

New vehicle bumper design for pedestrian protection during Impact

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Abstract. This study discusses the influence of the active bumper design on the performance of the selected current bumper in terms of pedestrian protection by using finite element method. The legform impactor is used to test the bumper models created according to EEVC/WG regulations (European Enhanced Vehicle-Safety Committee). The simulation was performed using LS-DYNA. The lower leg injury risk was discussed based on the performance of the bumper. Results of the study show a significant improvement in the bumper performance to mitigate the impact injury of the pedestrian's lower leg.

1. Introduction

Pedestrian accidents are increasing in the entire world annually. World Health Organization 2013 (WHO) reported more than 1.24 million people die on the roads annually while 50 million are injured. 75% of the total accident deaths are pedestrian [1]. According to the NHTSA 2012 (National Highway Traffic Safety Administration) statistics, 4,280 pedestrians were killed in United States in 2010 and an estimated 70,000 were injured in traffic crashes [2]. Globally pedestrian fatalities percentage is about 50% to the total accident in the world (22% pedestrian, 23% Motorized 2-3 wheelers and 5% Cyclists). About 75% of the pedestrian accident occurs with sedans (passenger vehicle) type, and 54% at the front of these cars [3]. The "pedestrian friendly cars" designs were proposed as a solution to reduce pedestrian fatalities and mitigate injuries. These designs start from the car hood and bumper in compliance to EEVC/WG regulations for pedestrian protection. About 35% of all pedestrian body non fatal injuries occurs in the lower leg [4]. In this study, the performance of the bumper was investigated by introducing the active bumper function and compared to that of the original bumper without the active function. The bumper model was developed in Solidworks, simulated in LS-DYNA and analyzed using finite element (FE) method. The bumper performance was evaluated in terms of upper tibial acceleration, lower leg injury risk, lower legform bending angle and knee shear displacement.

2. Numerical Models

2.1 FE Current Bumper Model

The current bumper design was modelled using finite element method as shown in Figure 1. The fascia material is plastic PVC fixed on the carbon steel material beam without absorber. All material

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properties and parameters used in the FE model were determined with reference to material databases and related studies [5, 6]. Material specifications of the bumper is given in Table 1. The total weight of the fascia is 5.6 kg.

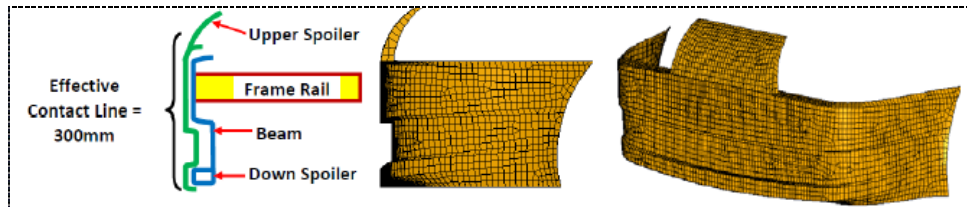


Figure 1. Current bumper system, fascia and beam are used in simulation

Table 1. Fascia and beam material specifications

Item	PVC Fascia	Steel Beam
Density ρ	$1.4 \times 10^{-6} \text{ kg/mm}^3$	$7.8 \times 10^{-6} \text{ kg/mm}^3$
Yield stress σ_y	46 MPa	215 MPa
Young's modulus E	2800 MPa	$210 \times 10^3 \text{ MPa}$
Poisson's ratio	0.45	0.3

2.2 FE Active Bumper Model

The active bumper design was modelled using finite element method as shown in Figure 2. It was proposed as a potential solution to improve the performance of the bumper for pedestrian protection. This model allows the bumper to absorb more impact energy by separating the beam for a specific distance by creating a gap between the beam and the bumper. This will prevent direct collision of the lower leg impactor with beam, as shown in Figure 3 [7]. This active bumper moves by means of an electric motor drive that is linked to a sensor system to push the bumper using two arms. Figure 3 shows the cross sections of the active bumper with beam and the gap between them.

