Optimization of Roll over Protection Structure

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Abstract— Vehicle accidents are of major cause to lead severe injuries and probability of occurrence of death when injury rate is severe. A rollover is a type of vehicle accident in which a vehicle tips over onto its side or roof due to the high centre of gravity and working on slopes and uneven terrain. The most common cause of a rollover is loss of balance when speed of the vehicle is too fast. All vehicles are susceptible to rollovers to various extents. After a rollover, the vehicle may lie on its side or roof, and block the doors complicating the escape for the passengers. Earthmovers are equipped with protective structure which even under rollover, provide safe zone (no intrusion by the structure) for operators. Such Rollover Protective Structures (ROPS) are expected to meet minimum performance criteria to ensure occupant safety. ROPS 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 Finite Element Analysis performed on newly designed SD190 FULL ROPS as per ISO 3471. It also handles the Optimization study performed on few of the load carrying parts in the Structure.

Keywords: ROPS, SD190, CG, Finite Element Analysis.

I. INTRODUCTION

Heavy vehicles like tractors and loaders when working on slopes and uneven terrain with high speed and high centre of gravity are susceptible to dynamic instability. Under these conditions, vehicle rollover, which results in many injuries and fatalities to occupants, increases. Heavy machinery is equipped with protective structure which even under rollover, provide safe zone (no obtrusion by the structure) for operators. Such Rollover Protective Structures (ROPS) are expected to meet minimum performance criteria to ensure occupant safety.

Rollover protective structures are safety devices fitted to heavy vehicles to provide protection to the operator during an accidental rollover. In addition to provision of safety, the ROPS also acts as a single rugged base for mounting various sub-systems of the vehicle. It also helps to strengthen the vehicle under various collisions, which is desirable in racing and off-road applications. There are different ROPS designs depending on the application, hence the vehicle manufacturers have differing specifications and regulations.

The present work aims to optimize the existing design to reduce weight; cost and stiffness of the structure need to be increased. Phenomena of experimental testing and performance parameters required for vehicle cabin are used as per the standards in mathematical model. Design of the cabin structure was developed by using CAD tool CATIA V5.

Methodology for simulating the rollover conditions was validated and then MODAL and NON–LINEAR analysis was carried out using Abaqus software using beam elements, shell and Hexa elements. Nonlinear analysis was done based on the loading standards.

The analysis of the cabin structure was compared with testing results, concluding that design is safe for the occupant in roll over conditions.

A. The specific potential benefits of this research include the following:

- This project depicts the importance of FEA modelling techniques for effective application of probabilistic design to roll bar design evaluation.
- It explains steps involved in FE Analysis of the ROPS as per ISO 3471 and correlated with tests performed.
- It also handles the Optimization study performed on few of the load carrying parts in the ROPS.
- It gives the direction to the designer for Optimized design of the product.
- Further scope of work is mentioned at the last. Project report includes some of the ideas and the tips for a ROPS designer in future.

II. LITERATURE REVIEW

Most of serious accidents occur when using a tractor which is not compliant with safety protection requirements, especially when the roll-over protective structure (ROPS) was not installed, or it was temporary folded in order to carry out some particular works. Even if two posts front mounted foldable ROPS can be folded down only for tractor storage or maintenance (as formally specified also in users' manuals provided by manufacturers), and always kept upright up the rest of the time the tractor is used, an high percentage of cases of non correct use of this type of ROPSs has been encountered. Thus, a specific research work by Gattamelata D (2012) was carried out in order to design a non foldable ROPS for narrow-track wheeled tractors, which provides rollover protection all the time without making agricultural works more difficult. [6]

Roll-over protective structures (ROPS) are known to prevent tractor overturn deaths, but not enough tractors are equipped with them in the United States to reduce the rate of these deaths to levels seen in several European countries. Data from a national survey for the calendar year 2003 were used to assess the prevalence of ROPS use on Hispanic-operated farms. The overall ROPS prevalence rate on Hispanic farms was 52.2%.The age of the farm operator, the farm status as a full- or part-time operation, and the type of farm operation were also important factors. The results can be used to target ROPS promotion programs for Hispanic farmers across the United States. [5]

A rollover protective enclosure is same kind of frame but totally encloses with metal and glass. Phenomena of experimental testing and performance parameters required for tractor cabin were used as per SAEJ2194 in mathematical model. Meshed model was created using

