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Study design and analysis of automobile bumper for pedestrian safety

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Abstract: This paper aims to design and analyse the bumper beam structure, in order to ensure the protection of the pedestrians along with the occupants inside the vehicle. The concern shown towards the pedestrian safety is because, each year about 2,70,000 pedestrians are killed in road accidents that accounts to 22 % of the total deaths. From the literature review, it was inferred that the mounting position of bumper and material selection play a crucial role in maximising the pedestrian safety. Hence in this paper, the effects of bumper mounting position and the bumper beam material have been studied, with reference to an explicit dynamic collision involving with a dummy human lower leg set-up. The acceptance of a particular mounting position/material was based on the fact that the maximum stress and deformation induced were less than the yield limits of the human leg form structure (representing the skin, femur and tibia).

1. Introduction

An automobile bumper, is considered to be the first point of contact in any frontal vehicular accident, it has to perform dual role, the primary role being absorption of the impact energy in case of a high speed impact and to ensure the safety of pedestrians in case of a low speed impact [3]. This Paper deals with the low speed impact test. Post the 1990s there has been a growing concern towards protection of the pedestrians. There has been a sharp increase in the death rate of pedestrian involving a collision with vehicle, according to the data from Euro-NCAP, about 4743 pedestrians were killed in USA in the year 2012 that accounts to 14% of the accidental deaths, while in the Euro-Zone, 5582 pedestrians were killed accounting to 18% of the accidental deaths [1]. Hence several standards are now being followed in countries like Japan, USA to ensure the design of softer and pedestrian friendly automobile bumpers. For the paper, the regulation and standards set forth by Automotive Research Association of India (ARAI) have been considered for the validation of the results [2]. According to these norms, one of the measures to analyse the pedestrian safety is Knee shear. ARAI has proposed the Knee shear to be less than 6mm for the leg foam impact test [2][4][11]. The following figure 1, illustrates the important parameters to be considered for a dummy human leg form model in case of a low speed impact with vehicle.



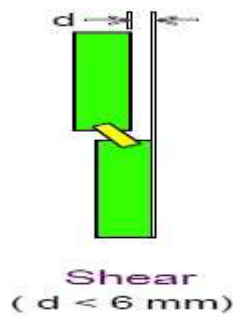


Figure 1. Knee Shear

Apart from the above mentioned criterion, as stated by ARAI and Euro NCAP, the fracture criterion of the bones have also been studied. A bone fracture will occur, if the value of maximum yield stress during collision exceeds the material yield stress. [13][14].

2. Methodology

The CAD model of the Bumper system and Human Leg-form were prepared using CREO 2 as shown in figure 4. A bumper system, primarily consists of a beam and energy absorber [15]. From the literature review, it was inferred that the double hat cross-section with the thickness (as shown in the drawing) provided the most optimum results [10]. Also the design of the energy absorber (crashbox) was done, considering the outcomes of literature studied and is as shown in the figure 3.

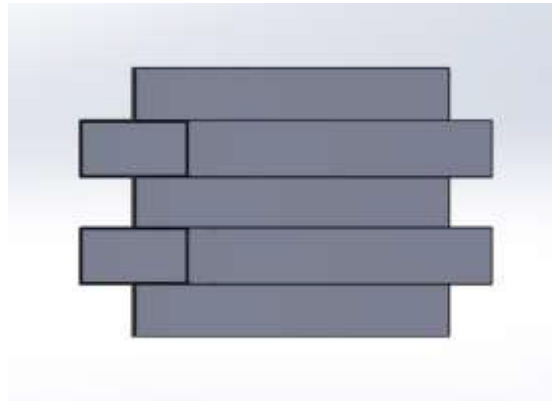


Figure 2. Double-hat cross-section bumper beam

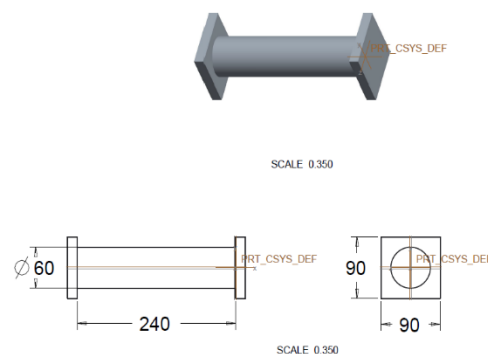


Figure 3. Energy Absorber

The human leg assembly was divided into three elements named as femur, tibia, knee joint (ball-socket joint) and skin. The physical properties of each are as shown in the table. Each of these components were individually part modelled in CREO, and later assembled to get the required leg