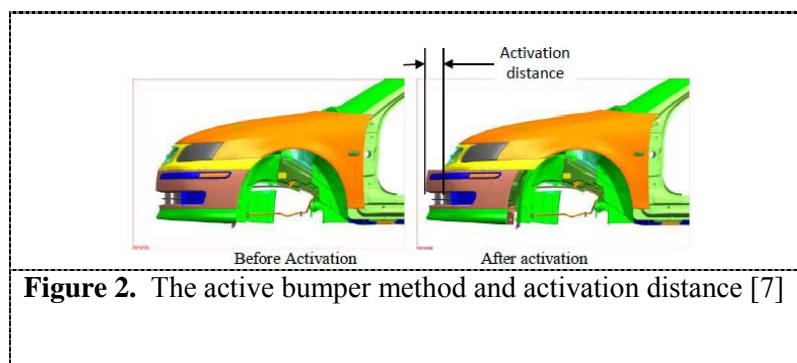


Figure 2. The active bumper method and activation distance [7]

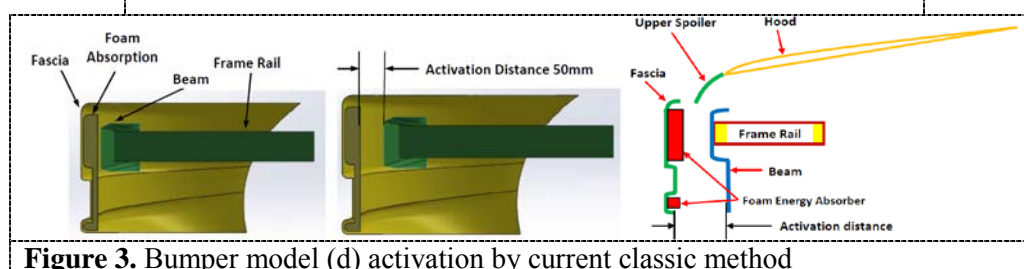


Figure 3. Bumper model (d) activation by current classic method

2.3 Impact Model

The impact test conditions according to EEVC/WG regulation [8] are; the legform impact velocity is 40 km/h = 11.1 m/s, parallel to the longitudinal axis of the vehicle. The impact point between the legform and the current bumper is 50 mm under the knee center at the tibia. The impact occurs at the centre of the bumper as shown in Figure 4.

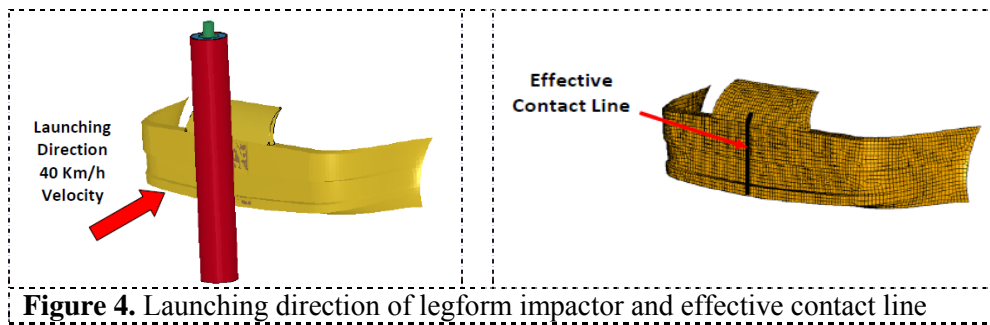


Figure 4. Launching direction of legform impactor and effective contact line

3. Results and Discussion

Figure 5 shows the impact simulation at different time period. Upon impact, the upper tibial acceleration, lower leg injury risk, lower legform bending angle and knee shear displacement are analysed and plotted.

