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Effect of Vehicle Bumper Shape Design on the Severity of Pedestrian Leg Injury at Collision

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Abstract:

Cars bumper an important part to protecting the front of the vehicle at slow speed, and was formerly used chrome-plated steel. Steel material is too stiff to pedestrian protection and lack amenability to absorb energy. Designers began looking for alternative bumper designs and materials to achieved two requirements protect the vehicle at slow speed and pedestrian at collision together. For designing a pedestrian friendly bumper and to quantify expected injury level in a pedestrian lower leg at car - pedestrian collisions must generating a legform impactor model and validating the performance of this model by following a regulation in this filed.

This simulation work focuses at design of friendly pedestrian bumper to reducing the proportion of pedestrian lower leg injury at collision through design a bumper shape. legform impactor model is generated according to the European Enhanced Vehicle-safety Committee EEVC/WG17 regulation data for tests and validation. The mechanism of collision between the legform impactor model and vehicle bumper have been investigated numerically and analyzing by using LS-DYNA software. To study the effect of bumper shape at the severity of pedestrian leg injury is used four different concept bumper shape that has been designed for this purpose.

Key words: *Pedestrian safety, Bumper shape, Finite element model (FEM), EEVC Legform impactor, Pedestrian lower leg injury*

1. Introduction

Road accidents are a real global tragedy continuously increases with increasing road users and claim thousands lives of pedestrians in the world every year. At World Health Organization report 2013 statistics, more than 1.24 million people die in the roads annually and 50 million are injured. 75% of total accident deaths are pedestrian [1]. As a result, a large number of deaths and injuries are now considered the road traffic accidents are a major problem for public health worldwide. So the subject of pedestrian protection at collision and "friendly cars" design is an important topic of interest to researchers and modern car designers. The world needs a car with these specifications, especially in low income countries that do not abide by the roads safety rules and the proportion of accidents is high "over a third of road traffic deaths in low- and middle-income countries are among pedestrians. However, less than 35% of low- and middle-income countries have policies in place to protect these road users". [2] Friendly - car leads to minimize human losses and reduce the severity of injury and thus reduce the costly expenses necessary to medical treatment globally.

In NHTSA's 2012 statistics (National Highway Traffic Safety Administration) at 2010: 4,280 pedestrians were killed in United States and an estimated 70,000 were injured in traffic crashes. On average, in traffic crashes a pedestrian was killed every two hours and one injury every eight minutes [3]. Globally pedestrian fatalities percentage about 50% to the total accident in the world (22% pedestrian, 23% Motorized 2-3 wheelers and 5% Cyclists) as shown in table 1, and about 75% of the pedestrian accident with sedans (passenger vehicle) type, 54% at the front of the car, figure 1.[1]

Table 1: Pedestrian fatalities percentage 50% for all accident at 2013[2]

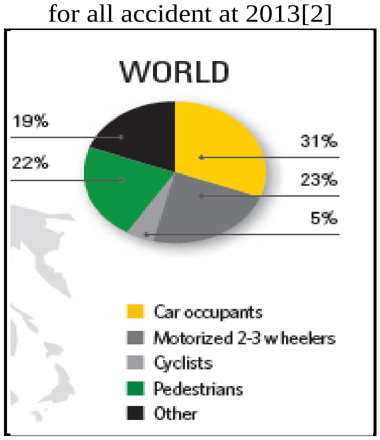
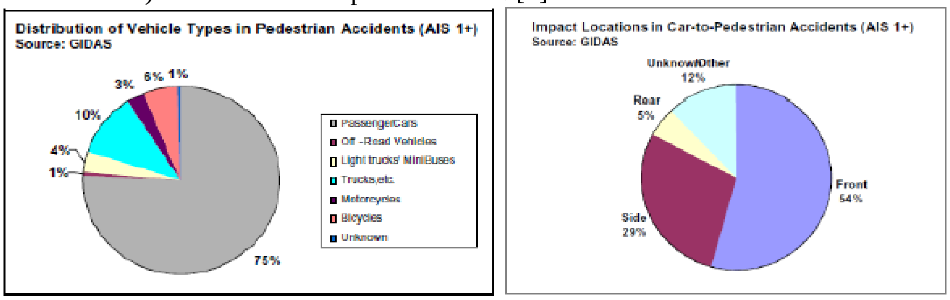


Table 2: A) Percentage of sedan vehicle type at pedestrian-car accident
B) Pedestrian car impact locations. [1]



(A) (B)

At car – pedestrian accidents with low speed, bumper system is the first vehicle contact part with pedestrian. Energy absorbers in front of the bumper and inside it can absorb impact energy to reduce pedestrian injuries. Increasing bumper energy absorption capacity is a commonly used method for reducing pedestrian leg injuries.

