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Bumper Shape Optimization for Pedestrian Safety

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Abstract:

Almost 28% of the total accidents are encountered annually in road traffic crashes worldwide are pedestrians. Pedestrian means a person traveling on foot, whether walking or running. The objective of project is to Optimize Bumper shape to increase pedestrian safety. The main focus will be to design a bumper shape to reduce lower and upper leg injuries. The system will be analyzed using computational codes like LS Dyna and Optimization tools like HyperStudy. This study indicates that the increase in the bumper area to optimize its shape not always a solution. If we just keep on increasing the bumper size then the bumper becomes very weak and fails during the pedestrian collision.The bumper shape optimization is done by a new method called HPERMORPH technique.

Keywords: LSDYNA, HYPERMORPH, HYPERMESH

1. INTRODUCTION:

Almost 28% of the total accidents are encountered annually in road traffic crashes worldwide are pedestrians. Pedestrian means a person traveling on foot, whether walking or running. In some communities, those traveling using roller skates or skateboards are also considered to be pedestrians. In modern times, the term mostly refers to someone walking on a road or footpath.

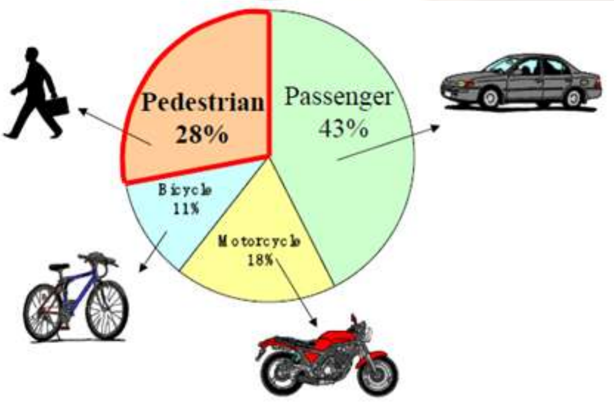


Figure 1: Contribution of pedestrian in total accident [1]

Despite the magnitude of the problem, most attempts at reducing pedestrian deaths have focused solely on education and traffic regulation. However, in recent years crash engineers have begun to use design principles that have proved successful in protecting car occupants to develop vehicle design concepts that reduce the likelihood of injuries to pedestrians in the event of a car-pedestrian crash. These involve redesigning the bumper, hood (bonnet), and the windshield and pillar to be energy absorbing (softer) without compromising the structural integrity of the car. Most pedestrian deaths occur due to the traumatic brain injury resulting from the hard impact of the head against the stiff hood or windshield. In addition, although usually non-fatal, injuries to the lower limb (usually to the knee joint and long bones) are the most common cause of disability due to pedestrian crashes.

2. KINEMATICS OF THE PEDESTRIAN ACCIDENT

In order to improve the crash performance of a car's front end concerning pedestrian protection, the first important step is to analyze the kinematics the human body experience in a car impact. Thus the parameter that influence on one hand the pedestrian's kinematics and on the other hand the car's crash behaviour can be investigated. This examination allows localizing critical impact zones that need consideration regarding pedestrian safety. Information about the kinematics of the human body in case of an impact on the car's front end can be obtained by evaluation of accident data, by reconstruction of accidents, furthermore by cadaver and dummy tests and in additional by simulation using a full dummy model. To perform simulation of full dummy impact a rigid body dummy is integrated into the finite element model of the vehicle. [7]

The examples show the impact of a 6 years old child and adult male on a sport car and on a van. The animation illustrates that the kinematics of the pedestrian are depending on one hand of the pedestrian's size and weight and on the other hand on the car's front structure. In the first contact of the 6 years old child to the car, many body parts are involved: such as upper leg, pelvis and torso are impacted by the bumper area. In the case of van, an even larger area is impacted due to the bigger bumper system of this vehicle. In the next step, the child's head hits the forward section of the bonnet top. In the case of the adult male, the first contact is with the leg by the vehicle's bumper system, initiating a rotation of the whole body. Depending on the car's front structure, the pelvis hits the bonnet leading edge; in this case the relatively flat sport car, pelvis and car do not get into contact whereas in case of the van, the upper leg and pelvis hit the bonnet top (as in the sports car) or the windscreen area (as in the van).