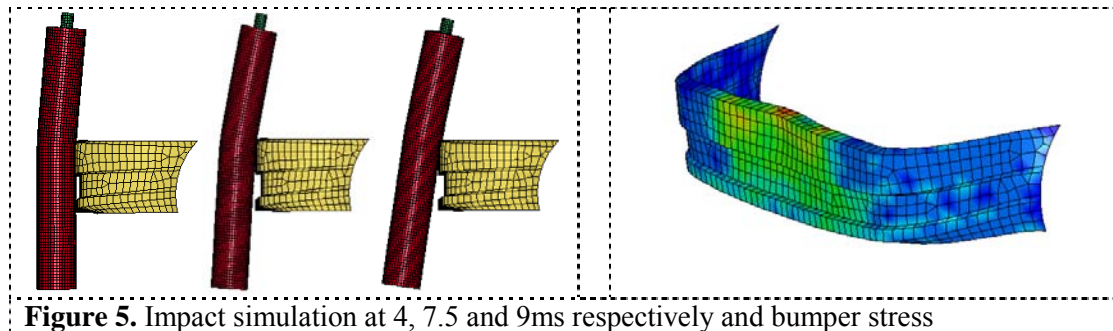


Figure 5. Impact simulation at 4, 7.5 and 9ms respectively and bumper stress

Figure 6 shows the upper tibial acceleration for current and active bumper. The higher the upper tibial acceleration is, the higher the risk of tibia and fibula bones fractures. For current bumper the maximum upper tibial acceleration is 190 G, whereas the maximum upper tibial acceleration for active bumper is greatly reduced to 150 G. The acceleration changes from negative to positive during the test period.

The lower leg injury level is described in the Injury Severity Score (ISS) as a moderate injury AIS2 for fibula fracture and series injury AIS3 for tibia fractures [9]. At 190 G, the current bumper results in a 20% injury risk for fibula and tibia fractures as shown in Figure 8(a). This percentage is considered high which indicates that the current bumper design is unsuccessful in mitigating pedestrian leg injury during accidents. On the other hand, at 150 G, the active bumper results in a 10% injury risk for fibula and tibia fractures as shown in Figure 8(b). This percentage is much lower compared to that of the current bumper which indicates a significant improvement in the bumper performance. The activation distance is limited through the deformation that occurs in the fascia resulting from the collision, which depends on the design of the bumper and material specification of fascia.

Figure 9 and 10 are shows the legform maximum bending angle and knee shear displacement respectively. The knee bending angle and the knee shear displacement indicates the severity of rupture of connective tissue surrounding the knee cartilage damage. Increased values of angle and

displacement indicates a more severe rupture. Although, displacement is increased, angel is however reduced for active bumper compared to the conventional bumper.