Protocols for safety car (friendly car) were built up around the world to protect the passenger in the beginning and have been developed to include a pedestrian, to decreasing the fatalities and serious injuries at accident.[4] This protocols are contain the required standards car specifications and testing method that makes the design more safer to ensure the protection of cars users and pedestrians also.

EURO-NCAP (European New Car Assessment Programmers) for safety car is the first protocol held in this area in the United Kingdom and spread to the whole world, at 1987 the Europe Enhanced Vehicle - Safety Committee (EEVC) Working Group 10 start to set-up the subject of “Pedestrian Protection”. At 1997 the committee has been developed to EEVC/WG17 which supporting the tests according to new regulation phase 1 and developed to phase 2 at 2005 as shown in figure 1[4]. According to this regulation identify the degrees of car safety (star ratings) from one star to the top at five stars according to these standard tests depending at “Weight Factor” which represent four boxes of safety are base to calculate the “Stars - Rate”.[5]

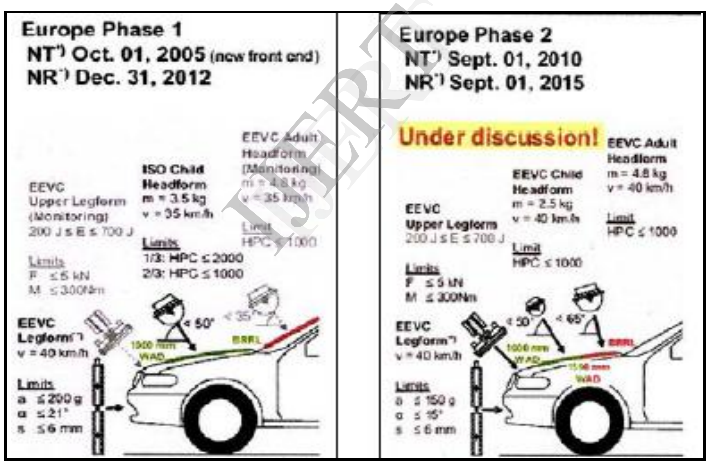


Fig 1: Impact tests (EU Phase 1, 2). *(EEVC/WG17)(Oasys-ARUP)*

For bumper design, almost of previous studies focusing at the materials of the bumper and types of energy absorbed to reducing the severity of lower leg injury. This study has been focusing at the effect of bumper geometrical shape at the performance of bumper to pedestrian protection. For testing this designs should creating finite element legform impactor and follow the EEVC/WG regulation to test and verification this impactors.

Numerical simulations are powerful design tools for automotive engineering. The ability of variation and low cost of the finite element method help designers to perform many more tests for pedestrian safety. [6]

To simulating and analyzing the pedestrian lower leg impactor- car bumper collision is used LS-DYNA software. Simulation results were analyzed to identify the optimum bumper design for pedestrian protection.

2. Lower legform impactor – bumper test

Frome figure 1, three EEVC/WG17 subsystem tests with three impactor models represent three parts of human body, head, upper leg and lower leg that often have most serious injury in car-pedestrian accidents. All of this impactor models impacted a specific part in the front of the car to test pedestrian friendliness of this parts.

Lower legform impactor is used to assess the performance of the bumper with regard to pedestrian protection. Leg impactor consists of two metals steel tube representing tibia and femur bones, physical properties, mass, moment of inertia and center of gravity specified in the EEVC/WG17 report [4]. There are three parameters required to assess the bumper performance for pedestrian friendliness. The first parameter is dynamic bending angle, second is dynamic knee shearing displacement and third parameter is the upper tibia acceleration as shown in figure 2.

