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Design and Structural Analysis of Truck Rear under Run Protection Device with Rapid Prototype

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ABSTRACT

Side under run protection devices protect road users such as pedestrians and cyclists from slipping sideways under the wheels of trucks and trailers, and can also improve the aerodynamic performance of heavy vehicles. The basic objective is to improve the safety of the car and the occupants by designing the RUPD and car bumper. The choice of material and the structural design are the two major factors for impact energy absorption during a crash. It is important to know the material & mechanical properties and failure mechanism during the impact. This study concentrates on component functions, geometry, behavior of material and other parameters that influence the compatibility of the car bumper and rear under run protection device. The Modeling on SOLIDWORKS and analysis was carrying out using Finite Elements software, SOLIDWORKS SIMULATION.

This analysis is a partial work of a major project wherein the RUPD will be subjected to static testing with variable load distributions at different locations on RUPD. After the analysis, the pattern of the part is obtained using Rapid prototyping machine. This can be used for Machining/casting of the original part. Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data.

INTRODUCTION

The collisions can be classified in many ways such as crashes oncoming vehicle's lane, under icy, snowy, or wet conditions; crashes into heavy vehicles generally occurred in daylight, on workdays, in winter etc. Primary evaluation is according to head and chest injuries. The injuries are categorized based on critical, death head injuries and multiple fatal injuries. Investigators also looked at data concerning suicide and driving with alcohol for a proper statistical representation. They also observed that the risk of frontal collisions may be reduced by a mid barrier, front energy absorbing structure for trucks and buses and driving conditions. The accidental event, when a passenger car or a light load-carrying vehicle crashes and is wedged under the rear part of the vehicle chassis, is called rear under run. The rear under run protection device (RUPD) prevents the vehicles from being wedged under the chassis during accidental crashes and with that significantly increases the safety of occupants. This necessitates the requirement of conscious a proper design. The most important condition is the RUPD resistance to loading forces acting along or parallel to the vehicle longitudinal axis. The regulation also calls for a practical RUPD testing on the testing machine, where the RUPD is subjected to prescribed loads at some particular loading points. If the measured deformations fall into the allowable range, the RUPD can be declared to comply with the regulation. The practical testing is required for all standard mounted RUPD

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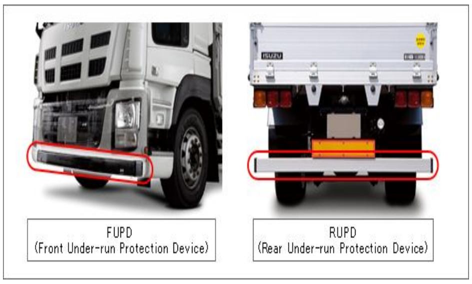


Figure 1.1 – Rear view of vehicle

LITERATURE REVIEW

A HISTORY OF UNDERRIDE GUARDS

In the United States, every trailer with a gross vehicle weight rating (GVWR) of 10,000lbs or greater manufactured on or after January 24th 1998 must be equipped with a rear underride guard. These devices must conform to the specifications found in the Federal Motor Safety Standards (FMVSS) No. 223 and 224 [7]. The FMVSS No. 223 describes the load testing, strengths and energy absorbing requirements for the guards and the FMVSS No. 224 describes their size requirements [7] [8] [9]. Previous to this regulation, the Federal Motor Carrier Safety Regulations required rear-impact guards on these vehicles however; they lacked physical strength testing and were of a smaller size. These were effective between January 1st 1952 to January25th 1998 [7]. In Canada, a regulation resembling the United States regulation is also established. Although the size requirements are the same, an additional strength test is conducted on the guards [10]. These requirements are outline in the next section of this chapter.

In Europe, there exists a regulation for the design and testing of front underride protective devices. The rules and standards are outlined in the Economic Commission for Europe (ECE) Regulation No. 93. This regulation had a date of entry into force of February 27th 1994 [11]. Along with the rear underride regulation, the United Nations also established a Lateral Protection Device (LPD) regulation to govern side guards for the protection of unprotected road users such a cyclists and pedestrians [12]. Much like the rear guards in the United States and Canada, the ECE has their own standards and testing procedures which are outline in the ECE Regulation No. 58 [13].

