

Design of a Two Post ROPS Structure through FEA OPEC Standard (Code-4)

Mohammad Shariq¹ and Amit Kumar²

¹M. Tech. (Machine Design) Scholar, CBS Group of Institutions, Jhajjar, Haryana, India

²Asst. Professor (Mechanical Engineering), CBS Group of Institutions, Jhajjar, Haryana, India

Abstract

The aim is to design and analyze a safety device for Tractors i.e. a rear mounted two post Roll over Protective Structure, (ROPS) thru FEA as per the OECD (Organization for Economic Co-operation and Development) - (Code-4). A two post Rops structure is modeled thru Pro-e with rectangular cross section for a given material. This Rops structure is analyzed thru FEA for roll over conditions. Implicit technique is applied for solving the FE model. Material non linearity is considered for capturing plastic behavior of the structure. Internal energy v/s Displacement curve is plotted to estimate the energy absorbed while applying load or enforced displacement thru the ground line. Deformed structure is checked for any intrusion with the zone of clearance as per standard.

Keywords: OPEC standard (Code-4), FEA Analysis, ROPS, Tractor Safety.

Abbreviations: ROPS– Roll over protective structure, DLV- Deflection limiting Volume, SIP– Seat Index Point.

Introduction

To avoid causality in farm sector a safety device called Rollover Protective Structure (ROPS), been installed on tractors. This safety is not from crash due to speed also not because of damage due to fall of any object in construction field but due to overturning of the tractors.

This overturning are due to-

- Poor ground conditions
- Working on gradients
- Puddling operations.
- Sand quarrying operations.

ROPS structure can be of two / Four Post type's front and rear mounted.

This paper is for two post rear mounted type.

The purpose is to design a parametric model of a two post Rops structure from scratch and then analyze its strength thru soft analysis against the OECD test std. Further scope of analysis by changing cross section & material is also available, Further there is also a scope of validating its results thru physical testing.

Methodology Adapted

1. With the reference of Seat Index point, dimensions of Clearance zone are available as per OECD Code-4.
2. Now enclosing it a parametric model of ROPS structure is created on Creo.
3. A rectangular cross section of 8 mm thickness is swept along U path for the height of 1865 mm and width of 1100 mm.
4. Since it is a parametric modeling hence dimensions have some approximations which can later be adjusted with the result of FEA.

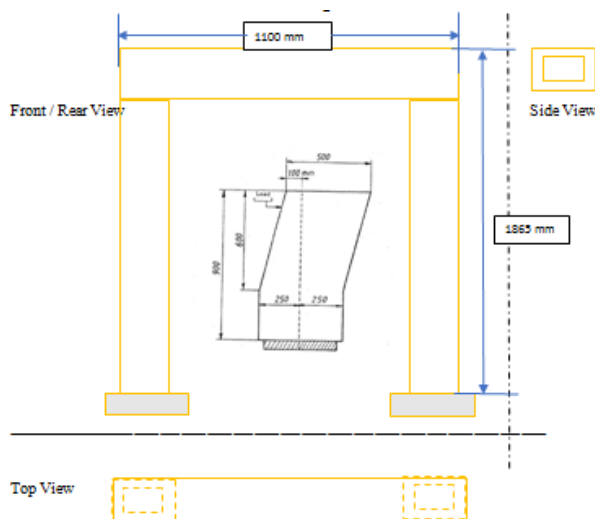
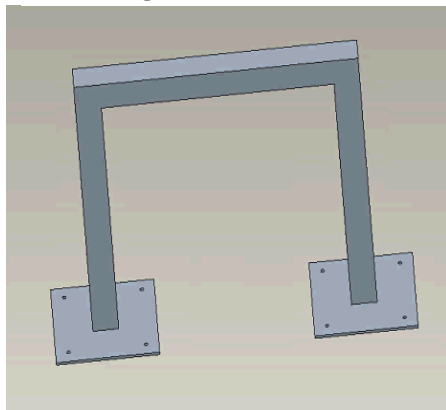


Figure 1: 2D-Model of ROPS

Figure 2: Final ROPS Model



5. High grade Mild steel is used as material. Material is assumed as homogeneous and isotropic.
6. Plastic properties are considered for material, and hence true stress –strain curve is provided in elastic –plastic curve later while applying in FEA.
7. Some rigid material property is considered for clearance zone or DLV.