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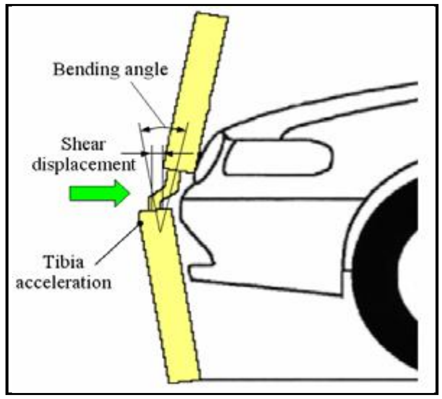

Fig 2: Major parameters, bending angle, shear displacement and upper tibia acceleration (EEVC/WG)

3. Finite element model of legform impactor

Tibia and femur are metal tubes with outer diameter of 70 ± 1, with shell thickness 1.5mm dimensions are shown in figure 3, thickness of flesh 25mm CF45 Confor™ foam flesh, 5 mm Neoprene cover skin faced with 0.5 mm thick nylon cloth both sides (EEVC/WG17). A hinge representing the actual knee joint and a limiting damper attached to the shear system. This model consists of 3349 shell elements, 13112 solid elements, and 4 dampers with springs.

Total mass and moment of inertia of the femur and tibia shall be 8.6 ± 0.1 kg, 0.127 ± 0.010 kgm^2, and 4.8 ± 0.1 kg, 0.120 ± 0.010 kgm^2, respectively. The moment of inertia for each part is defined about a horizontal axis through their centre of gravity and perpendicular to the direction of impact. C.G. of femur and tibia are 217 ± 10 mm, and 233 ± 10 mm away from the centre of the knee joint. The total mass of the femur and tibia shall be 8.6 ± 0.1 kg and 4.8 ± 0.1 kg respectively. By considering the mass density ρ=96.11 kg/m3 and ρ=1100 kg/m3 for cf-45 foam and neoprene skin respectively, the exact masses of bone of femur and tibia were achieved [7][8]. According to regulation if used a shell tibia and femur instead of solid material, must increased a 6 kg lump mass to femur and 2kg to tibia.

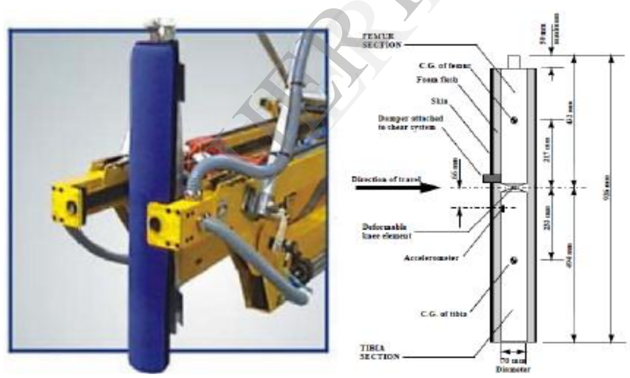

Fig 3: EEVC legform impactor with skin and foam covering (EEVC/WG17 regulation)

4. Legform knee joint

Knee joint was modeled by using a 3 - DOF (Degrees Of Freedom) discrete beam that the shearing of the knee represented by a linear force versus displacement curve and the bending response of the knee represented by a nonlinear moment versus rotational displacement curve[9]. Other degrees of freedom of the knee joint were tuned so that the static and dynamic characteristics were achieved.

Solid elements with low density foam material (LS-DYNA material type 38-*MAT_BLATZ_KO_FOAM) were selected for modeling Cf-45 foam; the exact model of flesh was achieved. The skin was modeled by using solid elements with neoprene skin. Vibrations have been observed in dynamic certification test and by using a translational spring-damper (k=551 N/mm) in knee joint, the vibration in legform impactor was prevented as shown at figure 4.