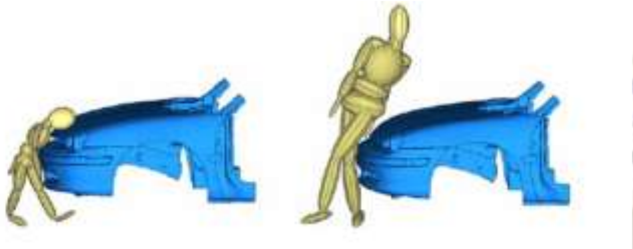


Figure 2: A 6 years old child and an adult male hit by a sport car [7]

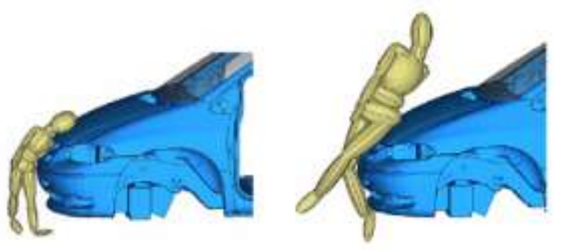


Figure 3: A 6 years old child and an adult male hit by a van [7]

Thus concerning adults, the collision of the pedestrian with the vehicle can be divided into three impact phases:

- Bumper hits the leg; rotation of the body is initiated.
- Pelvis hits the bonnet leading edge (depending on the vehicle)
- Head hits the bonnet top or the windscreenReduced Car Model of Toyota Yaris and Analysis of the Original model

3. REDUCED CAR MODEL OF TOYOTA YARIS AND ANALYSIS OF ORIGINAL MODEL

Figure 4: reduced Toyota Yaris

3.1 Reduced FE Model Preparations

FE Model Quality:

The FE model quality as measured in Hypermesh is given in table below.

Sr. No.	Element Property	Permissible Value	Actual Value
1	Minimum Element Size	5	5.7
2	Warpage <	15	15
3	Aspect Ratio <	5	2.13
4	Skew Angle <	60	44.09
5	Jacobean Ratio >	0.6	0.62
6	Min Angle (Quad) >	35	36.74
7	Max Angle (Quad) <	140	138.07
8	Min Angle (Tria) >	20	34.32
9	Max Angle (Tria) <	120	99.4
10	% of Trias / Pentas <	10%	7%

Table 1: FE Model Quality Criteria

The full co related model of ***Toyota Yaris*** is reduced up to the firewall section. The engine assembly, suspension and the wheels are excluded from model as they do not contribute to the bumper stiffness. The reduced model helps in fast processing of the LS Dyna runs due to reduced number of elements. The reduced model is validated for stiffness and connection by performing a modal analysis. The FE model considered is as shown below.

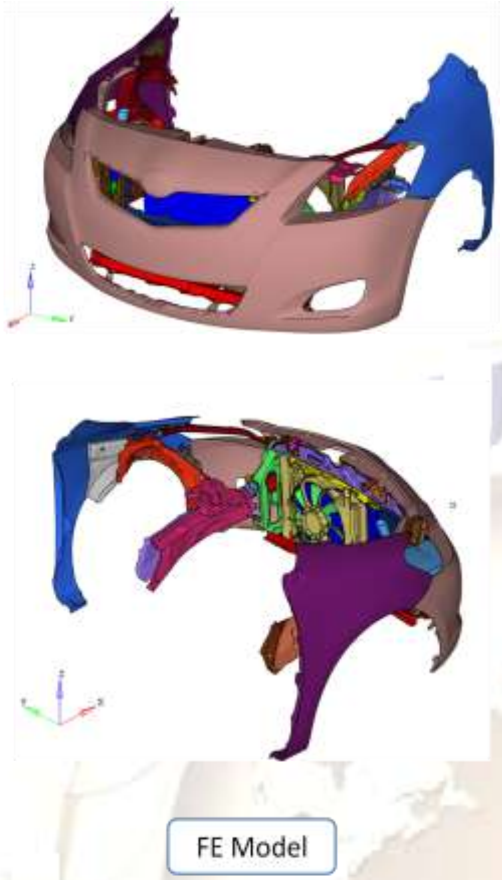


Figure 5: FE model of Toyota Yaris

3.2 FE Model Setup

The analysis setup consists of reduced car model and lower legform. The vehicle is placed at ground level and legform impactor is placed at 25 mm above ground level.

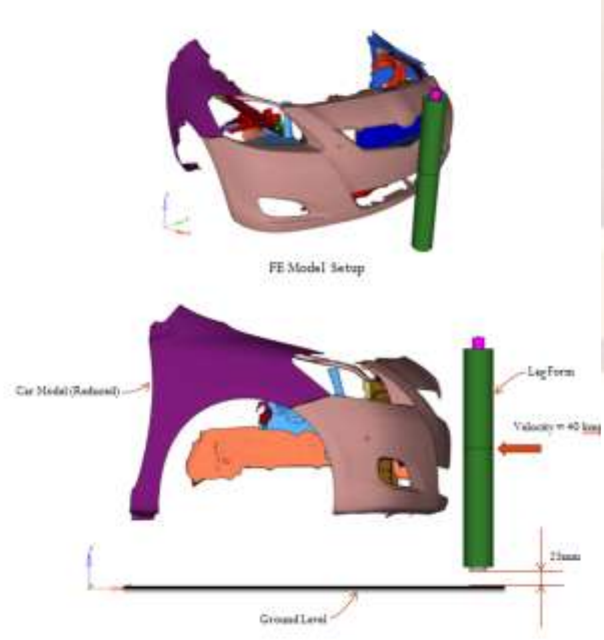


Figure 6: Impact test setup

3.3 Regulatory Requirements according to Automotive Industry Standard 100

- The maximum dynamic knee bending angle shall not exceed 19°.
- The maximum dynamic knee shearing displacement shall not exceed 6.0 mm.
- The acceleration measured at the upper end of the tibia shall not exceed 170 g.