form model. The dimensioning of the structure is as shown in the fig. 2 as well [2]. After CAD of the individual components, a final assembly comprising of the human leg form (femur+knee joint+tibia+skin) and the bumper system (beam+energy absorber) was modelled. This assembly was then analysed under the explicit dynamics module of ANSYS 17.2. For analysis, a fixed support was assigned to the energy absorber as shown in the figure and a velocity of 11 m/s was imparted to the Leg-form [2][7][11][12]. The parameters thus studied were, the maximum induced stress and total deformation of the skin and tibia bone. In order to minimise the injury to the pedestrian, the induced stress and deformation were controlled, by varying the mounting position and the material of the bumper system.

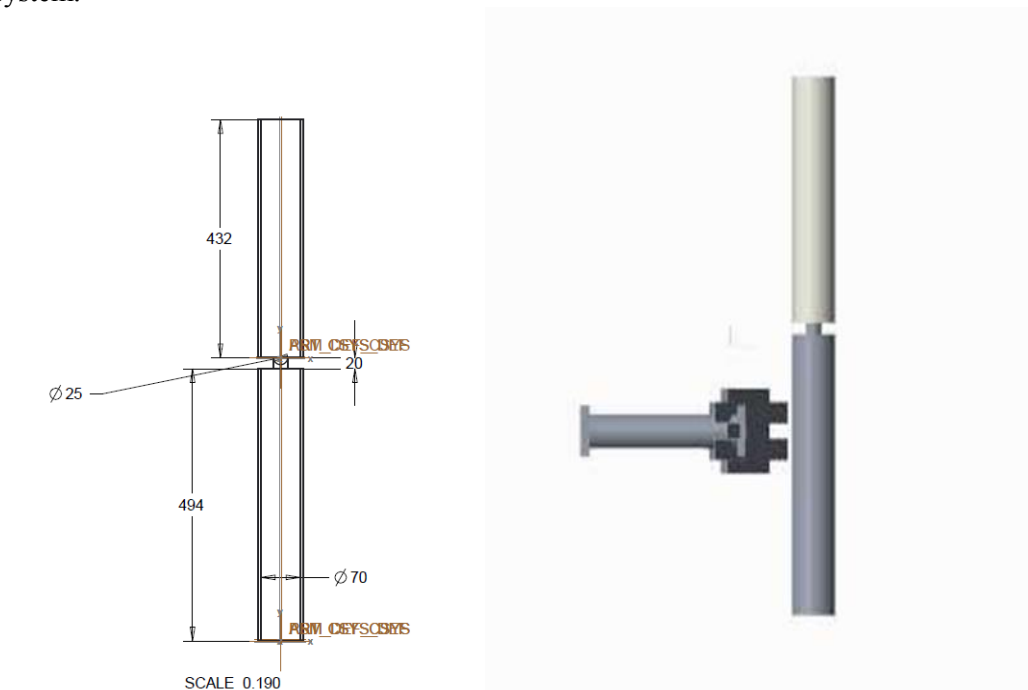


Figure 4. Human Leg-form and Bumper System

The stresses induced were later compared with the yield stress of the bone materials as shown in the table. The following table shows the material properties of the Leg-form components [5-9].

Table 1. Material Properties

Sr No.	Material	Density (Kg/m ³)	Young's Modulus (Mpa)	Poisson's Ratio	Yield Strength (Mpa)
	Femur	1990	14635	0.3435	133
	Tibia	1990	18500	0.3	146
	Skin Flesh	1000	459.3		
	Structural Steel	7850	2 * 10 ⁵	0.3	250
	Al 7075 T6	2805	71700	0.33	503
	Al 6061 T6	2703	68900	0.33	276
	Mg Alloy	1400	4200	0.284	200
	GMT	1280	5810	0.284	230

3. Explicit Dynamic Results

The Bumper Beam was set at various positions offset from the knee joint. The stress induced and deformation were studied at an offset of 40 mm, 60 mm and 100 mm from the knee joint. Initially the material selected for the Bumper assembly were as follows:

- Energy Absorber : Al 7075 T6
- Bumper Beam: Structural Steel

3.1 In-line with Knee joint

The Bumper system was assembled in-line with the Knee joint as shown in fig 5. It is observed that the maximum stress induced in femur is 141 MPa which is greater than its yield strength i.e. 133 MPa as from table 2.