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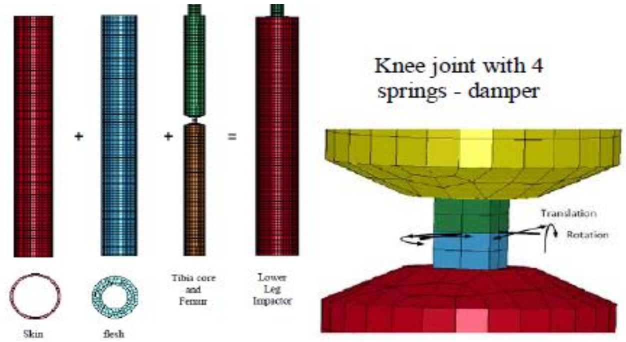

Fig 4: Complete FE lower legform impactor with knee joint

Two tests required for legform impactor model validation process, dynamic and static tests. First, the two static tests (bending and shearing displacement of knee) were done to checking the behavior of the spring – damper of the knee. Second, the dynamic test was done to adjust the damping factors [10]. Figures 5 and 6 show the model validation tests results. Tables 3 and 4 shows the compression of the static test result and dynamic test respectively with EEVC/WG regulation limits.

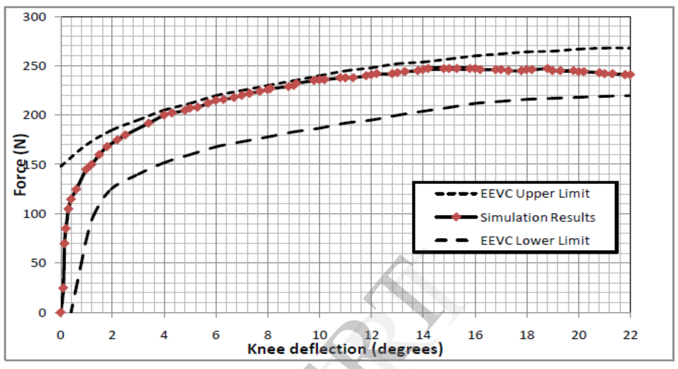

Fig 5: Acting Force - knee bending angle in static bending test

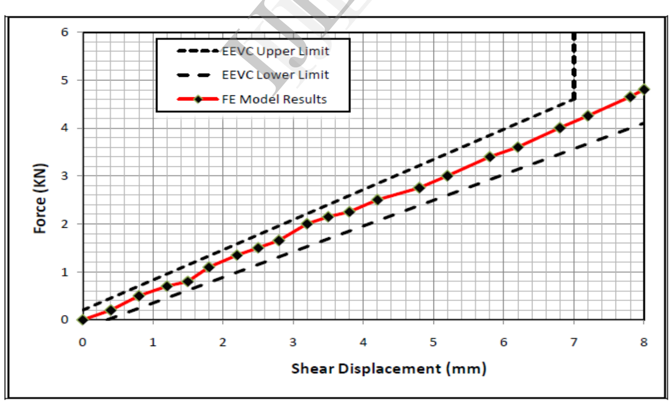

Fig 6: Acting force – knee shear displacement in static shearing test

Table 3: compression of the static result test with regulation at 15^{o} bending angle

Item	Energy (J)	Acceleration (g)
Analysis Result	98	160
EEVC/WG Limit	100 ±7	150 - 430

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Table 4: Compression the dynamic test result with regulation

Item	Maximum Upper tibia acceleration (g)	Maximum bending angle (degree)	Maximum shearing displacement (mm)
Analysis result	200	7.2	5.8
EEVC limit	120 -250	6.2 – 8.2	3.5 - 6

5. Analysis of bumper-pedestrian protection

Impact testing velocity between legform impactor and the bumper is 40 km/h = 11.1 m/s. Current (original) bumper are used in this study consist of; shell plastic fascia, shell elastic carbon steel beam, as shown in figure 7.

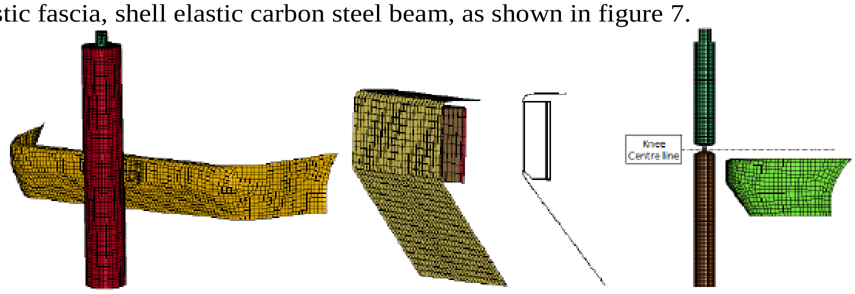

Fig 7: Current bumper parts with fascia side a section

The simulation of legform impactor to bumper is shown in figures 8, 9 and table 5.