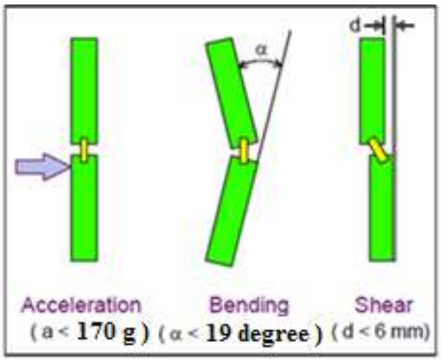


Figure 7: Pedestrian leg-form criterion [8]

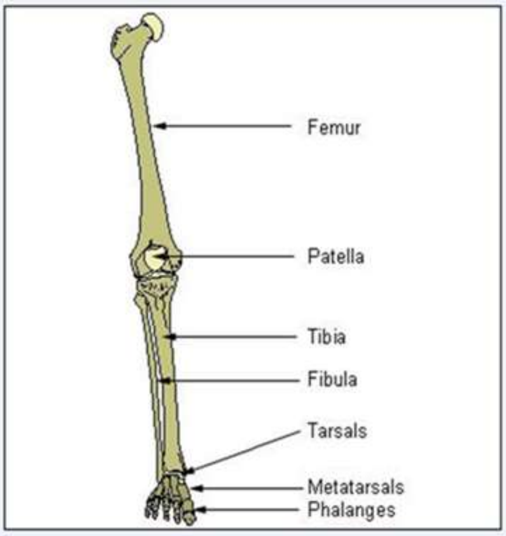


Figure 8: Lower part of human body [9]

FEA TOOLS

The following software's are utilized for Pre Processing (FEA model discritization), solving (FEA computation code) and Post Processing (FEA result visulization)

Pre Processor	- Hypermesh 9.0
Solver	-LS Dyna
Post Processor	-Hyperworks, LS Prepost

RESULTS FOR (ORIGINAL MODEL) BASELINE ITERATION:

- The Maximum Tibia acceleration is 217.9 g which is higher than the allowable limit of 170g. Hence, baseline design does not meet acceleration requirement.

- The Maximum Knee Shearing displacement is 2.87mm which is within allowable limit of 6 mm. Hence meets the requirement.
- The Maximum Knee Bending angle observed is 20.84 deg. which is higher than the allowable limit of 19 deg. Hence, baseline design does not meet acceleration requirement.

MODIFICATION OF BUMPER SHAPE FOR OPTIMIZED RESULTS:

The different shapes of bumper are created by using the HyperMorph module in HyperMesh. The HyperMorph module allows you to alter models in useful, logical, and intuitive ways while keeping mesh distortion to a minimum. Morph volume technique is used to modify bumper shapes. This method is ideal for making simple changes to complex models. This method encloses the mesh in one or more deformable 3-D blocks. Each block is a "morph volume" (often referred to as "mvol" for brevity) and governs the movement of the mesh within its boundaries. Thus, by changing the shapes of the blocks, you can change the shape of the mesh.

The process of morphing consists of entering either the domains panel to create global or local domains and handles, the morph volumes panel to create morph volumes, or the freehand or map to geom panels to morph the mesh directly. Morphing using domains, handles, and morph volumes is done in the morph panel by moving the handles and in the map to geom panel by mapping domains, nodes, elements, or morph volume edges to geometric entities. The freehand panel can be used with models that have (or lack) domains, handles, and morph volumes.

The red dots indicate the morph handles. The handles can be translated to get desired change in shape. We have altered the handles in specific manner to modify the bumper shape incrementally.

In all six combinations of shape were made by altering the dimensions of the handles.

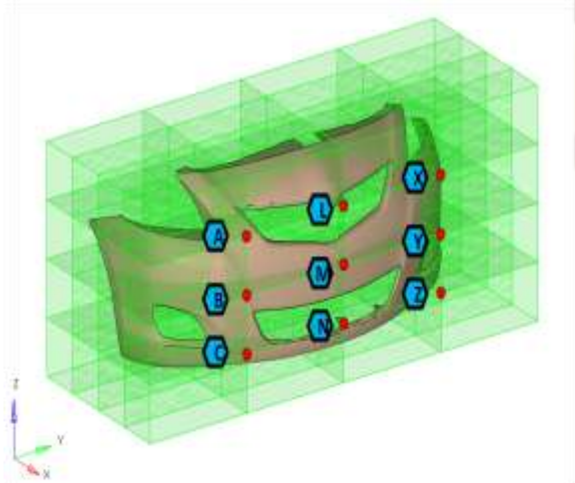


Figure 9: Morphing handle notation

Table 2: Showing Details for Handle Movement for Shape Generation

The handles were moved in X direction as shown in figure to get six different shapes of bumper.

