Roof Strength Simulation for a Concept Cab of Heavy Commercial Vehicle and Design Optimization of a Cab components

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Abstract

A rollover is a type of vehicle accident in which a vehicle tips over onto its side or roof. The most common cause of a rollover is loss of balance when travelling too fast while turning. All vehicles are susceptible to rollovers to various extents. Major factors governing roll over are position of the CG and the speed of the vehicle. After a rollover, the vehicle may end up lying on its side or roof, often blocking the doors and complicating the escape for the passengers. Roof is likely to collapse towards the occupants and cause severe head injuries as the space left for survival reduces drastically.

This Paper depicts the importance of the FEA in roof strength analysis. It explains the steps involved in the FE analysis of the Cab based on SAE J2422 standard. It gives idea of different directions to Optimize some of the load carrying parts of the Cab. It gives the direction to the designer for Optimized design of the product.

Keywords: GVWR, Kinetic Energy, Internal Energy, Potential Energy, Manikin ,Survival Space, Optimization, Roof Strength Analysis.

1. Introduction

Rollover accidents are of special concern for commercial vehicle safety. Rollover accidents are especially violent and cause greater damage and injury than other accidents. Moreover, the relatively low roll stability of the commercial truck promotes rollover and contributes to the number of truck accidents. These ideas are generally confirmed by the accident record. Commercial truck rollover is strongly associated with severe injury and fatalities in highway accidents.

In the preceding statistics, fatalities and injuries refer to anyone involved in the accident including occupants of other vehicles and/or pedestrians. Again, from the 1995 T&BFB, death or incapacitating injury is about ten times more likely to occur to the truck driver in rollover accidents than in the non-rollover accidents.

The low level of basic roll stability of commercial trucks sets them apart from light vehicles and appears to be a significant contributing cause of truck rollover accidents. The basic measure of roll stability is the static rollover threshold, expressed as lateral acceleration in gravitational units (g). The rollover thresholds of passenger cars are virtually always greater than 1g. For light trucks, vans, and SUVs, this property lies in the range of 0.8 to 1.2 g but the rollover threshold of a loaded heavy truck often lies well below 0.5 g.

Drivers regularly maneuver vehicles at well over 0.1g. The AASHTO guidelines for highway curve design result in lateral accelerations as high as 0.17 g at the advisory speed. Therefore, even a small degree of speeding beyond the advisory level will easily cause lateral accelerations to reach 0.25 g in regular driving. On the other hand, tire frictional properties limit lateral acceleration on flat road surfaces to a bit less than 1g at the most. These two observations clearly imply that the rollover threshold of light vehicles lies above, or just marginally at, the extreme limit of the vehicles maneuvering ability, but the rollover threshold of loaded heavy trucks extends well into the "emergency" maneuvering capability of the vehicle and sometimes into the "normal" maneuvering range. Refer Figure 1.

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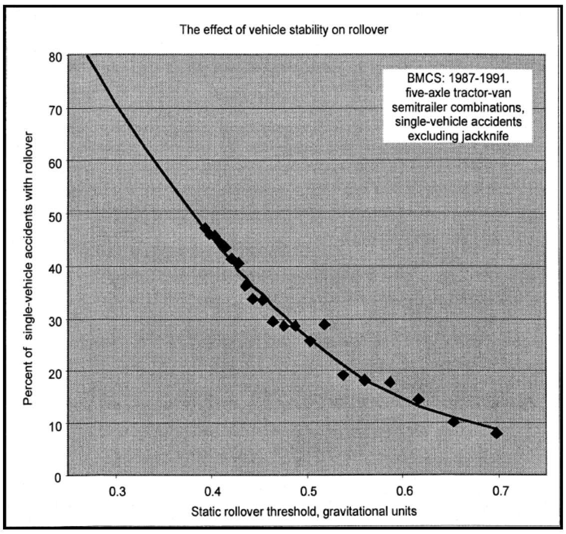

Figure 1 The effect of vehicle stability on rollover

2. Methodology

2.1. CAD Modelling

Figure 2 shows the Cad parts modeled in UG. Here are some guidelines followed during modeling the Cab. One should ensure that the only Non-Parameterized features (bodies) in the model should be the Styling Surfaces. We should always start the model with a solid block which can be trimmed and shelled. Use simple sketch/curve to create features.
For Rib creation use non-parametric curves & use extrude option.
Do not Unite Ribs/Boss/Blocks in Extrude command. For Draft angles use Draft command after completing Ribs/Boss/Block.
Profile of ribs mainly corner radius should be modeled using Fillet command.Cab model is done on Unigraphics.While creating mounting features (such as Screw boss, heat stakes, etc.)