FE Modelling of ROPS Structure

Software used: Altair Hypermesh & Abaqus

Steps-

1. Importing the ROPS geometry in hypermesh in .step format as modelled in creo.
2. Keep the scale factor same as in creo.
3. Keep the co-ordinate axis as per the right hand rule in which prime finger is +x, middle finger is +y and +z is towards viewer in the perpendicular of the plane of paper.
4. Mesh the model with average element size of 10 mm, thru F10 command.
5. Element type is S4 for Abaqus profile.
6. Weld is also modelled by S4 element and with same procedure as point5.
7. Heat affected zone is not considered in the modelling.
8. Corrosion, impurity etc. is not considered in weld.
9. All around weld is considered.
10. Weld material property is considered as of the parent material.
11. Weld thickness is least of the two connecting plate.
12. Load applying plate are created with the same S4 planer element.
13. Rigid (Beam element in Abaqus) is used to connect all the nodes of the plate to a single node.
14. Spring is connected from load application plate to Rops structure in all the x, y& z directions. Spring 2 element of Abaqus is used for this purpose. Speciality of spring-2 element is that node 2 of this element has relative motion with respect to node 1. Node-1 & node 2 are the end nodes of the spring element.
15. Load plate and spring both are modelled with general elastic steel material.
16. Spring stiffness is unity along the co-ordinate length of the element and it is almost rigid in other transversal directions.
17. S4 is a four nodal plane stress element which has zero stress in the thickness direction; 'S' represent shell. It has four gauss integration or calculation point.

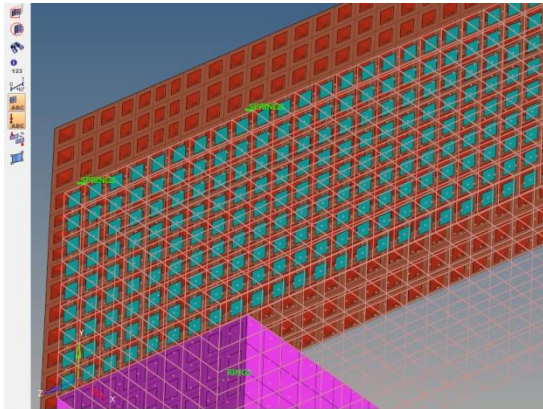


Figure 3: Contact Element between Load Plate and ROPS Structure

18. Node sets are created for Longitudinal, transversal and side loading to represent the load point.
19. Similarly element set is created for complete ROPS structure to check the energy absorbed in the structure.
20. Contact element is created to interact in the gap due to geometrical discontinuity. Contact pair is the pair between two contact facing plates are toward each other.
21. Surface interaction property is friction and its value is generic 0.15 for metal to metal contact.
22. Surface interaction behaviour is hard contact in Abaqus.
23. Bolts are modelled with rigid elements.
24. Units in FEA model; mass is in Tonn; displacement in mm; Energy is in mJ; Force is in Newton & Stress is in MPa.
25. *Step data is given for Load step.
26. * Static is given as Abaqus command since it is static analysis.
27. It is highly non-linear problem since geometric, material as well as contact non-linearity is available. Hence NLgeom= Yes is given as Abaqus card.
28. Initial time increment is taken as 0.1 i.e. it will apply 10% of the total load value in the first increment of the analysis.
29. Maximum increment can be taken as full load, hence given=1.0
30. Minimum increment to solve the model as per the sensitivity is 1.0+E-7

31. *Boundary command is applied for constraining the model.
32. Base plate is constrained in vertical Y direction; while bolts are in all the direction.
33. In Output block; displacement and Reaction forces are taken at particular Node set while Strain energy at the element set named as ROPS.
34. * Model change card is applied to change the model configuration from longitudinal loading to vertical crush to side loading etc.
35. * Restart command is used to carry forward the result of last Load step to the next one.
36. Run is given thru run command in Abaqus and in the queue to save the time and monitoring.
37. Implicit methodology will be used by the Abaqus to solve the model.
38. In Implicit method, for each incremental load, stiffness matrix will be re-solved.
39. In this method run progressing requires monitoring, but results are accurate.
40. There are 5 load cases generally been prepared followed by 5 spring back load cases, which provide the stability to the structure, to avoid the inertia effect of the previous load case and to make the model ready for the next load in other direction.

Load Calculation & Energy Criteria

As per the OECD std.required amount of Energy is calculated on the basis of Reference Mass.

Reference mass is the mass selected by the manufacturer for calculation of the energy inputs and crushing forces to be used in the tests.

Reference Mass; $M = 1750 \text{ Kg}$ (realistic assumption)

Load case1: Rear Longitudinal Loading:

$$\text{Energy target} = 1.4 \times M = 2450 \text{ J}$$

$$\text{Enforced displacement applied} = 218 \text{ mm}$$

Enforced displacement is the initial displacement to the structure for rear load case to achieve the required energy target.