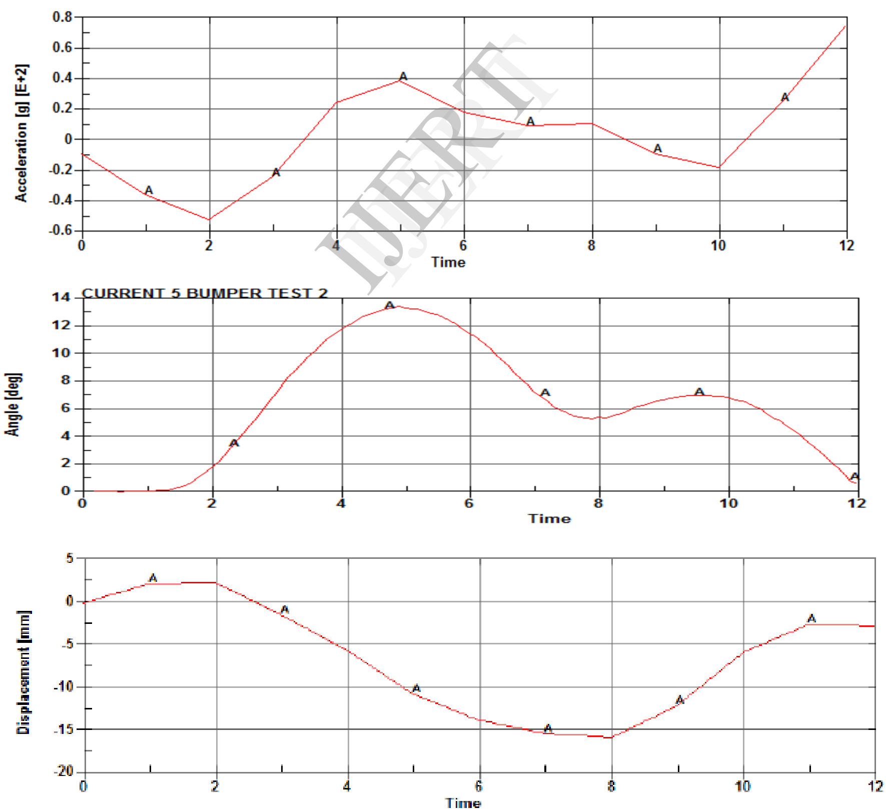

Fig 8: Analysis result for current bumper, upper tibia acceleration, knee bending angle and knee shear displacement

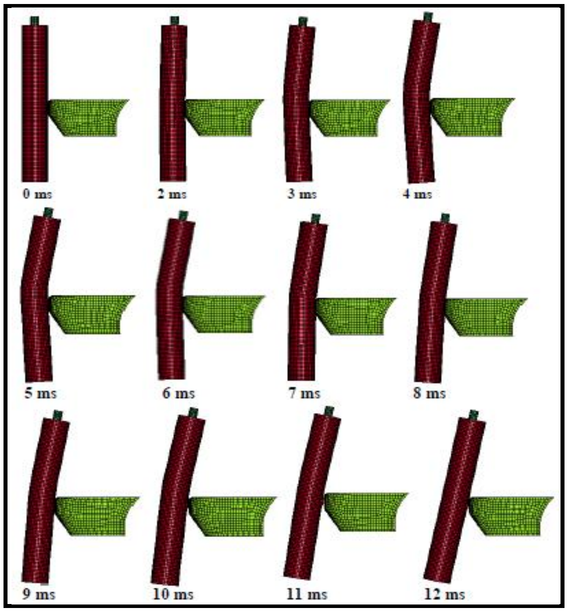

Fig 9: Legform deformation with time at impact with Current (original) bumper model

Table 5: Comparison between EEVC/WG limits and current bumper analyses results

Item	EEVC Max. Limits	Analyses result
Upper tibia acceleration (g)	150	500
Knee shear displacement (mm)	6	16
Knee bending angle (deg)	15	13.2

From figure 9, maximum knee bending angle occurred at range 4 - 6 ms after collision starting. Then, by decreasing the kinetic energy of the legform, the bumper pushed the legform in a reverse direction and the knee bending angle decreased.