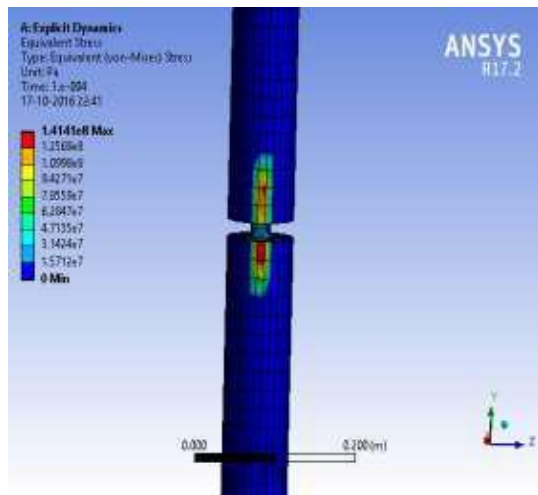


Figure 5. Stress on Leg-form at zero offset

Table 2. Results at 0mm offset

Sr No	Parameter	Max.
1	Stress	141
2	Deformation	3.9

The femur bone will fracture at this condition causing severe injury to the pedestrian. Thus in order to minimise the injury and avoid chances of fracture, the bumper assembly was offset from the knee joint.

3.2 Offset at 40 mm

The bumper beam was mounted at an offset of 40 mm from the knee joint of the human leg form, and then analysed. The results from the table 3 show that, the stress levels in femur have been reduced considerable as compared to the inline mounting position, however the stress induced in tibia were still more than the yield stress of the bone. The following figure 6 shows the stresses induced in the skin and tibia.

Table 3. Results at 40 mm offset

Sr No	Parameter		Max
1	Stress (MPa)	Skin	318
		Tibia	177
2	Deformation (mm)	Knee Joint	2.16
		Tibia	4.33

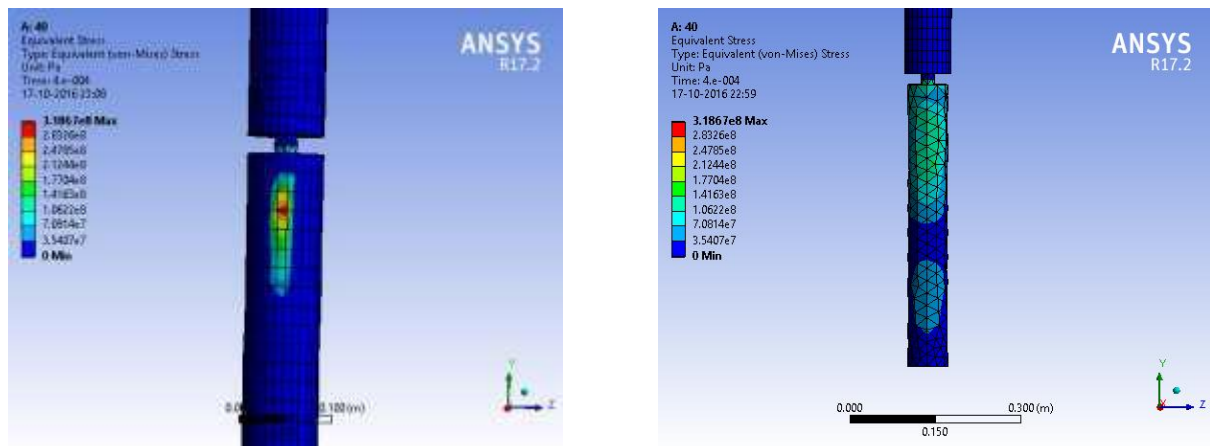


Figure 6. Stress on Tibia and Skin at 40 mm offset

3.3. Offset at 60 mm

The bumper beam was mounted at an offset of 60 mm from the knee joint of the human leg form, and then analysed. The results from table 4 show slight improvement in the stress induced in tibia, however, the stress induced in tibia were still more than the yield stress of the bone. The figure 7 shows the stresses induced in the skin and tibia.

