methods for pedestrian protection

Head protection - For improved head protection the importance of under-bonnet clearances, locating softer components at the top of the engine and avoiding localized stiffness of the bonnet in favor of a more distributed structure. Crush depths (under test) of 80 to 90 mm for the adult headform appear appropriate [5]. The traditional manner in which the bonnet joins the side of the car needs some lateral thinking - typically a vertical sheet metal section is attached to the gutter which supports the bonnet. This is very stiff under vertical impact loads and a cantilevered design with less vertical stiffness should be considered. Alternatively, a bonnet which wraps around the sides of the car would be good (i.e. the E-type Jaguar).

Upper leg protection: For improved upper leg protection moving the location of the bonnet latch rearward, or to the sides and moving transverse stiffeners back from the leading edge of the bonnet provides good results [9]. Crush depths, under test, of between 65mm and 150mm are appropriate, depending on geometry can also be useful.

Legform: The bumper needs localized compliance and then efficient energy absorption. Foam plastics are available to achieve this aim, together with recovery characteristics which minimize damage during low speed car-to-car collisions [5]. The deformed profile of the vehicle during the impact needs to be considered. Further spoilers and similar low-mounted, compliant structures can help to reduce the loads on the lower legs.

Conclusion

Road safety is a issue of major concern in Indian terrains, for which different agencies framing rules and regulations were discussed. Out of these discussed agencies it has been found that New Car Assessment Programs (NCAP) is the overall standard that are commonly followed by the major auto companies while designing vehicle foe pedestrian safety. Certain methodologies for performing these tests were also discussed in the paper. Indian standards are on the development stages or manufactures are making use of the European standards in the designing of vehicles for pedestrian safety. In India CMVR-TCS is the apex advisory committee who is determining the minimum test requirements and safety features that every new car in India should have in by 2017 and this norms will be called Bharat New Vehicle Safety Assessment Program. The United Nations has proclaimed 2011-20 as the decade of action on road safety so that the present rising trend of road accident stabilizes and is reversed by the year 2020.

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