The six shapes obtained are as given below.

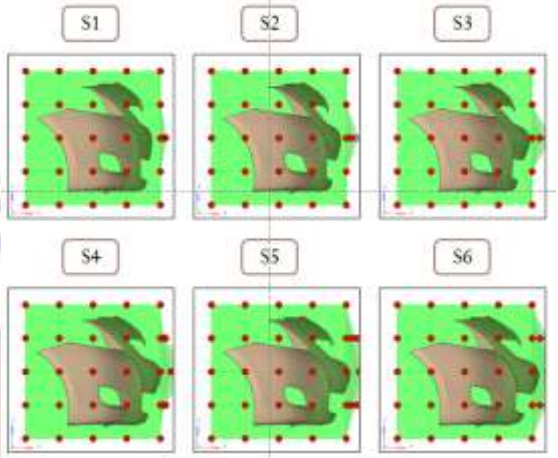


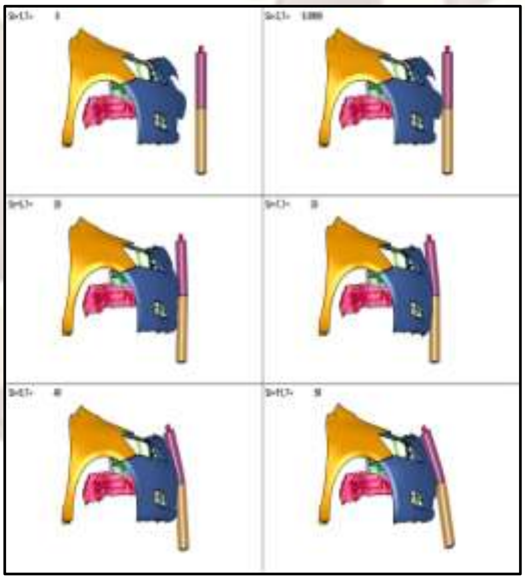
Figure 10: Six different shapes

RESULTS FOR SHAPE OPTIMIZATION:

1.1. Iteration for Shape 3

	LH Side Handles			Center Handles			RH Side Handles		
	A	B	C	L	M	N	X	Y	Z
S1	0	15	0	0	30	0	0	15	0
S2	0	30	0	0	60	0	0	30	0
S3	0	45	0	0	90	0	0	45	0
S4	15	60	15	30	120	30	15	60	15
S5	30	75	30	60	150	60	30	75	30
S6	45	90	45	90	180	90	45	90	45

1.1.1. Animation Instances



1.1.2. Stress and Strain Plots

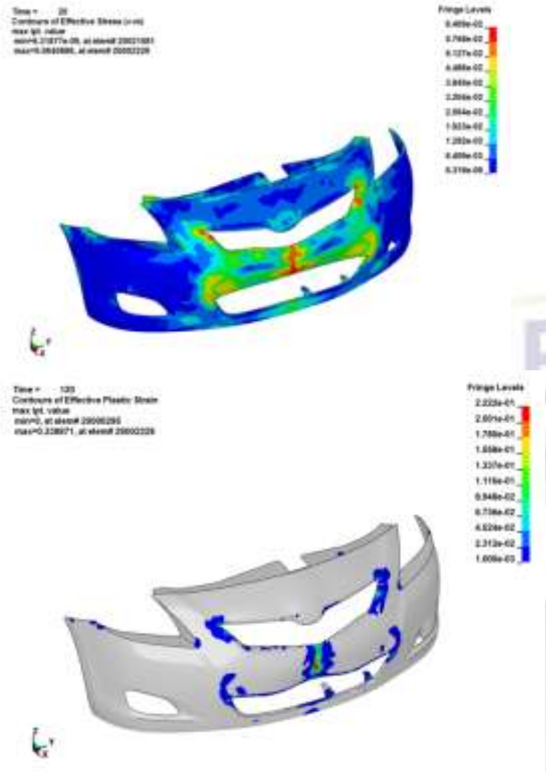
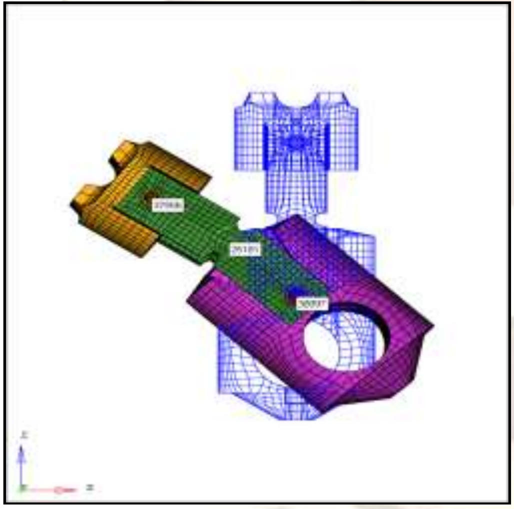


