Design and Analysis of Tractor Roll Over Protective Structure for the Influence of Deformation, Stress Distribution and Strain Energy

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Abstract. Roll over protective structure is an important safety device used to ensure that the tractor operator is free from injury when an accident happen. In case of tractor moving in an inclined plane (or) overturning, may be the tractor met with an accident due to roll over (or) fall over of the tractor. Sometimes, tractor may unbalance due to change the position of Centre of Gravity. Designer is to provide safe environment for the tractor operator during an accident. So that roll over protective structure is to save the life of tractor operator and protect from death. Therefore, ROPS design in the tractor by model, static and dynamic analysis as per the ISO 3471:2008 standard before prototype development. The main objective of this paper is to determine the ROPS stress distribution and deformation accurately under different load conditions by finite element method.

1. Introduction
A tractor consists of one of the most important system like roll over protection system. Protective system is used to secure operator and operator cabin. Each and every country having their own safety standard and depends upon the applications. According to ISO standard 3471:2008, to design such a way that reduce operator’s risk and safety. Most of the situations, the farmers are using older tractors without fully equipped ROPS and safety devices. Almost all the tractors are the risk of roll over and fall over, depending upon the performance of the tractor and agriculture field environment.

Therefore, there is an essential requirement to protect the operator from the risk and death due that the importances in the ROPS design and development of tractors. After completion of proto development to focus on safety precautions to prevent rollover a tractor. To test the roll over protective structure by sequence of static and dynamic case as per SAE J2194. The test should be observing performance characteristics of ROPS to withstand a standard, recommended criteria and validate through finite element approach.

2. Literature survey
There are many researchers and industrialist were studied and experimented about rollover protective structure and testing. Some of the discussions like minimize the failure and maximize the strength and
stiffness of the ROPS structure as follows: Amandeep Singh et al, explained about the numerical evaluation of a closed cabin of earthmovers for structural rigidity and safety. Sandeep R et al discussed about the experimental and analytical investigation of rollover protection structure for agricultural wheeled tractor. Abhay Kumar and Sudhir Darekar have analyzed regarding agricultural tractor cabin structure design for durability and rollover protective structure testing. Vamshichennuri et al, have done the design and stress analysis of four-post rollover protective structure of agricultural tractor. Carol Lehtola Jetal, discussed about the roll over protective structures for tractors used in agricultural operations.

3. Objective of this paper
The main objective of the paper is to design, modeling and finite element analysis of rollover protective structure for the static and dynamic analysis, strain energy absorption and stiffness of ROPS structure.

4. Design consideration
The specification of rollover protective structure as per ISO 3471:2008 tractor section of combined earth moving machine by the force and energy equations

| Tractor section of combined earth moving machine: Tractor |
|---------------------------------------------------------|
| Machine mass m (kg) | Lateral load force F (N) | Vertical load force F (N) | Longitudinal load force F (N) |
|----------------------|--------------------------|---------------------------|------------------------------|
| 700<m<1010           | 6m                       | 19.61 m                   | 76000 (m/10000)^1.2 |

Generally, the requirements of force resistance in the lateral, vertical and longitudinal directions also energy absorption in the lateral direction. There are some limitations on deflections under the lateral, vertical and longitudinal loading conditions with standard and recommended values. An assumed mass of 6000 kg (approx.) applied on the ROPS structure by lateral load force of six times of assumed mass, vertical load force of 19.61 times of assumed mass and 76000 (m/10000)^1.2 of longitudinal load force acting on the rollover protective structure. According to the equation of equilibrium conditions, summation of all the forces and moments should be equal to zero. The boundary conditions like bottom of the four post column is fixed and various loads such as lateral force, vertical force and longitudinal force acting in the respective locations as per the ISO 3471 standard and satisfy the equilibrium condition.

5. Methodology
To create a 3D cad model by any one of the software like creo 2.0, solid works and catia. The beams like a four post column and roof structure modelled as per the standard dimensions and standards as shown in the figure 1. The total number of structure consists of four column beams, square channels 20 * 20 * 4 and one cross-member by 10 * 10 * 2 as per standard channels.

The cad model is meshed by using eight nodded tetrahedron elements for getting almost closeness to the accurate results, color gradient contour pattern for better understanding of results.

Consider the medium mesh type for better connectivity of each element to avoid singularity error and ensure elements quality check.
6. Finite element analysis

In the finite element analysis, there are three basic steps has to be followed such as pre-processing, solution and post-processing. In pre-processing stage model definition, it includes cad import model in the form of model. igs file format, define the material properties of the solid model, mesh the element properties such as nodes, length, warpage, skew and max and min angle as shown in the figure 2. The fixed constraints and loading boundary conditions like lateral, longitudinal and vertical loadings.

In the solution phase, the governing differential equation is in the form of $F = Ku$ where, $F$ – Nodal forces, $K$ – Stiffness matrix and $u$ – Nodal displacement. The assemble matrix form the equation in the back end of the CAE software and compute the results of unknown values of the equations automatically.

In post processing, the finite element analysis results viewing and validation is conduct through as per standard and recommended values
Fig. 3 Lateral directional deformation

In an isometric view of contour plot represents that lateral directional force acting on the side of the ROPS structure and maximum deformation occur at the top of the ROPS structure with the value of 6.6 mm and deformation towards downward direction, maximum at the top of the ROPS structure. In 2D view ROPS structure deform towards front (or) back side of the structure as shown the figure 3.

Fig. 4 Total (or) vertical deformation

In an isometric view of contour plot represents that vertical of total force acting on the top of the ROPS structure and maximum deformation occur at the top of the ROPS structure with the value of 8.9 mm deformation towards downward direction. In 2D view ROPS structure deform towards right and deformation increase from bottom to the top of the column as shown the figure 4.
In an isometric view of contour plot represents that longitudinal directional force acting on the side of the ROPS structure and maximum deformation occur at the vertical column of the ROPS structure with the value of 0.27 mm deformation towards downward direction and maximum at the four post structure. In 2D view ROPS structure deform towards one side and deformation increase at the corner welded area of the structure as shown the figure 5.

In an isometric view of contour plot represents that equivalent stress distribution of throughout the ROPS structure and maximum stress distribution at the top of the structure and bottom of the column with the value of 256 Mpa. Therefore, the factor of safety is 1.9 and within the recommended value. In 2D view ROPS structure deform towards down and side and stress increases at the corner welded area and bottom of the column (welded area) of the structure as shown the figure 6.
In an isometric view of contour plot represents that the maximum strain energy shows at the top and bottom of the ROPS structure with the value of 59.93 mJ. In 2D view the energy absorption at the top and bottom of the vertical column (four posts) structure. ROPS structure deform towards down and deflecting towards side of the entire structure as shown the figure 7.

7. Conclusion
Rollover protective structure is analyzed by using CAE simulation software. From this analysis the maximum deformation around 8.9 mm, maximum stress 256 Mpa at the top and bottom of the four post ROPS structure. Strain energy absorption 59.9 mJ in the welded area. The generated lateral, vertical and longitudinal deformation, von misses stress & strain energy will be within the permissible and recommended value. Therefore, the proposed ROPS design will be safe. Further, the stress concentration areas (welded area) of the ROPS structure will be improve strength and stiffness by adding gussets and validate through finite element analysis.

8. References
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