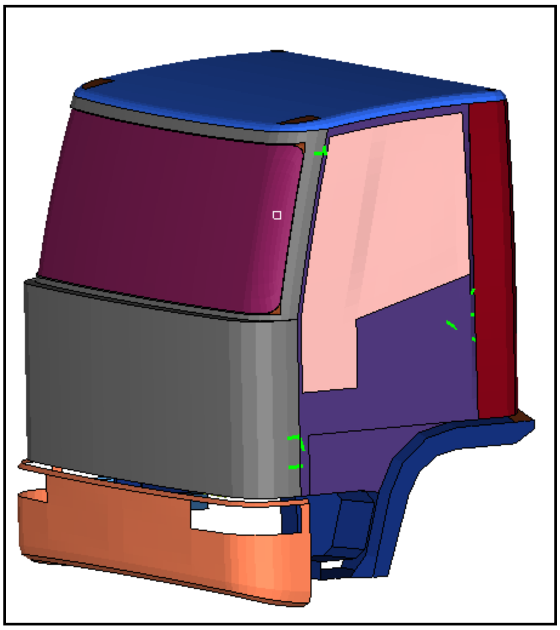

Figure 2: CAD model generated on UG

Cylinder command should be used. For creating holes for the screw bosses and heat stakes, use Hole command .
While creating hole in non planar surfaces: create circle, extrude and subtract the cylindrical object. Primitives such as "Cylinder" should be used wherever possible. If not possible then create circle and then extrude.
Use relative Datum planes wherever possible. Unite the Blocks/Boss with main part & provide edge fillets. Within the Model, if a surface needs to be reused for some other operation , such as trimming or to creating flanges. Instead of copying the surface offset the surface by 0 distance, this will maintain associatively with the original surfaces, and the model will change when the original surfaces change. While using filleting & Trim body commands, disable preview option. (Regenerating process, which consumes time, can be avoided).
Machined Holes should be made at the end of modeling. Wherever possible, Unite and blend operations should be kept at the end. Think on the design intent at the beginning and make sure that your model can be easily edited for the next design change. Do not copy features from other parts. If this has to be done then there should not be any link between the parts to avoid unexpected changes happening. Keep number of features to the minimum.

2.2. FE Modelling

Figure 3 shows the parts modeled in FE. During FE modeling one should be clear about the area of interest. All metallic parts need to be converted in to FE entities. Ornamental parts, cloths, rubber

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padding, etc. may not be modeled to help reduce work. The FE model of the cab was created using CQUAD4 and CTRIA3 elements.

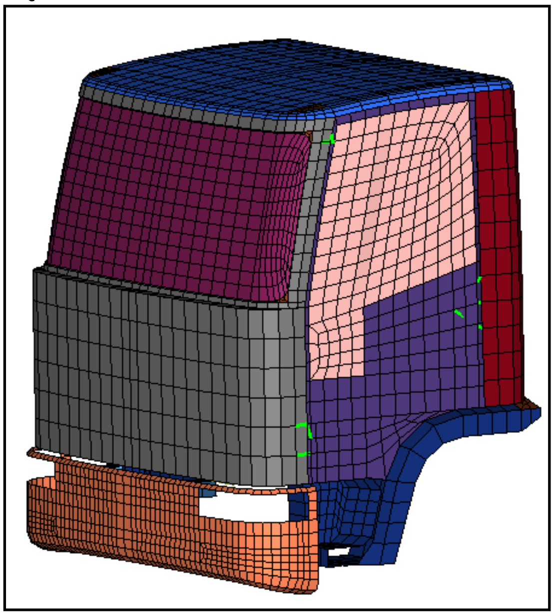

Figure 3: FE Model generated in Hyper Mesh

We have to ensure that no free edges are left in the model. If unintended free edge is left, it is treated as a crack in the part. Duplicate elements should be avoided. Shell normal should be consistent. It makes considerable difference in the results if there are any deviations as mentioned above. Mesh should be refined in the area of our interest. There should not be triangular elements near weld and the bolt holes. There should not be a triangular elements over fillet. Mesh transition should be smooth and features should be properly captured. Element size should not be very small to avoid high computation cost.