Hyper Mesh and 1D mesh model was created using Hyper Beam. Methodology for simulating the rollover conditions was validated and then non–linear quasi-static analysis was carried out using Radioss Bulk and Block on structure using beam elements and full shell mesh model. Displacement control method was used for simulating the rear and front longitudinal crushing, rear and front vertical crushing and lateral crushing. Design of the cabin structure used in the analysis was safe under rollover, pitch over and crushing loading. Obtained results show that middle post contributes significantly to the resistance of the structure to vertical crushing loads. Hence, a six posts design is better over four posts structure. [4]

Saini Amandeep Singh study will deals with edge preparation techniques employed prior to welding to strengthen the ROPS and corresponding strain energy absorption at the time of collision. The ROPS is subjected to different loading conditions like front impact, rear impact, side impact and roll-over. The experiment to be performed will be scrutinized considering different edge preparations i.e. the welding of pipes at the joints will be performed with no space groove preparation, with 2.5 mm space groove preparation and 5.0 mm space groove preparation. After performing the analysis, the strength of the weld is compared against all the considered cases. Also the strain energy absorbed in each case is investigated. Obviously the one with lesser Von-Mises stress will be a better design. From the simulation it can be concluded that, the ROPS with no space provided during groove preparation, provides better protection and safety i.e. higher weld strength. The deformation during the collision increases correspondingly with the groove gap of the edge preparation. The strain energy absorption shows an upward trend parallel to the stress value. [3]

III. METHODOLOGY AND PROBLEM IDENTIFICATION

Generation of the CAD and FE model was first significant stage. Result representation and test correlation were part of the second stage. Third stage included Optimization of the design and design suggestions.

A. CAD Modeling

CAD modeling was done by using the tool CATIA V5. Like any modeling package CATIA has some modeling guidelines. The ROPS structure was prepared and Figure 1 shows the isometric view of the ROPS.

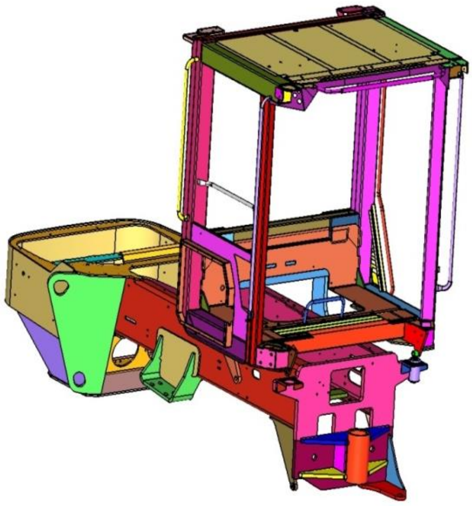


Fig.1: CAD Model generated using CATIAV5

B. FE Modeling

FE modeling is converting CAD model in to small elements which will be used to solve the problem by iterative method. One should know the area of interest for the analysis. Normally, all metallic parts need to be converted in to FE entities. Ornamental parts, cloths, rubber padding, etc. may not be modeled to help reduce work. FE model has been created using HM 10.1. The complete FE model is shown in fig 2

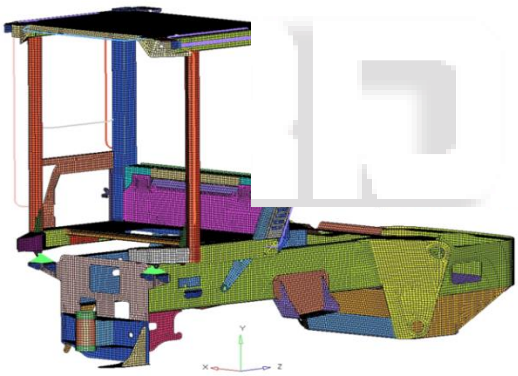


Fig. 2: FE Model generated in Hyper Mesh

C. Boundary Conditions

Frame is constrained in all 6 DOF at bolt holes on both sides and also front cylinder is constrained in only vertical direction (UY) as shown in the figure 3.

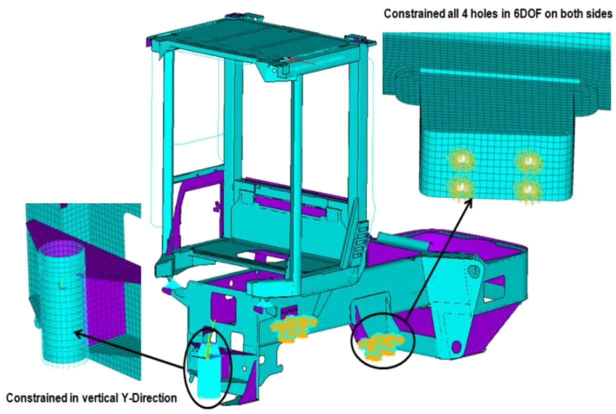


Fig. 3: Remote displace boundary conditions

D. Loading Conditions

ROPS analysis is carried out on SD190 FULL ROPS for 6 load cases as shown in Table 1.