Figure 11: Von mises and plastic strain plots

1.1.3. Legform Outputs



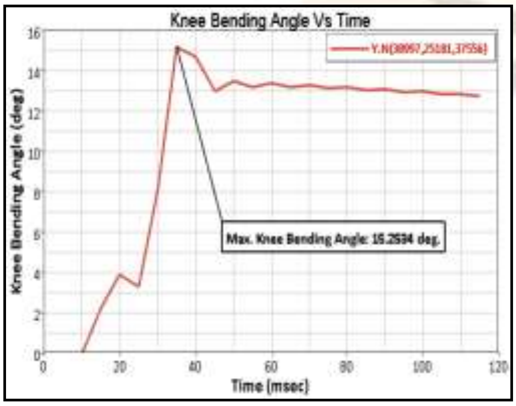
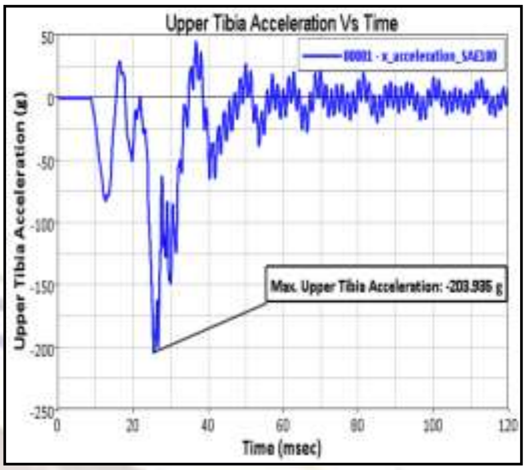


Figure 12: Knee Bending Angle



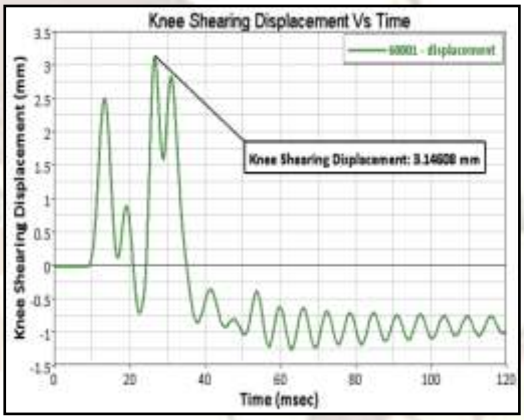
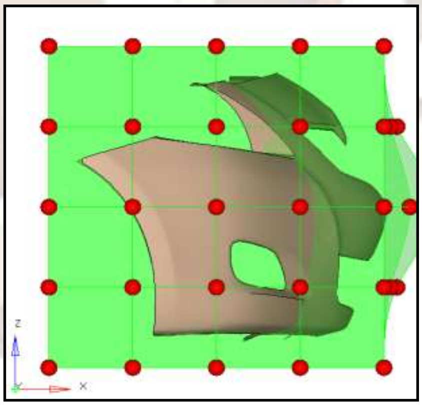
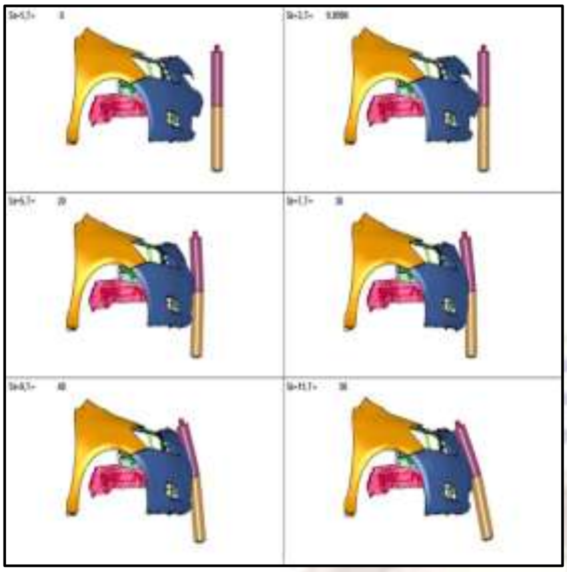