2.3. Test Set Up Result Interpretation

The cab roof strength test is designed to evaluate the resistance of a heavy-truck cab in 180-degrees rollover. The SAE J2422 roof strength test involves a dynamic preload phase I and a quasi-static roof load phase II. Dynamic preload phase specifies impacting upper side of the cab with a rigid platen to transfer energy equal to a maximum recommended target level of 17,625.6 J. Both phases are performed on the cab attached to actual or simulated frame rails with its standard cab mounts. The loading is applied to the cab with the help of a platen. The energy for the dynamic pre-loading is generated by the inertia of the plate and the structure carrying it. To assist with the description of the platen orientation and direction of motion, a reference coordinate system is defined for the cab and chassis relative to its original orientation on the vehicle.

For phase II, SAE J2422 specifies a load equal to the FAWR. For safer predictions it is required that the quasi-static roof load be equal to 100% of the FAWR used for the physical test. An additional overload load case of 120% is used in the analysis to account for generally stiffer response of the simulation model compared to the physical test. The platen is oriented vertically, and aligned parallel to the chassis longitudinal axis. Either side of the cab may be loaded, depending on whether a driver side or passenger side leading rollover is to be evaluated. The chassis of the test cab shall be fixed to the ground at a roll angle of 20 degrees. The longitudinal axis of the chassis shall be perpendicular to the direction of travel of the platen. The pre-load configuration is shown in Figure 4.

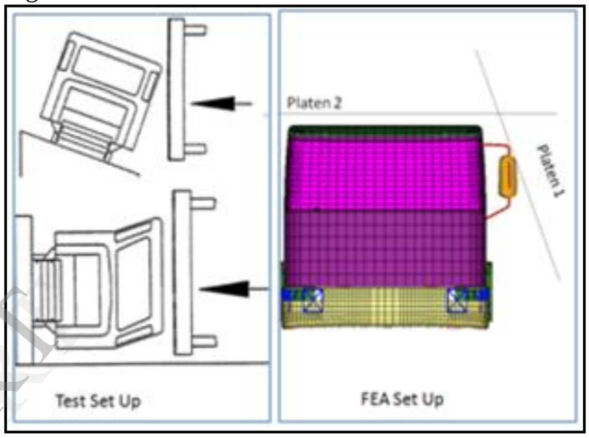

Figure 4: FE and Test Set Up

If the cab or its mounting is not symmetric, the weak side of the assembly should be evaluated. The energy to pre-load the cab comes from the kinetic energy of the platen and its supporting structure. For the pre-load phase of the test, the target energy level is 1.6 times the reference energy level, up to a maximum recommended target level of 17 625.6 J (13 000 ft-lb). The recommended maximum is based upon the limited testing performed to evaluate this test procedure and to produce cab damage consistent with the rollover accidents. Manufacturers can, at their discretion, exceed this maximum. The reference energy level is an approximation of the kinetic energy developed when a vehicle is tipped from its static stability position to a rest position on its side after fall.

2.4 Boundary Condition:

Figure 5 shows the boundary conditions used for the test. The platen was made to preload the cab so as to absorb an energy of 17,625 J. Phase I ended when the platen bounced back and lost contact with the cab structure. Phase I took 800 msec to complete. For the quasi-static roof load phase, the cab was constrained similar to the cab in dynamic preload phase. A rigid platen hits the deformed cab from the top slowly so as to exert a force equal to 100% and 120% of the

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20k FAWR.

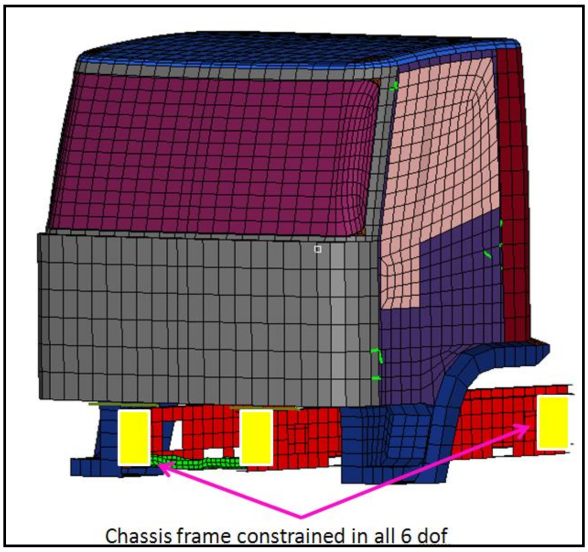

Figure 5: Boundary conditions and the Analysis set up for the Roof Strength Analysis.