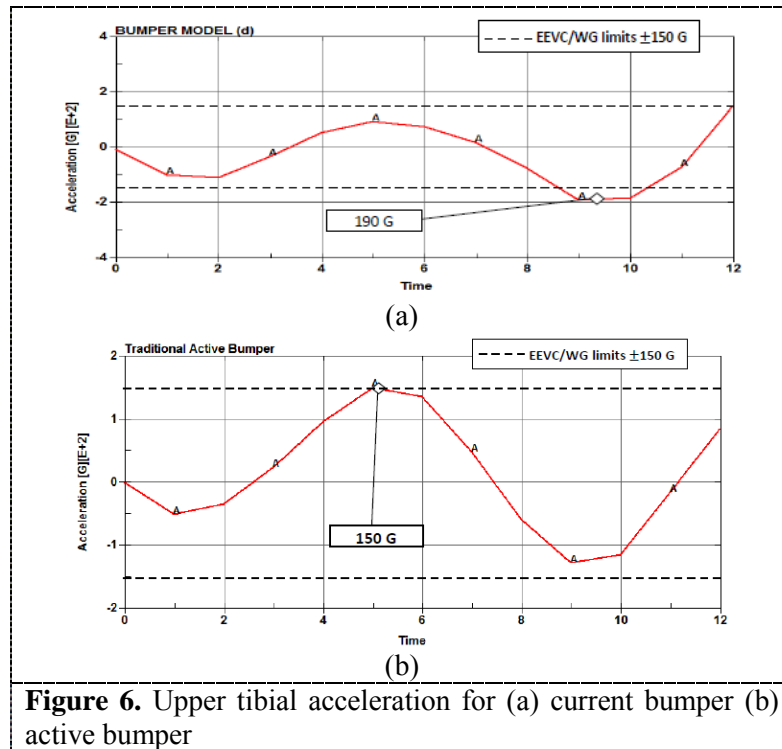


Figure 6. Upper tibial acceleration for (a) current bumper (b) active bumper

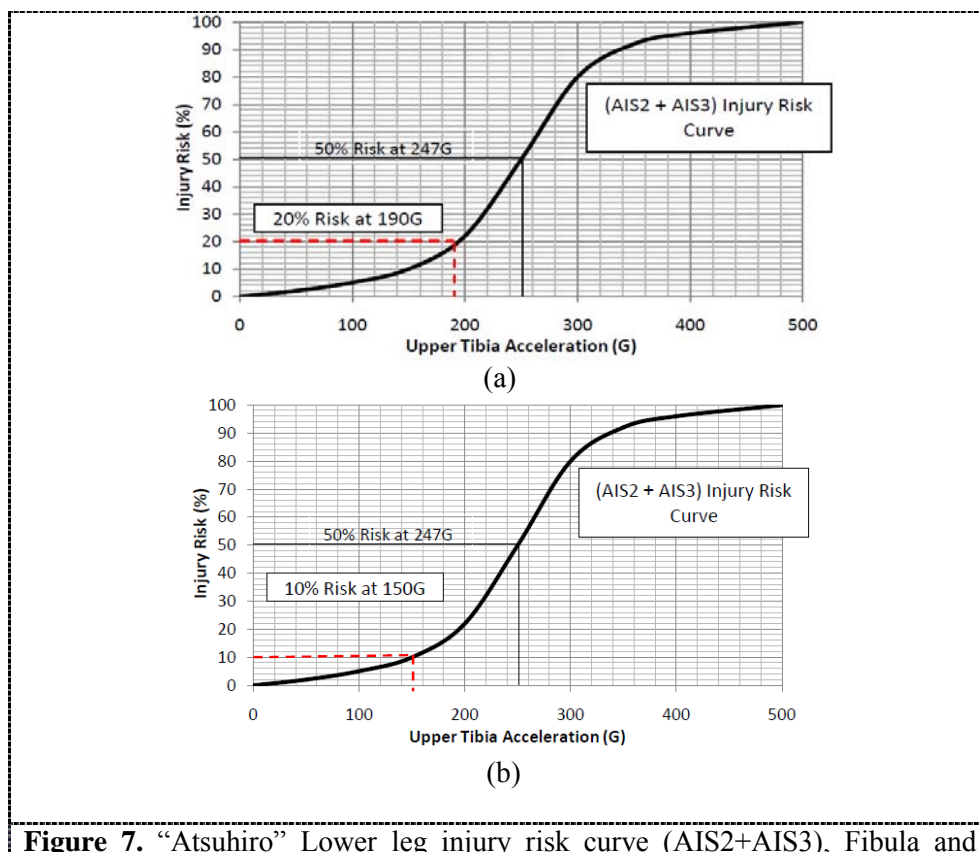


Figure 7. "Atsuhiro" Lower leg injury risk curve (AIS2+AIS3), Fibula and

Tibia fractures for (a) current bumper (b) active bumper

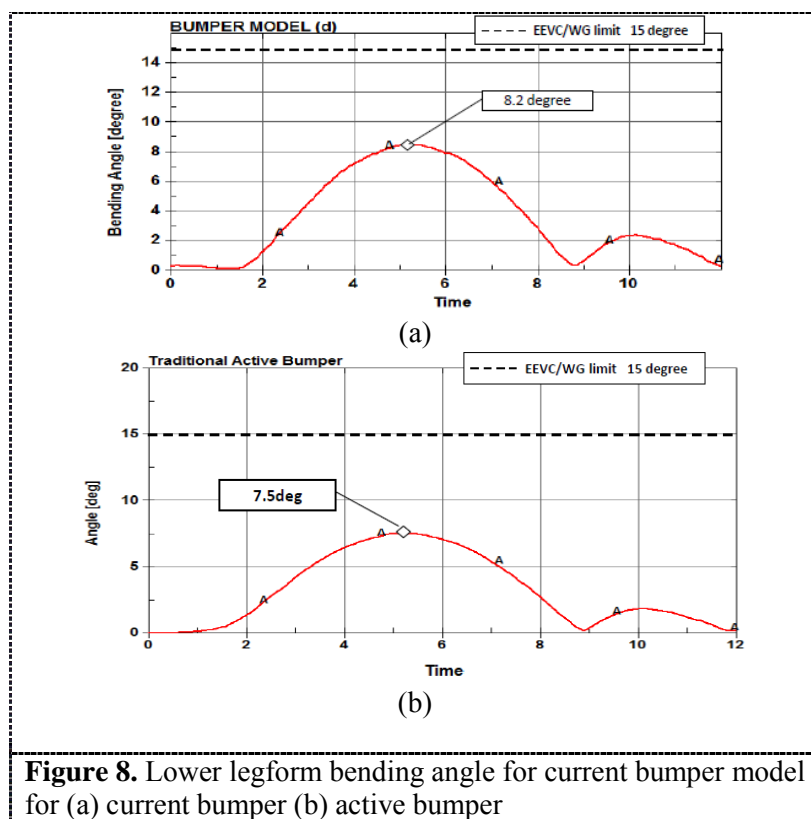


Figure 8. Lower legform bending angle for current bumper model for (a) current bumper (b) active bumper