Figure 13: Upper Tibia Acceleration and Knee Shearing Displacement Plots

1.2. Iteration for Shape 4



1.2.1. Animation Instances



1.2.2. Stress and Strain Plot

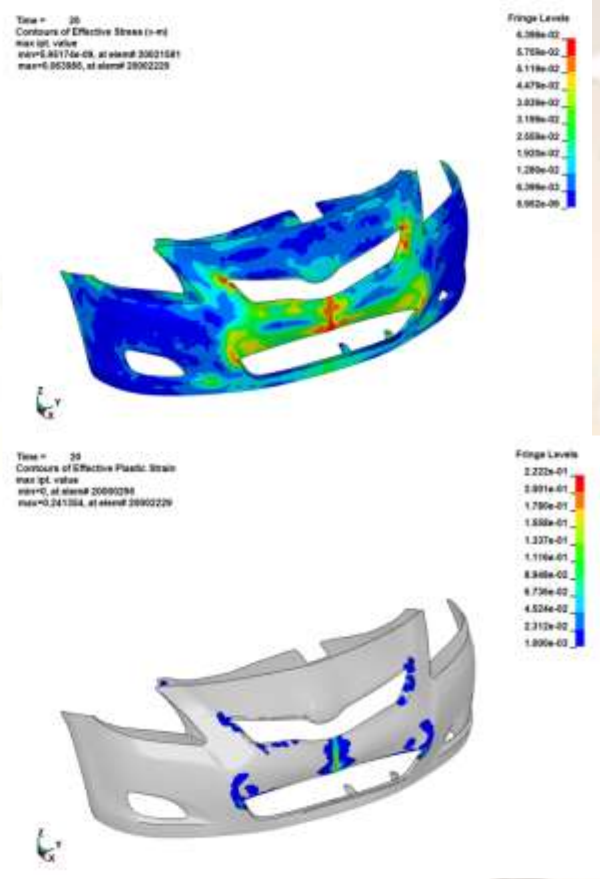
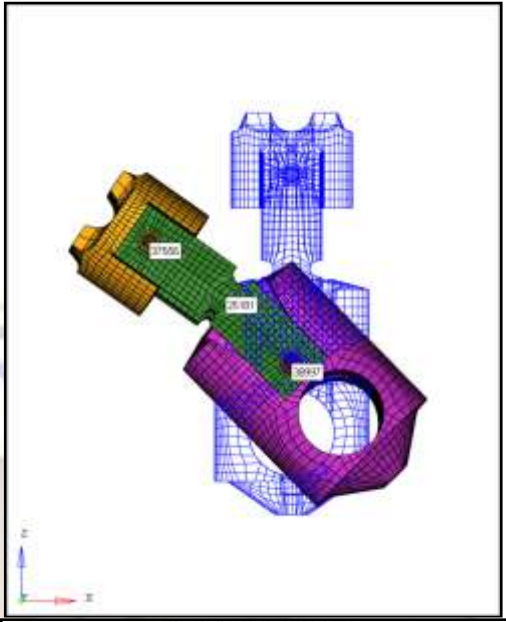


Figure 14: Von mises and plastic strain plots

1.2.3. Legform Outputs



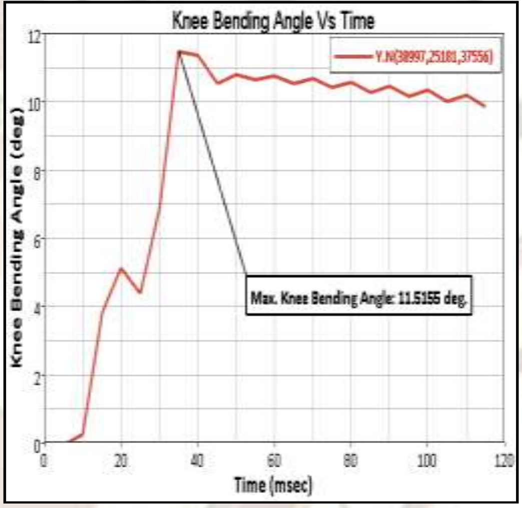
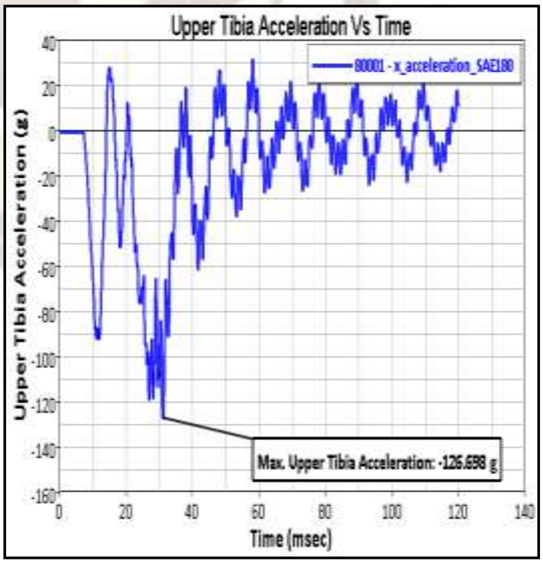