Modeling of RUPD

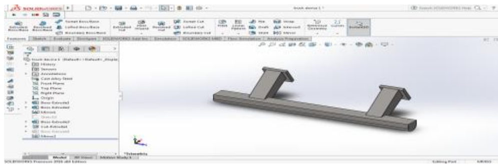


Figure 4.2 - Truck RUP device isometric view

MODELING OF FIXED PLATE

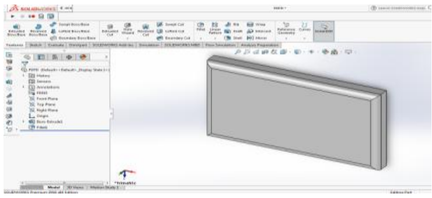


Figure 4.6 - Isometric view of fixed plate

MODELING OF FOAM

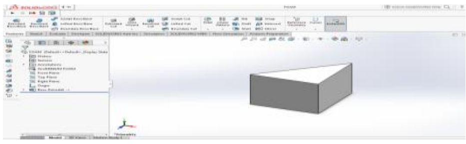


Figure 4.9 - Isometric view of foam

ASSEMBLY OF TRUCK REAR UNDERRUN PROTECTION DEVICE

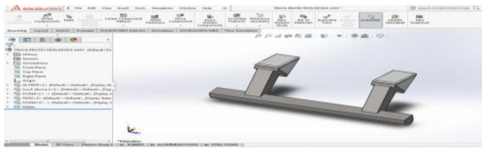


Figure 4.12 - Isometric view of Assembly

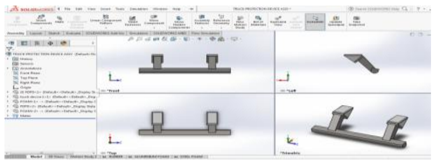


Figure 4.13 - Four different views

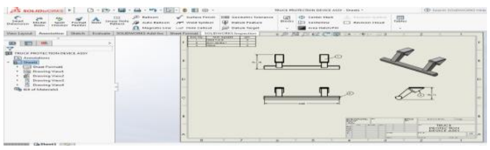


Figure 4.14 - Drawing views of Assembly

STRUCTURAL ANALYSIS OF TRUCK UNDERRUN DEVICE

There are 9 different load cases (P1, P2, and P3) which have to be tested with different materials. The load applied is 50,000N which is more than TRUCK weight.

THREE MATERIALS USED FOR TRUCK DEVICE:`

1. E38
2. FE410
3. FE690

THREE MATERIALS USED FOR FOAM:

1. RUBBER
2. ALUMIUM
3. STEEL

So for every truck device material three foam material analysis has to be done.

STUDY PROPERTIES:

Study name	**RUBBER**
Analysis type	**Static**
Mesh type	**Solid Mesh**
Thermal Effect:	**On**
Thermal option	**Include temperature loads**
Zero strain temperature	**298 Kelvin**
Include fluid pressure effects from SOLIDWORKS Flow Simulation	**Off**
Solver type	**FFE Plus**
In plane Effect:	**Off**
Soft Spring:	**Off**
Inertial Relief:	**Off**
Incompatible bonding options	**Automatic**
Large displacement	**Off**
Compute free body forces	**Off**
Friction	**Off**
Use Adaptive Method:	**Off**

UNITS:

Unit system:	**SI (MKS)**
Length/Displacement	**mm**

Table 6.1 - Study properties and Units

CASE 6.1: STRUCTURAL ANALYSIS OF R.U.P.D WITH E38MATERIAL ALONG RUBBER FOAM

MATERIAL PROPERTIES:

Model Reference	Properties	
 Figure 6.1 - E38 as truck RUPD material	Name:	**E38**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**4.7e+008 N/m^2**
	Tensile strength:	**5.6e+008 N/m^2**
	Elastic modulus:	**2.1e+011 N/m^2**
	Poisson's ratio:	**0.28**
	Mass density:	**7800 kg/m^3**
	Shear modulus:	**3.189e+008 N/m^2**
 Figure 6.2 - Rubber foam used as compressing material	Name:	**Rubber**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Unknown**
	Yield strength:	**9.23737e+006 N/m^2**
	Tensile strength:	**1.37871e+007 N/m^2**
	Elastic modulus:	**6.1e+006 N/m^2**
	Poisson's ratio:	**0.49**
	Mass density:	**1000 kg/m^3**
	Shear modulus:	**2.9e+006 N/m^2**
	Thermal expansion coefficient:	**0.00067 /Kelvin**

Table 6.2 - Material properties of E38 and Rubber

LOADS AND FIXTURES:

Fixture name	Fixture Image	Fixture Details	
Fixed-1	 Figure 6.3- Fixed positions	Entities:	**2 face(s)**
		Type:	**Fixed Geometry**

Table 6.3 -Fixtures

Load name	Load Image	Load Details	
Gravity-1	 Figure 6.4 - gravity load	Reference:	**Top Plane**
		Values:	**0 0 -9.81**
		Units:	**SI**
Distributed Mass-2	 Figure 6.5 - Distributed mass	Entities:	**1 face(s)**
		Type:	**Displacement (Direct transfer)**
		Coordinate system:	**Global Cartesian coordinates**
		Remote Mass:	**5000 kg**

Table 6.4 - Loads details

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.171037 N/mm^2 (M-Pa) Node: 3161	208.942 N/mm^2 (M-Pa) Node: 416

Figure 6.9 - von MISES Stress of E38 with rubber foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 33	495.717 mm Node: 3070

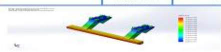


Figure 6.10 - Resultant Displacement of E38 with rubber foam

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	7.07888e-007 Element: 693	1.00145 Element: 612

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0663377 N/mm^2 (M-Pa) Node: 12737	243.17 N/mm^2 (M-Pa) Node: 1919

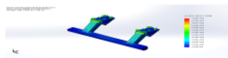


Figure 6.15 - von MISES Stress of E38 with ALUMINIUM foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 65	42.4312 mm Node: 14047

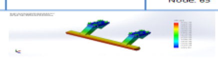


Figure 6.16 - Resultant Displacement of E38 with ALUMINIUM foam

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.17748e-007 Element: 6839	0.0742885 Element: 2526

CASE 6.3: STRUCTURAL ANALYSIS OF R.U.P.D WITH E38 MATERIAL ALONG STEEL FOAM

By applying same boundary and load conditions the result are as follows:

Material Properties:

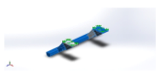
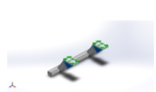
Model Reference	Properties	
 Figure 6.19 - E38 as truck RUPD material	Name:	**E38**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**4.7e+008 N/m^2**
	Tensile strength:	**5.6e+008 N/m^2**
	Elastic modulus:	**2.1e+011 N/m^2**
	Poisson's ratio:	**0.28**
	Mass density:	**7800 kg/m^3**
	Shear modulus:	**3.189e+008 N/m^2**
 Figure 6.20 - Steel foam used as compressing material	Name:	**STEEL FOAM**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**7.4e+006 N/m^2**
	Tensile strength:	**3e+007 N/m^2**
	Elastic modulus:	**3.15e+009 N/m^2**
	Poisson's ratio:	**0.05**
	Mass density:	**0.145 kg/m^3**
	Shear modulus:	**3.189e+008 N/m^2**

Table 6.9 - Material properties of E38 and Steel foam

CASE 6.4: STRUCTURAL ANALYSIS OF R.U.P.D WITH FE410 MATERIAL ALONG RUBBER FOAM

By applying same boundary and load conditions the result are as follows:

MATERIAL PROPERTIES:

Model Reference	Properties	
 Figure 6.25- FE410 as truck RUPD material	Name:	**FE410**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Max von Mises Stress**
	Yield strength:	**2.55e+008 N/m^2**
	Tensile strength:	**4.1e+008 N/m^2**
	Elastic modulus:	**2.15e+011 N/m^2**
	Poisson's ratio:	**0.28**
	Mass density:	**6220 kg/m^3**
	Shear modulus:	**2.943e+008 N/m^2**
 Figure 6.26 - Rubber foam used as compressing material	Name:	**Rubber**
	Model type:	**Linear Elastic Isotropic**
	Default failure criterion:	**Unknown**
	Yield strength:	**9.23737e+006 N/m^2**
	Tensile strength:	**1.37871e+007 N/m^2**
	Elastic modulus:	**6.1e+006 N/m^2**
	Poisson's ratio:	**0.49**
	Mass density:	**1000 kg/m^3**
	Shear modulus:	**2.9e+006 N/m^2**
	Thermal expansion coefficient:	**0.00067 /Kelvin**

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.13682 N/mm^2 (M-Pa) Node: 3161	167.146 N/mm^2 (M-Pa) Node: 416

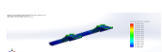


Figure 6.27 - von MISES Stress of FE410 with rubber foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 33	396.521 mm Node: 3070

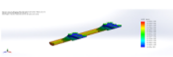


Figure 6.28 - Resultant Displacement of FE410 with rubber foam

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CASE 6.5: STRUCTURAL ANALYSIS OF R.U.P.D WITH FE410 MATERIAL ALONG ALUMINIUM FOAM

By applying same boundary and load conditions the result are as follows:

MATERIAL PROPERTIES:

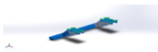
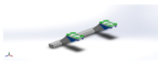
Model Reference	Properties	
 Figure 6.31 - FE410 as truck RUPD material	Name:	FE410
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	2.55e+008 N/m^2
	Tensile strength:	4.1e+008 N/m^2
	Elastic modulus:	2.15e+011 N/m^2
	Poisson's ratio:	0.28
	Mass density:	6220 kg/m^3
	Shear modulus:	2.943e+008 N/m^2
 Figure 6.32 - ALUMINIUM foam used as compressing material	Name:	ALUMINIUM FOAM
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	1e+007 N/m^2
	Tensile strength:	1.24e+006 N/m^2
	Compressive strength:	2.53e+006 N/m^2
	Elastic modulus:	1e+008 N/m^2
	Poisson's ratio:	0.3
	Mass density:	0.00024 kg/m^3
	Shear modulus:	1.9995e+008 N/m^2

Table 6.11 - Material properties of FE410 and ALUMINIUM foam

the result are as follows:

MATERIAL PROPERTIES:

Model Reference	Properties	
 Figure 6.37- FE410 as truck RUPD material	Name:	FE410
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	2.55e+008 N/m^2
	Tensile strength:	4.1e+008 N/m^2
	Elastic modulus:	2.15e+011 N/m^2
	Poisson's ratio:	0.28
	Mass density:	6220 kg/m^3
	Shear modulus:	2.943e+008 N/m^2
 Figure 6.38 - Steel foam used as compressing material	Name:	STEEL FOAM
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	7.4e+006 N/m^2
	Tensile strength:	3e+007 N/m^2
	Elastic modulus:	3.15e+009 N/m^2
	Poisson's ratio:	0.05
	Mass density:	0.145 kg/m^3
	Shear modulus:	3.189e+008 N/m^2

Table 6.12 - Material properties of FE410 and Steel foam

Study Results:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00273729 N/mm^2 (M-Pa) Node: 12737	17.7456 N/mm^2 (M-Pa) Node: 941

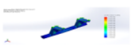


Figure 6.39 - von MISES Stress of FE410 with Steel foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 65	0.277319 mm Node: 14047

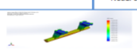


Figure 6.40 - Resultant Displacement of FE410 with Steel foam

CASE 6.7: STRUCTURAL ANALYSIS OF R.U.P.D WITH FE690 MATERIAL ALON RUBBER FOAM

By applying same boundary and load conditions the result are as follows:

MATERIAL PROPERTIES:

Model Reference	Properties	
 Figure 6.43 - FE690 as truck RUPD material	Name:	FE690
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	4.1e+008 N/m^2
	Tensile strength:	6.9e+008 N/m^2
	Elastic modulus:	2.15e+011 N/m^2
	Poisson's ratio:	0.28
	Mass density:	7800 kg/m^3
	Shear modulus:	3.189e+008 N/m^2
 Figure 6.44 - Rubber foam used as compressing material	Name:	Rubber
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Unknown
	Yield strength:	9.23737e+006 N/m^2
	Tensile strength:	1.37871e+007 N/m^2
	Elastic modulus:	6.1e+006 N/m^2
	Poisson's ratio:	0.49
	Mass density:	1000 kg/m^3
	Shear modulus:	2.9e+006 N/m^2
	Thermal expansion coefficient:	0.00067 /Kelvin

Table 6.13 - Material properties of FE690 and Rubber foam

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.119274 N/mm^2 (M-Pa) Node: 3161	147.249 N/mm^2 (M-Pa) Node: 416

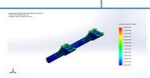


Figure 6.45 - von MISES Stress of FE690 with rubber foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 33	348.719 mm Node: 3070

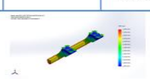


Figure 6.46 - Resultant Displacement of FE690 with rubber foam

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.79491e-007 Element: 693	0.704578 Element: 612

CASE 6.8: STRUCTURAL ANALYSIS OF R.U.P.D WITH FE690 MATERIAL ALONG ALUMINIUM FOAM

By applying same boundary and load conditions the result are as follows:

MATERIAL PROPERTIES:

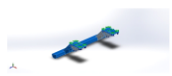
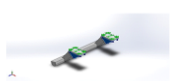
Model Reference	Properties	
 Figure 6.49- FE690 as truck RUPD material	Name:	FE690
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	4.1e+008 N/m^2
	Tensile strength:	6.9e+008 N/m^2
	Elastic modulus:	2.15e+011 N/m^2
	Poisson's ratio:	0.28
	Mass density:	7800 kg/m^3
	Shear modulus:	3.189e+008 N/m^2
 Figure 6.50 - ALUMINIUM foam used as compressing material	Name:	ALUMINIUM FOAM
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	1e+007 N/m^2
	Tensile strength:	1.24e+006 N/m^2
	Compressive strength:	2.53e+006 N/m^2
	Elastic modulus:	1e+008 N/m^2
	Poisson's ratio:	0.3
	Mass density:	0.00024 kg/m^3
	Shear modulus:	1.9995e+008 N/m^2

Table 6.14 - Material properties of FE690 and ALUMINIUM foam

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.0466682 N/mm^2 (M-Pa) Node: 12737	171.351 N/mm^2 (M-Pa) Node: 1919

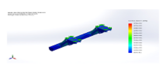


Figure 6.51 - von MISES Stress of FE690 with ALUMINIUM foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 65	29.8273 mm Node: 14047

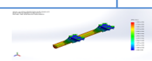


Figure 6.52 - Resultant Displacement of FE690 with ALUMINIUM foam

CASE 6.9: STRUCTURAL ANALYSIS OF R.U.P.D WITH FE690 MATERIAL ALONG STEEL FOAM

By applying same boundary and load conditions the result are as follows:

MATERIAL PROPERTIES:

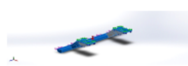
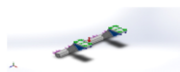
Model Reference	Properties	
 Figure 6.55 - FE690 as truck RUPD material	Name:	FE690
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	4.1e+008 N/m^2
	Tensile strength:	6.9e+008 N/m^2
	Elastic modulus:	2.15e+011 N/m^2
	Poisson's ratio:	0.28
	Mass density:	7800 kg/m^3
	Shear modulus:	3.189e+008 N/m^2
 Figure 6.56 - Steel foam used as compressing material	Name:	STEEL FOAM
	Model type:	Linear Elastic Isotropic
	Default failure criterion:	Max von Mises Stress
	Yield strength:	7.4e+006 N/m^2
	Tensile strength:	3e+007 N/m^2
	Elastic modulus:	3.15e+009 N/m^2
	Poisson's ratio:	0.05
	Mass density:	0.145 kg/m^3
	Shear modulus:	3.189e+008 N/m^2