Table. 1: Load Cases

LOAD CASES	
Load Case – 1	Lateral Loading
Load Case – 2	Lateral Unloading
Load Case – 3	Vertical Loading
Load Case – 4	Vertical Unloading
Load Case – 5	Longitudinal Loading
Load Case – 6	Longitudinal Unloading

The loading conditions for both the designs remain same, except for lateral loading, since we need to attain the load and strain energy limits as per the standard ISO 3471 in lateral loading.

E. Methodology to find over design parts in structure

Von Mises stress is widely used by the designers to check whether their design will withstand a given load condition. The von-Mises stress results of both the designs for lateral, vertical and longitudinal loading are as shown in figure 4, figure 5 and figure 6 respectively.

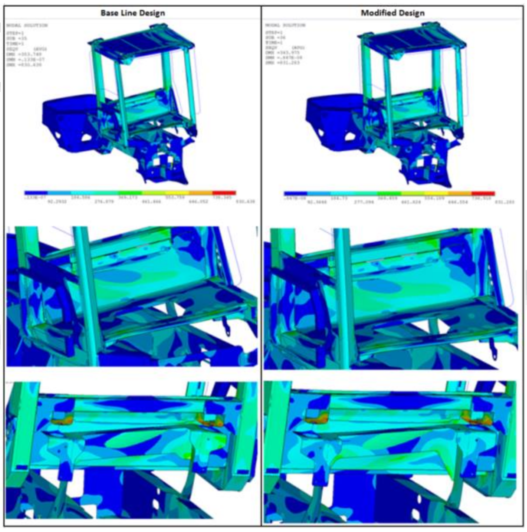


Fig. 4: von-Mises Stress Plot for Lateral Loading

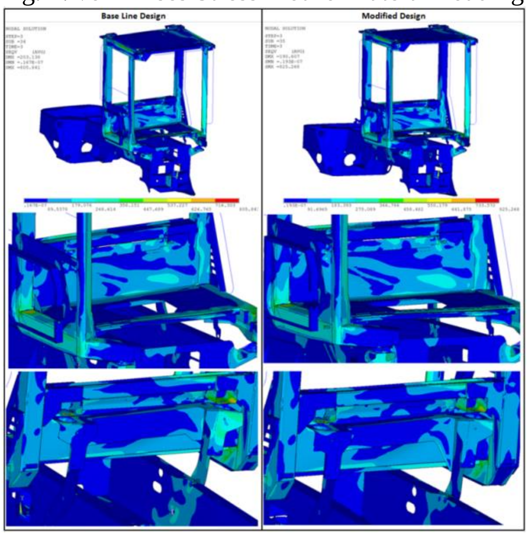


Fig. 5: von-Mises Stress Plot for Vertical Loading

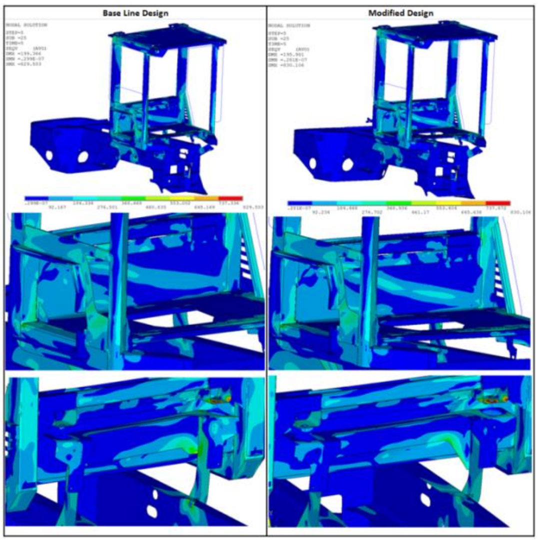


Fig. 6: von-Mises Stress Plot for Longitudinal Loading

F. Design Modifications

Three major modifications have been made to the Full ROPS cab model referred as "modified design" as shown below. The three design modifications between "baseline model" to “modified model” have been classified as shown below under sections (i) Design modifications -1 (ii) Design modifications -2 (iii) Design modifications -3. All the three modifications have been incorporated in the "modified design" together to assess the structural performance.