From simulation results at table 5, current bumper is not friendly to pedestrian. To improve its pedestrian protection performance, the profile shape must be changed. Impact line should be wider in vertical direction to reduce bending angle and shearing displacement leads to decreasing upper tibia acceleration.

6. Concept bumpers-shapes design of pedestrian friendly bumper

To study the effect the bumper shape on the performance in terms of pedestrian protection, will be studied a four deferent concept bumpers geometrical shape with deferent impact line dimensions between legform and bumper as shown in figures 10 and 11. The distance between upper bumper and knee center line is important factor effect at the result and has been taking it in to account.

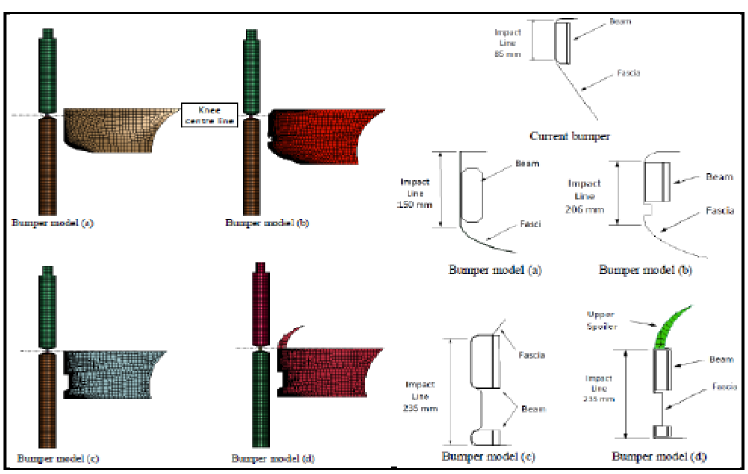

Fig 10: Concept bumper models, position from knee centre line and dimensions

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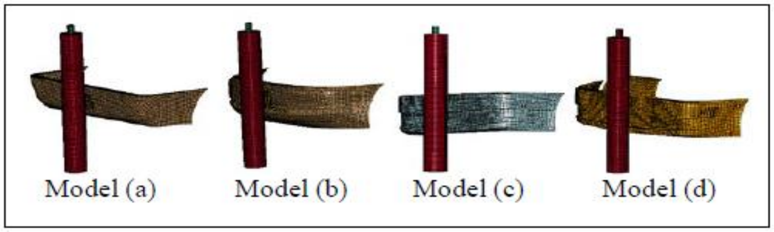

Fig 11: The four concept bumper models

7. Results and Discussion

From figure 12, the highest upper tibia acceleration occurs at current bumper model and the lowest with bumper model (d), the distance between knee centre and upper current bumper 50 mm, this distance effecting adversely at the model result so that the has made the knee and femur moving with more freedom withdraw upper of tibia make increasing at acceleration value. Shear displacement also increasing for the same reason, freedom at femur movement make more shear displacement between tibia and femur.

At bumper model (d) the upper end of bumper within the centre line of knee as shown in figure 10, making more concentrated to knee and femur so that, the upper tibia acceleration decreasing. At figure 13, knee bending angle values are changing from 14.3deg at model (b) to 8.2deg at model (d), the increasing at impact line between legform and bumper leads to decreasing the knee bending angle. At model (d) the upper spoiler make the bending angle at the lowest value.

Figure 14 shows the Knee shearing displacement analyses result for four concept bumpers all models within the EEVC regulation limits. Tables 6 and 7 shows the summary and comparison of the simulation results.