Figure 6 shows the load curve used for quasi-static loading of the cab. Phase II ends with a total time of 1450 msec.

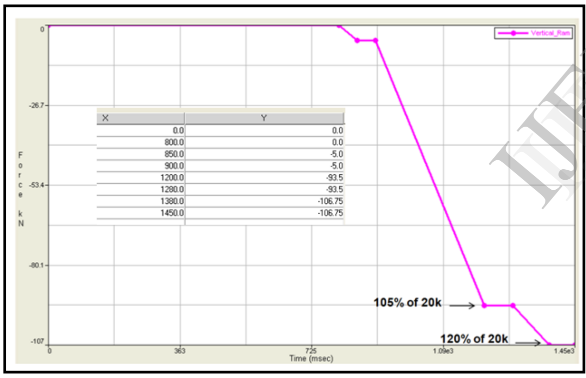

Figure 6: Roof strength phase II - load curve.

2.5 Performance Criteria :

The cab should sustain 120% of the 20k lb FAWR without contact of the manikin head to non-resilient interior components when tested as per SAE J2422. Plastic parts and the foam parts can be ignored in these Criteria. For CAE, the cab should sustain 120% of the 20k lb FAWR without contact of the manikin head to non-resilient interior components when tested per SAE J2422.

As per SAE J2422 test description this may be applied to all vehicle classes, but the recommended performance requirements are limited to NHTSA defined GVWR class 6 and above (greater than 8845 kg). The load applied to the roof shall be equivalent to the maximum rated capacity of the front axle of the vehicle, subject to a maximum of 98.07 kN. During the test, components attaching the cab to the chassis frame may become distorted or broken, but the cab shall remain attached, and in an orientation similar to the original. None of the doors shall open during the test, but the doors may not open after the test. Following the test, the cab of the vehicle shall exhibit a survival space allowing accommodation of the manikin defined in ECE Regulation 29 on the seat, with the seat in its median position, without contact between the manikin and non-resilient parts. The seat and manikin shall be adjusted so that the H point of the manikin lies within a 50 mm cube centered about the designed Seating Reference Point (per SAE J1516), and the torso angle of the manikin within 5 degrees of the nominal design torso angle. The manikin may be inserted in dismantled form and assembled in the cab. The seat and the manikin shall be adjusted to the median position prior to the assessment of survival space.

3. Results and Discussion

3.1 Results Interpretation :

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Energy plot key parameter to evaluate the system and it reflects the behavior of the system. Figure 7 shows energy balance plot. Total energy is stable after phase 2. Due to unstable contacts, sliding energy increases. This results in to unstable energy plot.

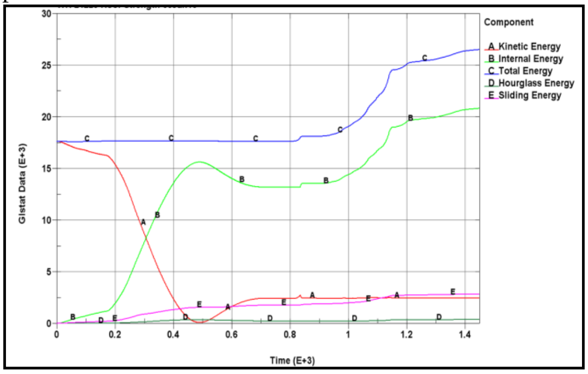

Figure 7: Correct Energy balance plot.

Kinetic energy imparted by Platen 1 reduces over the event and stabilizes by end of the event. It is converted in to Internal energy causing the damage in the system. Total energy remains almost same. This is as per the Law of Conservation of the Energy.

Hourglass energy and Sliding energy are the losses in the system which are unavoidable. Hour glass energy and Sliding energy should be less than 5% of the Internal energy. In the Figure 7. Internal energy has stabilized. These metrics indicate a stable solution. In Phase 2 platen does external work and the Internal energy increases. In both the cases platen is subjected to reaction force offered by the Cab. Figure 8 shows that all the forces applied by the top platen are transferred to the cab.