1) Design Modification- 1

The small Gussets at bottom of rear pillars are removed to overcome the problems occurred during manufacturing as shown in figure 7

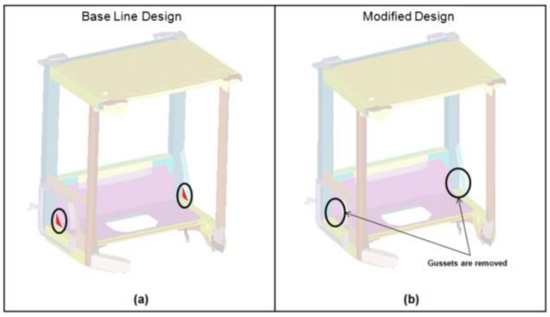


Fig. 7: Design Modification - 1(a) baseline design (b) Modified design

2) Design Modification – 2

The geometry of rear isolator support plate is modified by extending 100mm vertical down as shown in figure 8. The support plate is extended to reduce the bending behavior of rear isolator plate and to add stiffness too.

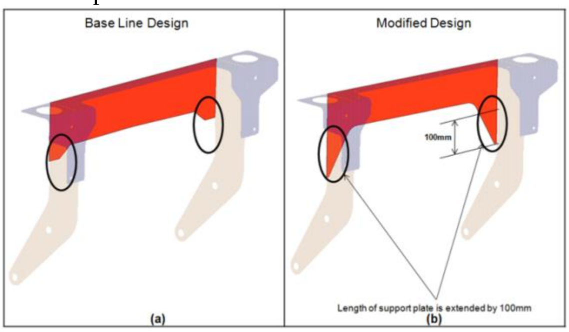


Fig. 8: Design Modification - 2 (a) baseline design (b) Modified design

3) Design Modification – 3

The thickness of rear isolator support plate is changed from 10mm to 12mm to increase the stiffness and to reduce the bending behavior of the plate. Also 9 holes of 12mm diameter are added for mounting the miscellaneous components as shown in figure 9.

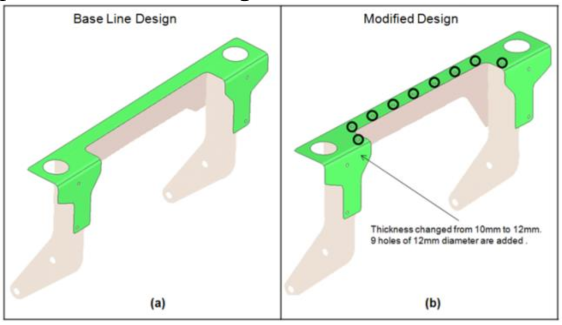


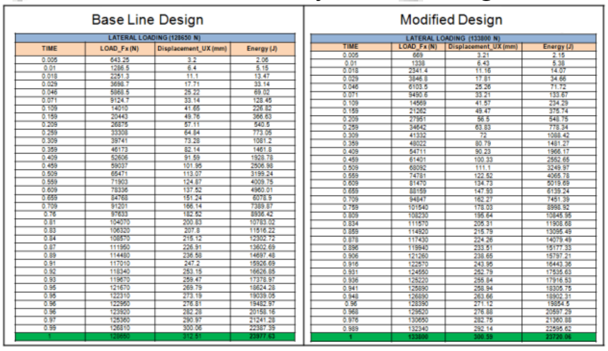
Fig. 9: Design Modification - 3 (a) baseline design (b) Modified design

IV. COMPARISON OF RESULTS

A. Lateral Loading

For baseline design, the strain energy (23818 J) is attained at 128650N lateral load with a displacement of 312.51mm.

For Modified design, the strain energy (23818 J) is attained at 133800N lateral load with a displacement of 304.99mm. The results summary is shown in figure.