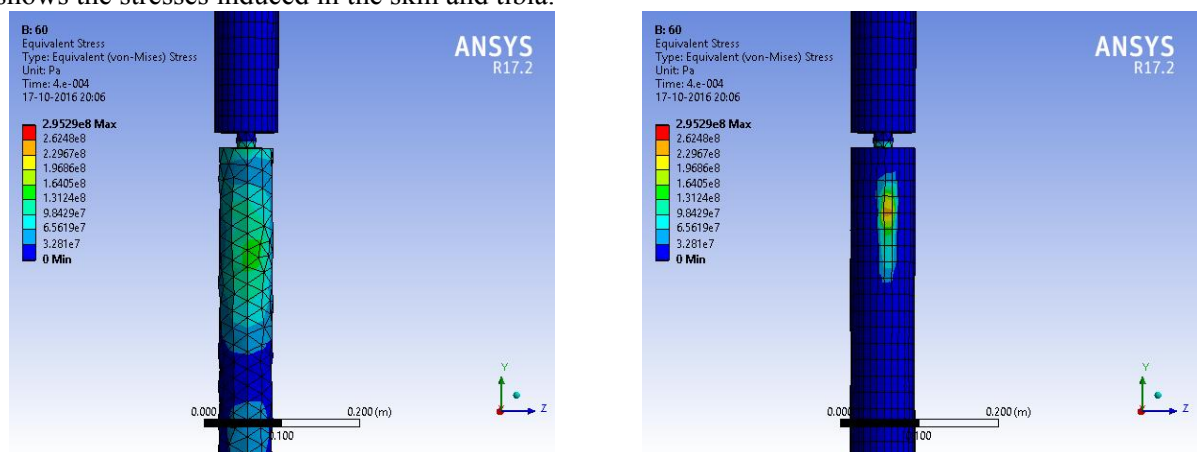


Figure 7. Stress on Tibia and Skin at 60 mm offset

Table 4. Results at 60 mm offset

Sr No	Parameter	Material	Max
1	Stress (MPa)	Skin	295
		Tibia	164
2	Deformation (mm)	Knee Joint	1.61
		Tibia	3.77

3.4 Offset at 100 mm

The bumper beam was mounted at an offset of 100 mm from the knee joint of the human leg form, and then analysed. The results from table 5 show great improvement in the stress level. At the current position the maximum yield stress is lower than the yield stress of the tibia bone, but is close to the value.

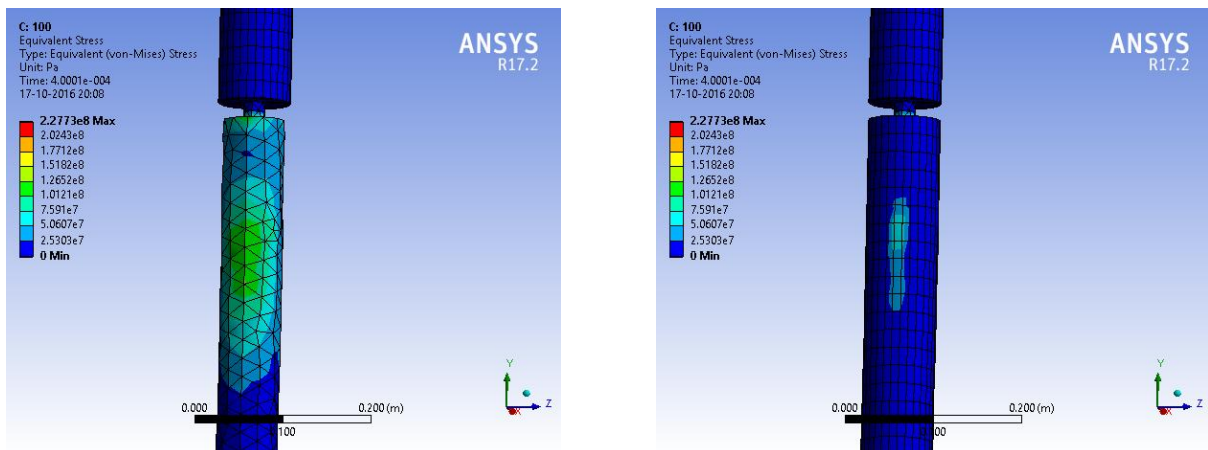


Figure 8. Stress on Tibia and Skin at 100 mm offset

Table 5. Results at 100 mm offset

Sr No	Parameter	Material	Max
1	Stress (MPa)	Skin	177
		Tibia	151
2	Deformation (mm)	Knee Joint	0
		Tibia	4.264

Further increase in the offset will bring down the stress levels, however this is not a feasible option due to the dimensional constraints of the bumper fascia. Hence to ensure substantial improvements, in the stress levels Al6061, Mg alloy and Glass Mat Thermoplastic (GMT) were considered as alternative materials for the bumper beams. An explicit dynamic analysis was performed with these materials with the mounting position of 100 mm offset as a constraint as shown in fig 8.