Figure 15: Knee Bending Angle



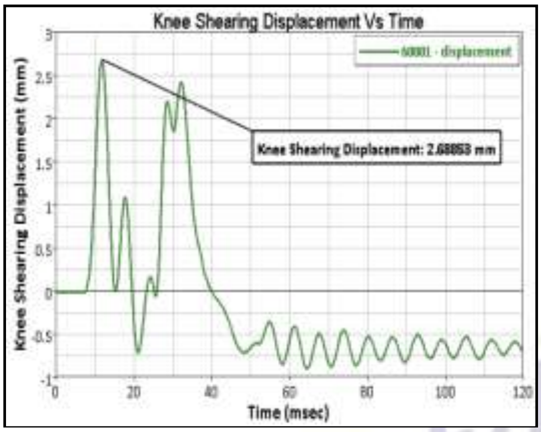
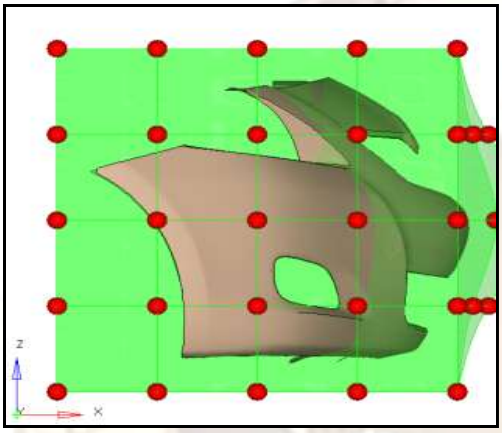
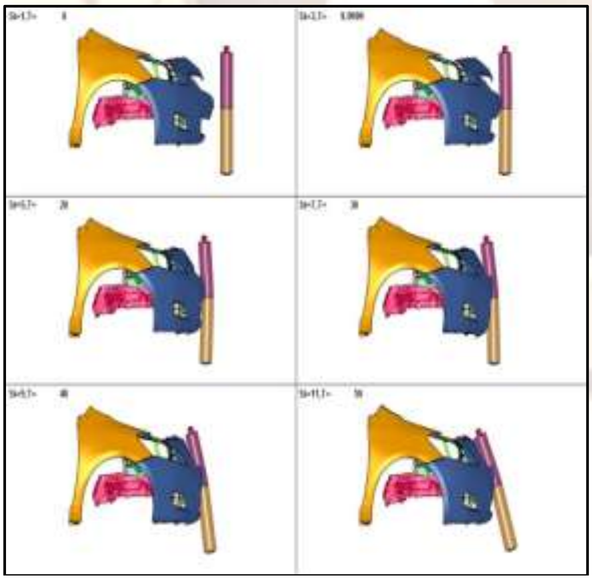


Figure 16: Upper Tibia Acceleration and Knee Shearing Displacement Plots

1.3. Iteration for Shape 5



1.3.1. Animation Instances



1.3.2. Stress and Strain Plots

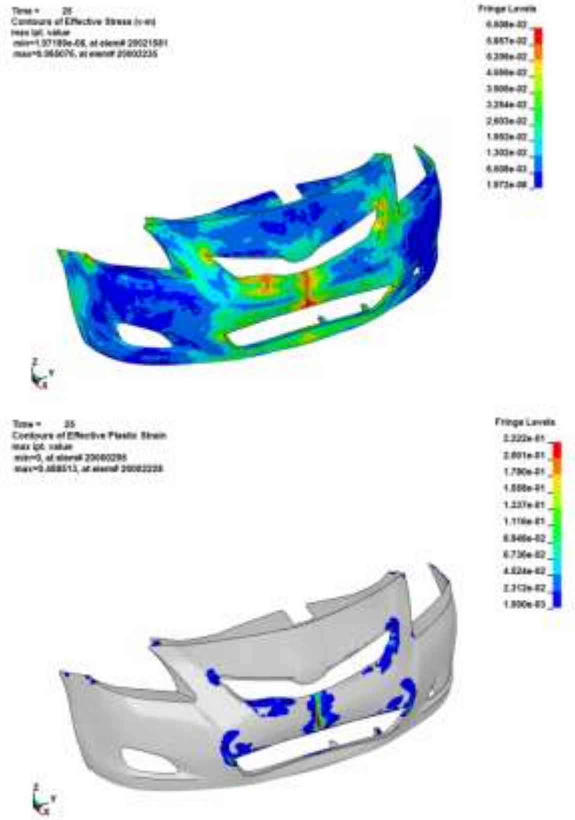
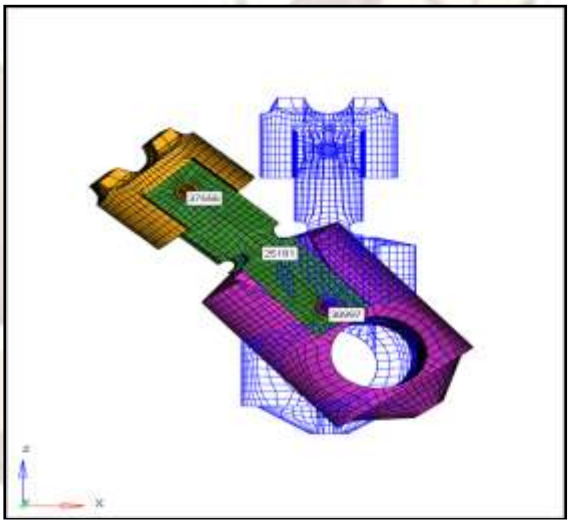