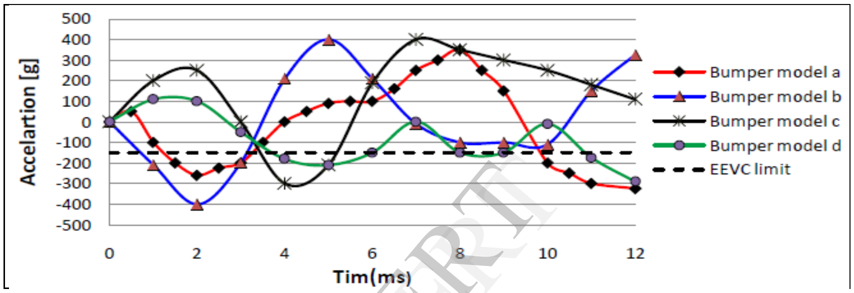

Fig 12: Upper tibia acceleration analyses result for concept bumpers design

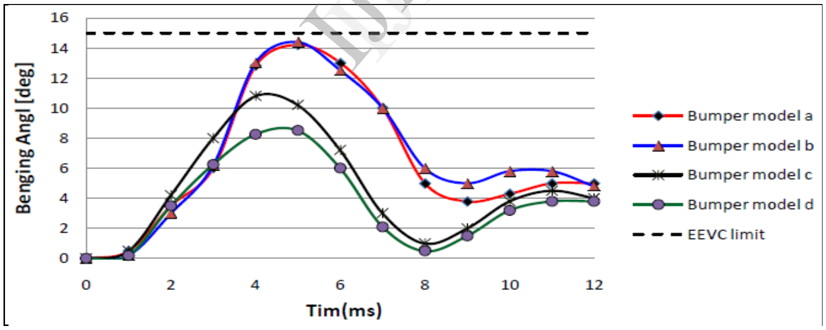

Fig 13: Knee bending angle analyses result for concept bumpers design

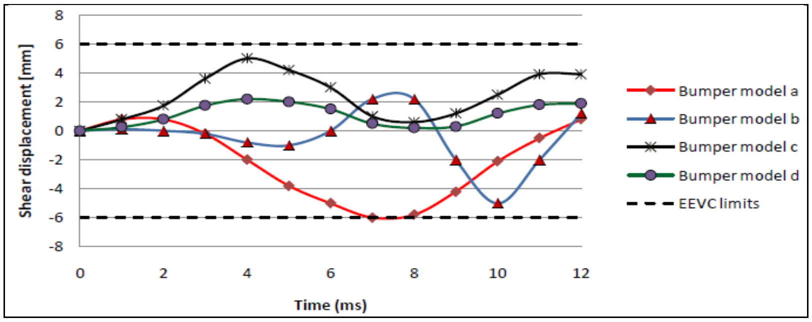

Fig 14: Knee shearing displacement analyses result for concept bumpers design

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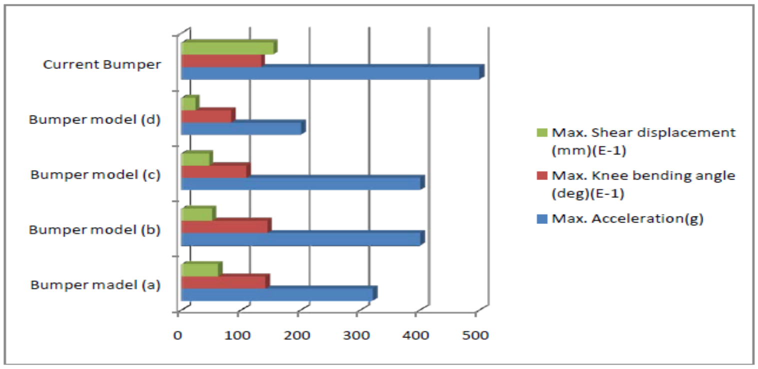
Table 6: Summary of simulation results

Model	Max. Upper Tibia Acceleration (g)	Max. Knee Bending Angle (deg)	Max Knee shear Displacement (mm)	Impact Line length (mm)
Current bumper	500	13.2	15.3	85
a	320	14	6	150
b	400	14.3	5	206
c	400	10.8	4.5	235
d	200	8.2	2.2	235

Table 7: Bumper models analysis results comparison



From table 7, bumper model (d) is the lowest value for all three factors, maximum tibia acceleration, maximum knee bending angle and maximum shear displacement. The current bumper is the highest value.

8. Conclusion

Shape of the bumper is one of important factors affecting at performance of the bumper in term of pedestrian protection. Shape of current bumper, led to high value of negative results, while, shape of the model (c) and (d) leads to positive results.

Bumper impact line should be wider in vertical direction to reduce bending angle and shearing displacement leads to decreasing upper tibia acceleration. The upper edge of bumper should be filleted with upper spoiler to make the combination of bumper and hood leading edge profiles smoother (bumper model d). The lower edge of bumper should be filleted with lower spoiler that is reducing bending angle.

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BIOGRAPHIES

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