3.5 Material – Al 6061 T6

Al 6061 is an aerospace grade Al alloy that is known for its light weight and high strength. The results of the explicit dynamic analysis are as shown in the fig 9 and table 6.

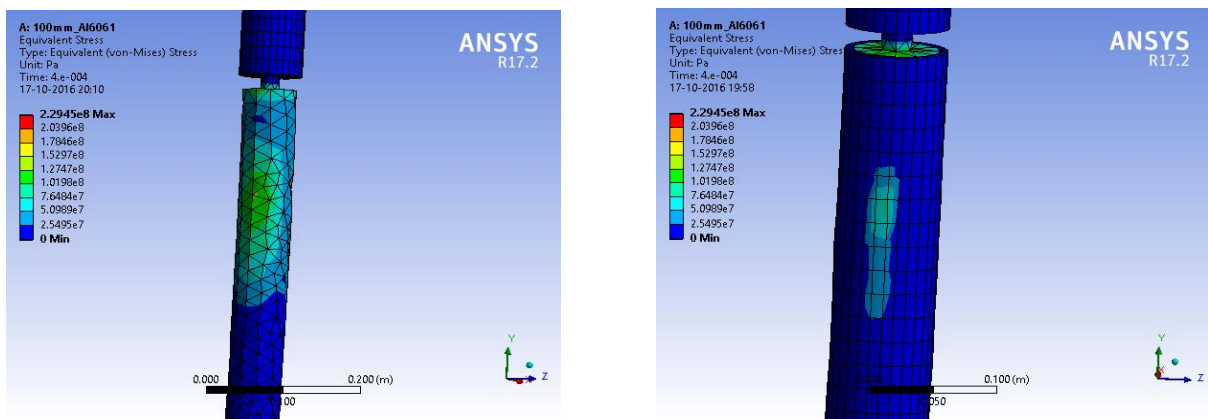


Figure 9. Stress on Tibia and Skin with Al 6061 T6 as bumper material

Table 6. Results for Al 6061 T6

Sr No	Parameter	Material	Max
1	Stress (MPa)	Skin	203
		Tibia	127
2	Deformation (mm)	Knee Joint	0
		Tibia	4.15

3.6 Material – Mg Alloy

It is considered to be one of the lightest materials; hence its alloys are widely used as automotive and aerospace applications. The material was assigned for the bumper beam and analysed. The results are as shown in the fig 10 and table 7.

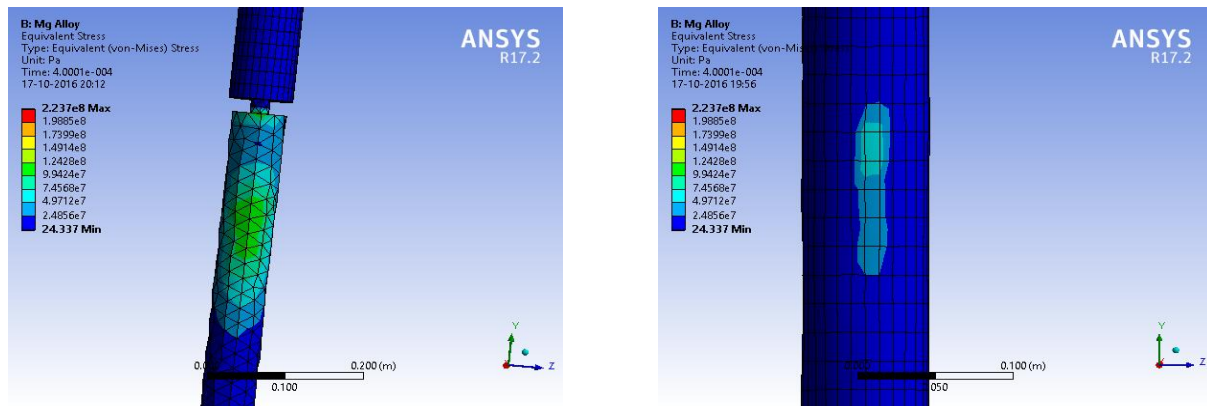


Figure 10. Stress on Tibia and Skin with Mg Alloy as bumper material

Table 7. Results for Mg alloy

Sr No	Parameter	Material	Max
1	Stress (MPa)	Skin	198
		Tibia	124
2	Deformation (mm)	Knee Joint	0
		Tibia	4.45

3.7 Material – GMT

GMT is a classic Glass Mat Reinforced Thermoplastic which is an endless glass fibre reinforced with Pre impregnated epoxy. This Pre impregnated epoxy gives GMT better mechanical properties as compared to injection moulded thermoplastic. This is due to higher residual strength of glass strands. Due to this, GMT finds wide applications in automobiles such as Seat structures, under-body shields, and front ends. The results with GMT are as shown in fig 11 and table 8.