Figure 17: Von mises and plastic strain plots

1.3.3. Legform Outputs



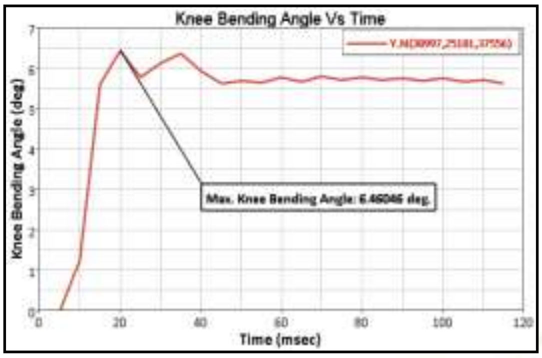


Figure 18: Knee Bending Angle

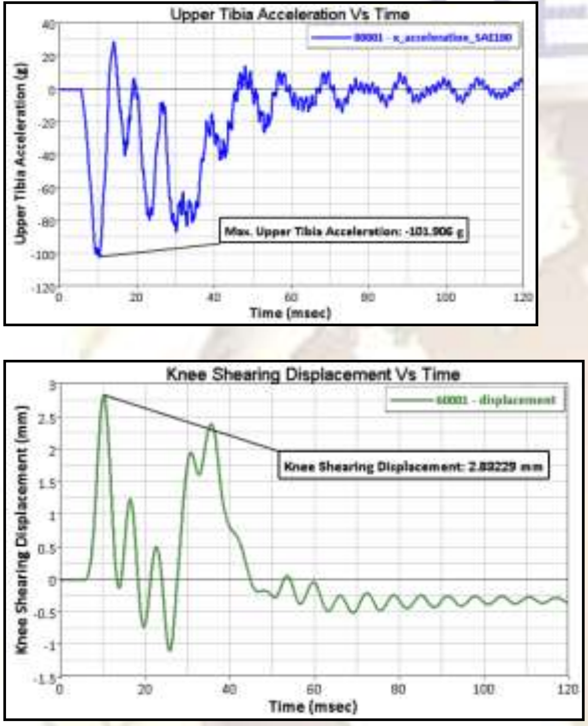


Figure 19: Upper Tibia Acceleration and Knee Shearing Displacement Plots

RESULT SUMMARY & OBSERVATIONS

	Acceptable Limits	Baseline	Shape 01	Shape 02	Shape 03	Shape 04	Shape 05	Shape 06
Knee Bending Angle	< 19°	20.84°	19.65°	18.34°	15.25°	11.51°	6.46°	7.34°
Upper Tibia Acceleration	< 170 g	217.9 g	198.69	176 g	203.9	126.69	101.9	108.6
Knee Shearing Displacement	6.0 mm.	2.87	2.76	1.97	3.14	2.68	2.83	2.89
Plastic Strain in Bumper	20% Plastic Strain	26% Localized	28% Localized	22% Localized	33% Fail	24% Localized	48% Fail	50% Fail

Table 3: Result Summary

From the above study following observations are deduced

- **Baseline Design**: Only meet Knee shearing displacement and shows maximum upper tibia acceleration among all shape changes i.e. 217g which is beyond acceptable limit of 170g.
- **Shape 01:** Marginal improvement over the baseline design but shows same failure trend compared to Baseline Design.
- **Shape 02**: Improved over earlier design shapes, only does not meet Upper Tibia Acceleration.
- **Shape 03:** Bumper behavior is worsen compared to earlier shape. Also shows Plastic Strain beyond allowable limits.
- **Shape 04:** All the requirements are satisfied and are well bellow the acceptable limits with ensuring the component integrity.
- **Shape 05:** Component meet the regulatory requirement but fails in component integrity as plastic strain shows values beyond allowable limit f 22%.
- **Shape 06:** Bumper behavior has worsened as compared to earlier shape. Also shows Plastic Strain beyond allowable limits.

CONCLUSION

- Shape 04 is the best possible shape among all design as all the requirements are satisfied and are well below the acceptable limits with ensuring the component integrity.
- The Max. Tibia acceleration is 126.69 g which is lower than the allowable limit of 170g. Hence, meet acceleration requirement.
- The Max. Knee Shearing displacement is 2.68 mm which is within allowable limit of 6 mm. Hence meets the requirement.
- The Max. Knee Bending angle observed is 11.51 deg. which is higher than the allowable limit of 19 deg. Hence, baseline design does not meet acceleration requirement.
- Energy transfer has a vital role in shape optimization.
- To reduce upper tibia acceleration designer need to avoid Sharpe changes in the Bumper at first hitting area, which is well evident from first three shape changes.
- **Increase in the bumper area to optimize its shape not always a solution which is well evident from shape 05 & 06.**

4. RECOMMENDATIONS

- The Bumper optimization is studied on reduced model due to computational limitation of available software.
- The material data used is just three point curve data in nonlinear zone. Detailed material curve will give the good results.
- Bumper is modeled with 5mm minimum element size. Fine model will help us to get the more accurate prediction of knee angle and acceleration.

- Material change is not considered in the bumper designing.
- Energy absorptions techniques need to be also considered while designing bumper shape such as use of soft and hard foam.

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