Load case 2: Spring back - Rear Longitudinal Loading:

Load Case 3: 1st Top Crushing Load:

$$\text{Crushing Load} = 20 \times M = 35000 \text{ N}$$

I.e. in first top crushing load case, 35000 N of force should be applied in $-Y$ direction; vertically downward.

Load Case 4: Spring back - 1st Top Crushing Load:

Load Case 5: Side Loading:

$$\text{Energy Target} = 1.75 \times M = 3062.5 \text{ J}$$

$$\text{Enforced displacement applied} = 223.5 \text{ mm}$$

I.e. 223.5 mm of enforced displacement is applied to the structure from side of the structure to achieve the required energy target.

Load Case 6: Spring back - Side Loading:

Load Case 7: 2nd Top Crushing Load:

$$\text{Crushing Load} = 20 \times M = 35000 \text{ N}$$

I.e. in second top crushing load case, 35000 N of force should be applied in -Y direction; vertically downward.

Load Case 8: Spring back - 2nd Top Crushing Load:

Load Case 9: Front Longitudinal Loading:

$$\text{Energy target} = 0.35 \times M = 612.5 \text{ J}$$

Enforced displacement applied = 23.5 mm

I.e. 23.5 mm of enforced displacement is applied to the structure from the front of the structure to achieve the required energy target.

Load Case 10: Spring back - Front Longitudinal Loading:

Rear or Longitudinal Loading:

Rear-load application shall be distributed uniformly on the frame over an area perpendicular to the direction of load application. Size and location of the plate is as per the OECD guidelines. Enforced displacement is applied at the plate center and mounting holes of ROPS is constrained in all d.o.f. E-D curve is plotted representing the strain energy.

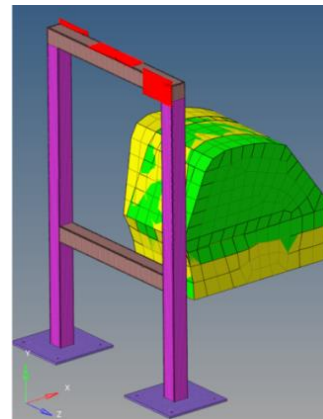


Figure 4: Rear Loading in in FEA + X Direction

First Top Crushing Loading:

Apply the required amount of Load from Top on the same frame; mounting holes of ROPS is constrained in all d.o.f.

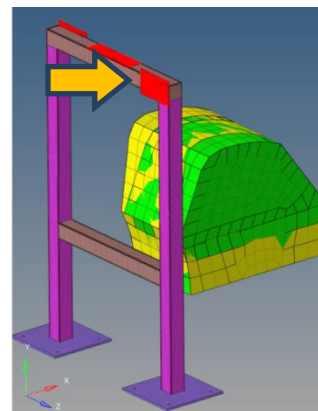


Figure 5: Top Loading in FEA in -Y Direction

Side or Transverse Loading:

Apply the enforced displacement on side-load on the same frame, and record energy simultaneously. Side-load application is also applied as per the given condition and guidelines of OECD, mounting holes of ROPS is constrained in all d.o.f.

Side or Transverse Loading is followed by **Second Top Crushing Load** and **Front Rear Loading**.

The Loading is again performed with the same procedure as per OECD Code-4

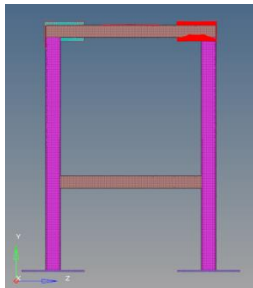


Figure 6: SIDE LOADING IN FEA IN +Z

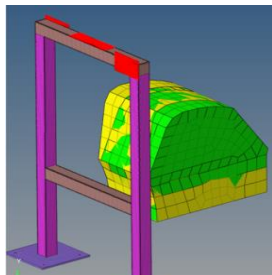
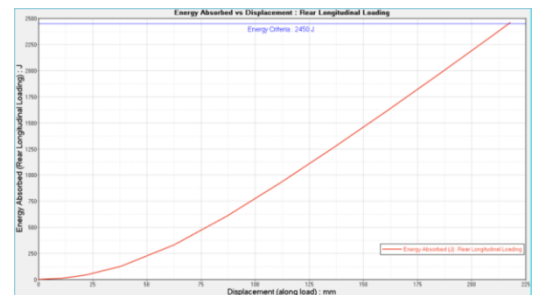
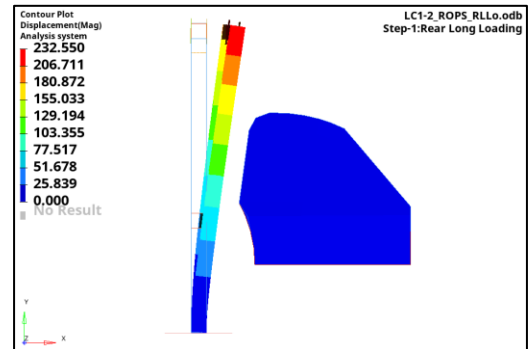