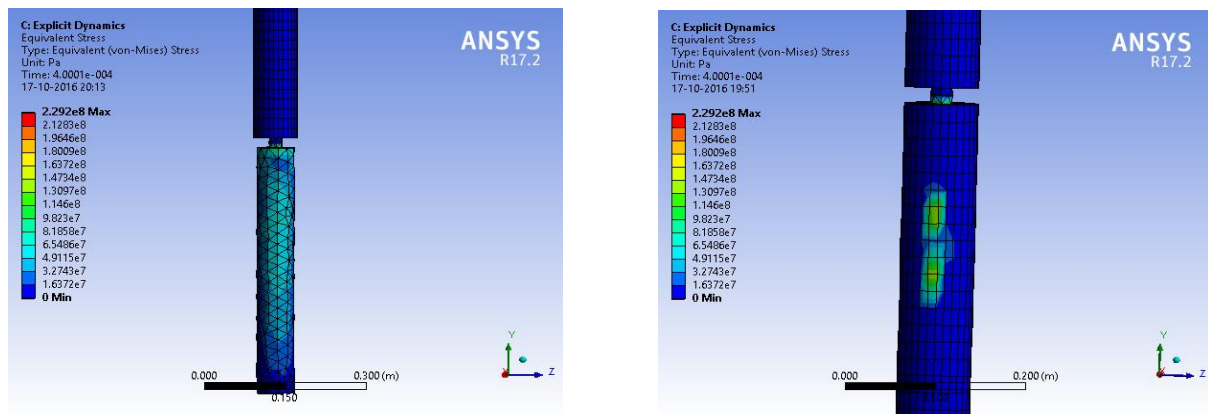


Figure 11. Stress on Tibia and Skin with GMT as bumper material

Table 8. Results for GMT

Sr No	Parameter	Material	Max
1	Stress (MPa)	Skin	180
		Tibia	98
2	Deformation (mm)	Knee Joint	0
		Tibia	5.38

4. Conclusion and Inference

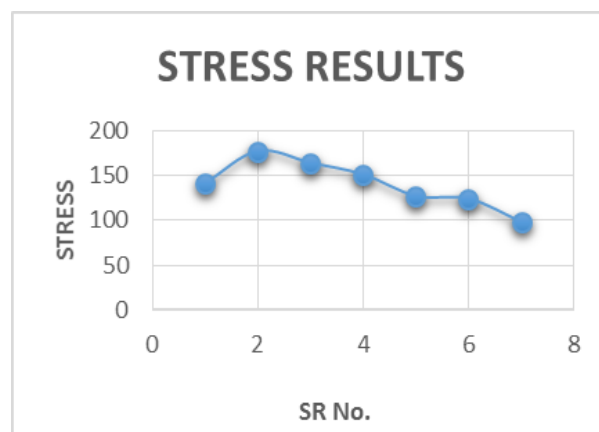
From the results obtained as described in the above mentioned sections it can be concluded that,

- A decrease in the mounting position of the bumper, lowers the stress and deformation induced in the tibia bone.
- Minimum deformation and stress were observed at the mounting position of 100 mm offset from the knee joint. However the stress induced was comparable with that of the yield stress of the bone.
- Material selection plays a crucial role in the pedestrian lower leg protection and further minimises the stress and deformation induced. The GMT material gives the best result amongst the materials studied.
- The maximum stress induced in tibia bone, with GMT as bumper beam material is 98 MPa , that is significantly less than the yield stress of tibia i.e 146 MPa. Hence the pedestrian has least chances of bone failure (limb fracture).
- Hereby, the mounting position with 100 mm offset from the knee and GMT as a material for bumper beam, serves to be ideal parameters to lower the pedestrian impact.

The following table 9 shows the stress values of the Tibia bone at various mounting positions and with different materials along with stress results as shown in fig 12.

Table 9. Stress Results for Tibia

Sr No.	Material	Stress
1	SS Inline	141
2	SS 40 mm	177
3	SS 60 mm	164
4	SS 100 mm	151
5	Al 6061T6	127
6	Mg Alloy	124
7	GMT	98

**Figure 12.** Stress Results for Tibia

Acknowledgement

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