Base Line Design

LATERAL LOADING (128650 N)			
TIME	LOAD_Fx (N)	Displacement_UX (mm)	Energy (J)
0.005	643.25	3.2	2.06
0.01	1286.5	6.4	5.15
0.018	2251.3	11.1	13.47
0.029	3698.7	17.71	33.14
0.046	5868.5	25.22	69.02
0.071	9124.7	33.14	128.45
0.109	14010	41.65	226.82
0.159	20443	49.76	366.63
0.209	26875	57.11	540.5
0.259	33308	64.84	773.05
0.309	39741	73.28	1081.2
0.359	46173	82.14	1461.8
0.409	52606	91.59	1928.78
0.459	59037	101.95	2506.98
0.509	65471	113.07	3199.24
0.559	71903	124.87	4009.75
0.609	78336	137.52	4960.01
0.659	84768	151.24	6078.9
0.709	91201	166.14	7389.87
0.76	97633	182.52	8936.42
0.81	104070	200.83	10783.02
0.83	106320	207.8	11516.22
0.84	108570	215.12	12302.72
0.87	111950	226.91	13602.69
0.89	114480	236.58	14697.48
0.91	117010	247.2	15926.69
0.92	118340	253.15	16626.85
0.93	119670	259.47	17378.97
0.95	121670	269.79	18624.28
0.95	122310	273.19	19039.05
0.96	122950	276.81	19482.97
0.96	123920	282.28	20158.16
0.97	125360	290.97	21241.28
0.99	126810	300.06	22387.39
1	128650	312.51	23977.63

Modified Design

LATERAL LOADING (133800 N)			
TIME	LOAD_Fx (N)	Displacement_UX (mm)	Energy (J)
0.005	669	3.21	2.15
0.01	1338	6.43	5.38
0.018	2341.4	11.16	14.07
0.029	3846.8	17.81	34.66
0.046	6103.5	25.26	71.72
0.071	9490.6	33.21	133.67
0.109	14569	41.57	234.29
0.159	21262	49.47	375.74
0.209	27951	56.5	548.75
0.259	34642	63.83	778.34
0.309	41332	72	1088.42
0.359	48022	80.79	1481.27
0.409	54711	90.23	1966.17
0.459	61401	100.33	2552.65
0.509	68092	111.1	3249.97
0.559	74781	122.52	4065.78
0.609	81470	134.73	5019.69
0.659	88159	147.93	6139.24
0.709	94847	162.27	7451.39
0.759	101540	178.03	8998.92
0.809	108230	195.64	10845.95
0.834	111570	205.31	11908.68
0.859	114920	215.79	13095.49
0.878	117430	224.26	14079.49
0.896	119940	233.51	15177.33
0.906	121260	238.65	15797.21
0.916	122570	243.95	16443.36
0.931	124550	252.79	17535.63
0.936	125220	255.84	17916.53
0.941	125890	258.94	18305.75
0.948	126890	263.66	18902.31
0.96	128390	271.12	19854.5
0.968	129520	276.88	20597.29
0.976	130650	282.75	21360.88
0.989	132340	292.14	22595.62
1	133800	300.59	23720.06

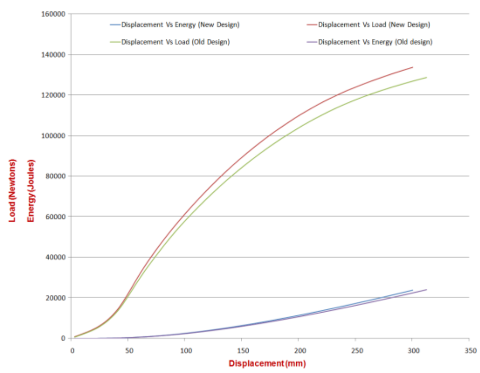


Fig. 10: Strain energy, Load and Displacement plot

V. EXPERIMENAL RESULTS

The figure below shows that ROPS for SD190 had tested laterally. The load 134 KN had applied laterally according to analysis performed by using Abacus to achieve Strain energy.

Fig. 11: Testing for Lateral Loading

VI. CONCLUSION

Based on the information available in Literature and papers listed below 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 structure of driver cabin need to sustain as much load as possible to protect the driver.

FEA analysis can be done effectively to evaluate the strength of the roof. The results obtained are very close to the results obtained in physical test.

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. 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.

The Analysis and test results are compared. The loads are applied according to analysis performed in all loading cases and displacements are compared.

The Baseline design has been assessed with 3 design modifications including removing gussets, adding holes and increased thickness of rear plate and extending rear isolators support plate.

The modified design has shown a slight marginal improvement (3 %) in the max displacement under the load achieved for similar strain energy.

The results indicate all these 3 design modifications can be incorporated and needs to be incorporated together as a package

- Removing gusset
- Extending the support plate
- Increasing the thickness of rear isolator plate from 10mm to 12mm. Holes made in the rear isolator plate

The modified design passed the standard ISO 3471.

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