Figure 7: Front Longitudinal Loading -X

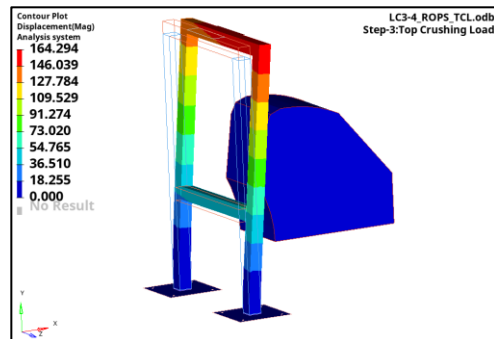
Results & Discussions

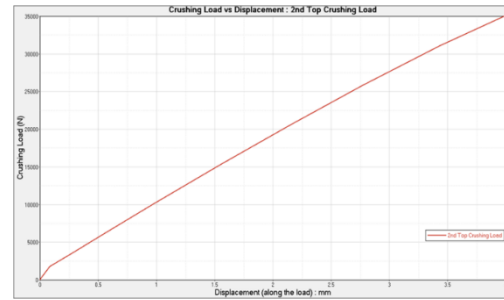
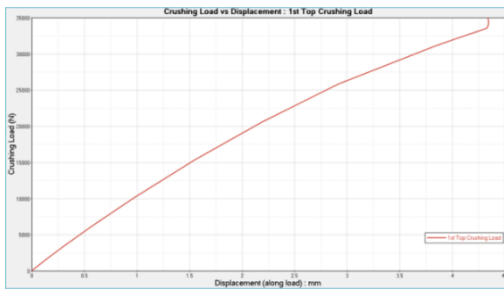
1. Rear or Longitudinal Loading

ROPS simulation is carried out in Abaqus. The rear load cases were simulated as per OECD standard guideline.



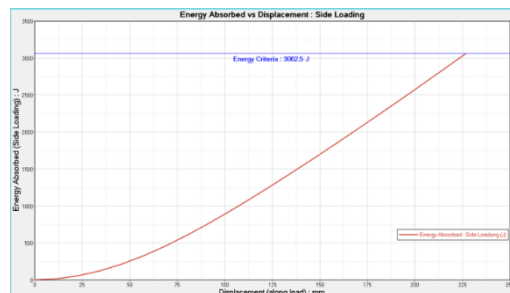
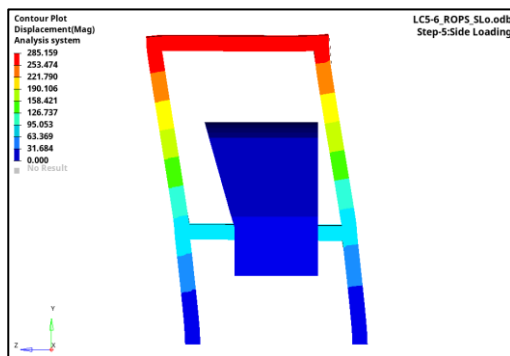
2. First Top Crushing Load ROPS Simulation is carried out in Abaqus. The load cases i.e. side and rear load cases were simulated as per OECD standard guideline.





3. Side Loading:

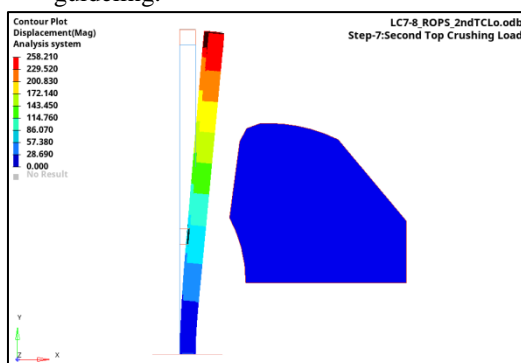
ROPS simulation is carried out in Abaqus. The load cases i.e. side and rear load cases



were simulated as per OECD standard guidelines.