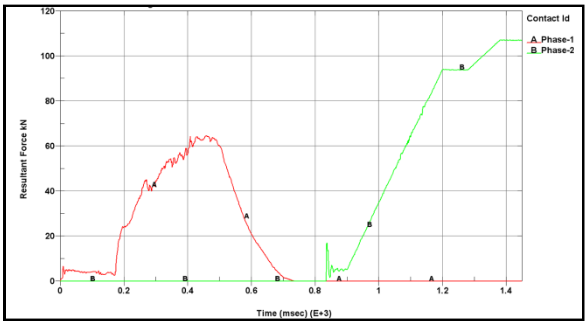

Figure 8: Reaction force observed on side top platen

3.2 Test Correlation

As shown in the Figure 9, Survival Space is about 67 mm and is marginally same as that observed in the reference test data. This indicates that the test correlation is obtained.

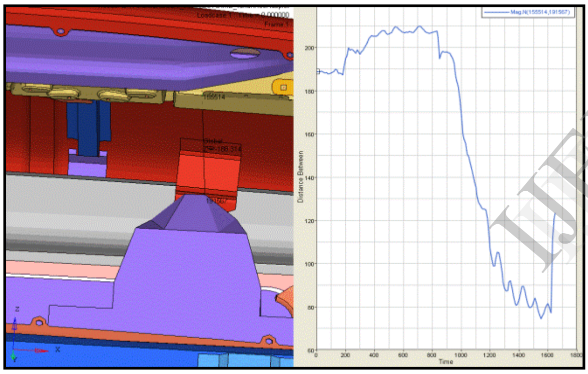

Figure 9: Survival Space for Roof Strength Analysis

During analysis non structural parts like cloth, foam and similar parts are not considered. The idea behind calculating survival space is to ensure that the driver has sufficient space to come out after an accident. Also no structural part should be freed and hit the driver. In project task the survival space observed is very close to the test value. It is also close to the FEA analysis performed by analyst. Test data is not possible to present due to confidentiality reason.

Total energy, Internal energy and Kinetic energy pattern is also observed to be same as the simulation performed by the analyst. Sliding energy & Hourglass energy are also found to be within the acceptable levels and were very close to the energy observed during project task. Test correlation certificate is an evidence for matching of the simulation results with the test results.

3.3. Design Modifications and Optimization

Anything which reduce cost by maintaining the quality of the product is Optimization. There is a vast scope to optimize the Cab design. A designer is interested in reducing weight which is directly measurable quantity and quickly shows the reduction in cost. We also decided to work towards reducing weight for the Cab. This also gives direct benefits of better mileage.

Non structural parts does not add stiffness to the Cab so optimization of the structural members is important for our study. Structural members can be evaluated by FEA. So, it was decided to choose some parts which lie in load path during the roof loading. A-Pillar, A-Pillar Reinforcement & Panel Rear Corner Outer were selected for the purpose. The selected parts are shown in the Figure 10.

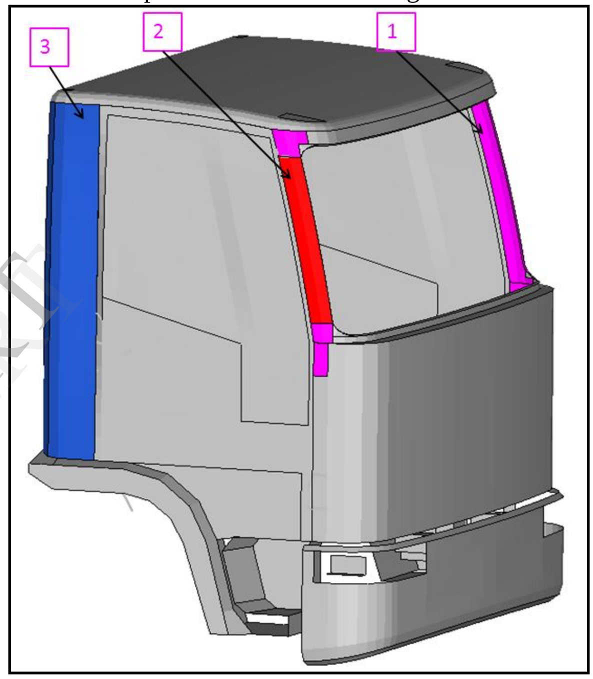

Figure 10 : Parts selected for Cost Reduction.

The material details of the 3 parts are listed in the Table 1 below.