Table 6.15 - Material properties of FE690 and Steel foam

STUDY RESULTS:

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.00181321 N/mm^2 (M-Pa) Node: 12737	13.8029 N/mm^2 (M-Pa) Node: 941

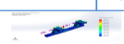


Figure 6.57 - von MISES Stress of FE690 with Steel foam

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 65	0.20843 mm Node: 14047

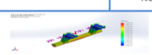


Figure 6.58 - Resultant Displacement of FE690 with Steel foam

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.60935e-008 Element: 6839	0.000159562 Element: 2630

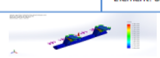


Figure 6.59 - Equivalent Strain of FE690 with Steel foam

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LOAD BEARING CAPCITY OF THE TRUCK PROTECTION DEVICE IS AS FOLLOWS:

LOAD CASE	LOAD IN KN
REQUIRED LOAD BEARING CAPACITY	47KN

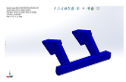


Fig 6.61 - load bearing capacity up to 47KN

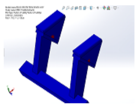


Fig 6.62 - Load bearing capacity>47KN

RESULTS AND DISCUSSIONS

The results are as follows for each truck protection device with different foam materials:

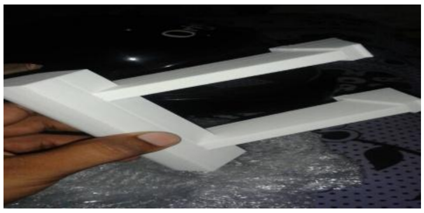
S.NO	FOAM MATERIAL	VON Misses Stress (M-pa)	Displacement (mm)	Strain
1.	RUBBER	208.942	495.717	1.00145
2.	ALUMINIUM	243.17	42.4312	0.0742885
3.	STEEL	18.3192	0.286447	0.000219779

Table 7.1 - Comparison of results between rubber, aluminium and steel foam material with E38 truck RUPD material.

RAPID PROTOTYPING OF R.U.P.D

The model has been scaled to 50% as the volume of machine is confined to 230LX150WX140H. After the .STL file of gear is imported into the fused deposited machine. The 3D printing has been done for 36hrs.The following prototype has been obtained. The material used is ABS material.

Print: Once these slicing settings are given, when you save the slicing file, it will be saved as g codes. put that in a sd card and feed it in 3D Printer. The printer will first get pre heated and later it will start printing. Once the print over, Supports are removed, The rough areas due to supports are post processed with a sand paper.



CONCLUSIONS& FUTURE SCOPE

- Side under run protection devices protect road users such as pedestrians and cyclists from slipping sideways under the wheels of trucks and trailers, and can also improve the aerodynamic performance of heavy vehicles.
- The basic objective is to improve the safety of the car and the occupants by designing the RUPD and car bumper. The choice of material and the structural design are the two major factors for impact energy absorption during a crash.
- It is important to know the material & mechanical properties and failure mechanism during the impact.
- After these processes the structural analysis has been carried for the landing gear assembly for three different materials E38,FE410 & FE690 with three different foam materials namely Rubber, aluminum & steel foam.
- The results show that the Fe690 with steel foam holds a good performance when compared to other materials. The result has been compared on the basis of the parameters like deformation, stress and strain. The Fe690 with steel foam has a less stresses when compared to other materials. So the implementation of this material would help to avoid the landing gear damage and also it can have a better life than the other materials due to its less damage.
- As our Truck under run protection device is within the limits then RAPID PROTOTYPING of Truck under run protection device has been done.
- The Prototype has been used as pattern for limited volume of production.

This study can be further extended by performing experimentations and developing suitable manufacturing methods, the above study includes only static position of Truck .we further to consider the dynamic analysis of during collision to get better results.

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