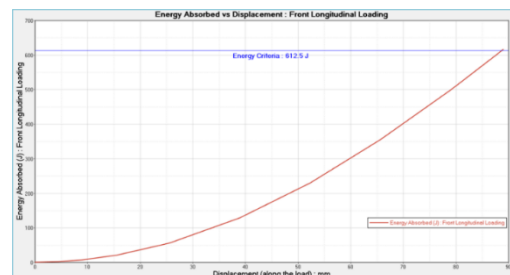
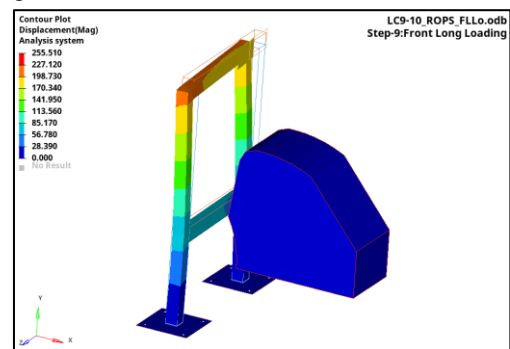
4. Second Top Crushing Loading

ROPS simulation is carried out in Abaqus. The load cases i.e. side and rear load cases were simulated as per OECD standard guideline.



5. Front Longitudinal Loading

ROPS simulation is carried out in Abaqus. The load cases i.e. side and rear load cases were simulated as per OECD standard guideline.

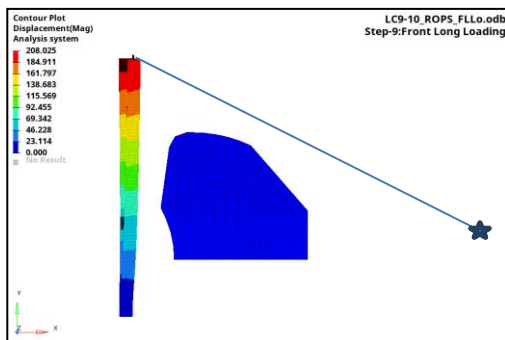


Passing Criteria/ Condition of Acceptance

1. For all the above load cases, the deflection of ROPS should not intrude the Deflection Limiting Volume (DLV) as defined by OECD Code – 4 std. I.e., No part shall enter the clearance zone during any part of the tests. No part may strike the seat during the tests. Furthermore, the clearance zone shall not be outside the protection of the protective structure. For this purpose, it shall be considered to be outside the protection of the structure if any part of it

would come in contact with flat ground if the tractor overturned towards the direction from which the test load is applied.

2. In all the above load cases, Energy absorption and Force criteria must be met without exceeding the limiting stress and strain in the ROPS structure.
3. Clearance zone must not intrude in the line connecting the Front top point of the ROPS structure and top of the front hood of the Tractor. This inclined line represent flatten surface which hits the tractor first in case of overturn.



Test Result Summary

Load Case	Max Displacement (mm)	Target Value	Observed Stress Von-Mises (MPa)	Observed Strain (%)	Result (A/M/N)
Rear Longitudinal Loading	232	2459 J	460	3.5 %	A
1st Top Crushing Load	164	35000 N	270	3.5 %	A
Side Loading	285	3063 J	540	11 %	A
2nd Top Crushing Load	258	35000 N	526	11.5 %	A
Front Longitudinal Loading	147	616 J	536	11.6 %	A

1. Energy and Force Criteria are met for all the Load cases.
2. Observed Stresses are also below 670 MPa in all the Load-cases.
3. Maximum Plastic Strain are also less than 18 % in all the Load Cases.
4. As we can see in the Displacement Plot of all the Load Cases ROPS is not intruding during Loading & Un-Loading.
5. Final Position of Ground Line; clearly visible that it is not intruding in DLV.
6. Remark "A" is the representation of applicability or Pass.

Conclusion

ROPS meets all the criteria laid down by OECD Code -4.

1. The critical components like ROPS for Tractors can be very accurately simulated using Hyper-Works to describe the standard criteria.
2. The Methodology proves effective in predicting maximum allowable ROPS deflections when considering the standard criteria.
3. The results can be correlated with the actual lab testing, thereby reducing cost and time in the development.
4. The accelerated method of computation proved effective thereby arriving at correct design after several iterations but in much reduced time.

Future Scope of Work

1. A prototype of ROPS structure can be manufactured and physical test result should be compared with this virtual test to validate the accuracy of the analysis.
2. ROPS structure can be generalised as per the ratio of height and different types of cross section.
3. Cost effective design can also be explored by doing iterations with respect to material and thickness.

References

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