Table 1: Effective Plastic Strains for the parts under study

Effective Plastic Strains for the parts selected for weight reduction			
Name	Material	Allowable Plastic Strain (%)	Effective Plastic Strain (%)
A Pillar	Aluminium 2008 T4	13.9	23.1
A Pillar Reinforcement	Aluminium 5182 O	13.7	15
Panel Rear Corner Outer	Aluminium 5052 H 111	14.7	20.9

The same solution run was repeated by reducing thickness by 10 %, incrementally. The survival space was monitored for all the runs. It was

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observed that the survival space reduces as per expectations. The table and the graph (Figure 11) shows the reduced Survival Space and the trend of the survival space. This trend brings out correctness of the model to represent real vehicle model. Figure 12 shows comparison table for all the iterations performed during the optimization study. Similar study is also possible for different material grades and new alloys available in market. The material properties are difficult to get from the manufacturers due to confidentiality and intellectual property issues.

Survival Space	
Design Iteration	Survival Space (mm)
Base Line	67
Itr 1 (10 %)	54
Itr 2 (20 %)	49
Itr 3 (30 %)	38

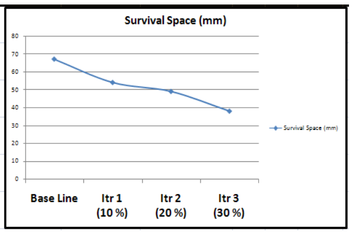

Figure 11: Survival Space for Reduced Thickness

Comparative Study

Name	Material	Allowable Plastic Strain	Effective Plastic Strain (%) Base Line	Iteration 1	Iteration 2	Iteration 3
A Pillar	Aluminium 2008 T4	13.9	23.1	26.9	30	36.15
A Pillar Reinforcement	Aluminium 5182 O	13.7	17	19	20.9	23
Panel Rear Corner Outer	Aluminium 5052 H 111	14.7	20.9	25	27.6	29.7

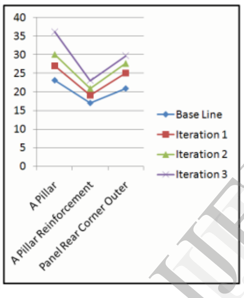

Figure 12: Effective Plastic Strain Comparison Table for various Iterations.

3.4.Costing Summary

Cost reduction is the key to the success of any industry and if it supplemented with the weight reduction, it gives further advantage of additional mileage (fuel efficiency) to the vehicle. In product life cycle, integrated approach of the CAE and conventional design leads to significant reduction in the design cycle time. This CAE driven design methodology not only reduces the product development cycle but also can provide verified and optimized design concepts to the design group before releasing final design. Table 2 shows the sample costing table. For 0.6 Kg weight reduction for a batch production of 10,000 vehicles per year saves Rs 4.8Lakhs. Here price of the processed steel is considered as Rs 80 per kg. Though this is hypothetical case cost reduction can be achieved to great extend.

Table 2: Sample costing Table.

Cost Reduction Table							
No	Name	Material	Allowable Plastic Strain	Weight of the Part (Kg)	Weight of the Part after optimization (Kg)	% Reduction in the weight	Weight Reduction (Kg)
1	A Pillar	Aluminium 2008 T4	13.9	0.576	0.45	21.8 %	0.126
2	A Pillar Reinforcement	Aluminium 5182 O	13.7	0.5	0.4	20 %	0.1
3	Panel Rear Corner Outer	Aluminium 5052 H 111	14.7	1.745	1.374	21.2 %	0.371
						Total Weight Reduction per vehicle (Kg)	0.597

Final Cost of Processed Steel (Rs)	80
Total Volume per Year (Nos)(Assumed)	10000
Saving /Year (Rs)	480000

4. Conclusion:

Based on the information available in Literature and study performed above we come to a conclusion that Rollover accidents in Heavy commercial vehicle are violent and cause greater damage and injury as compared to other type of accidents. Roll over analysis is still fairly unexplored topic and needs lot of further research. During roll over the weight of the front axle hits and crumbles the driver cabin and so Roof strength is critical during the Roll over.

Roll over analysis can be performed with the help of Finite Element Method. FEA analysis can be done effectively to evaluate the strength of the roof. Survival space is the key parameter in evaluating the roof strength. The results obtained are very close to the results obtained in physical test.

Design optimization is possible for the case study considered in the project. FEA plays important role in Design optimization for structural parts. High cost in prototypes preparation, specialized set up are some of the drawbacks of the physical test. CAE being a shared investment is definitely affordable for various tests for CAE.

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