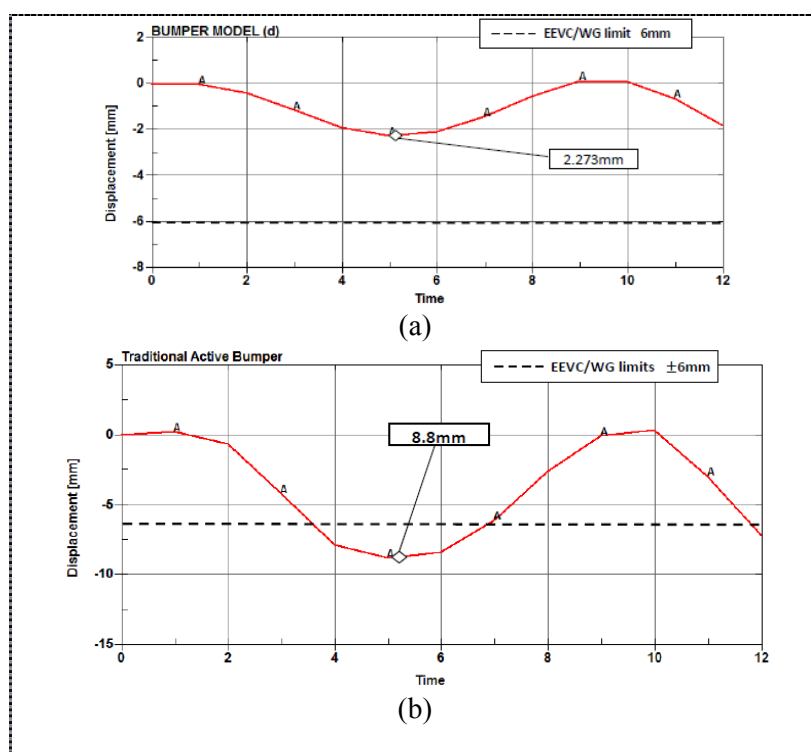


Figure 9. Knee shear displacement for (a) current bumper (b) active bumper

Table 2 shows the comparison of current and active bumpers simulation test results with EEVC/WG regulation required limits.

Table 2. Comparison of current bumper simulation test results with EEVC/WG limits

Item	EEVC/WG Max. Limits	Simulation Test Results	
		Current Bumper	Active Bumper
Upper tibial acceleration (G)	150	190	150
Knee shear displacement (mm)	6	2.3	8.8
Knee bending angle (deg)	15	8.2	7.5

For the active bumper design, the upper tibial acceleration is reduced to a value that falls within the limits of the EEVC/WG regulations. This reduction also leads to a decrease in the injury risk to 10% which is half of the risk without the active bumper. The analyses of these tests suggest that leg injury is caused by the hardness of the beam. The effectiveness of the impact energy distribution and absorption depends on the bumper stiffness which is directly proportional to the amount of energy absorption. The active bumper controls the amount of stiffness by creating a gap between the bumper and the beam, thus reducing the severity of the impact on the leg. These findings indicate that the active bumper design is effective and has greatly improved the bumper performance for pedestrian safety.

4. Conclusions

The current bumper design and active bumper design were studied to evaluate its performance in terms of pedestrian protection during impact. The findings can be summarized as follows:

- The maximum upper tibial acceleration for active bumper was greatly reduced to 150 G which falls within the limits of the EEVC/WG regulations
- The “Atsuhiro” lower leg injury risk for active bumper was reduced to 10% which is half of that of the current bumper
- The active bumper design reduces the bumper stiffness thus reducing the severity of the impact on the leg and greatly improved the bumper performance for pedestrian safety.

5. Acknowledgements

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6. References

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