International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 4, No. 1, January 2015

Research Paper

DESIGN AND STRESS ANALYSIS OF FOUR-POST ROLLOVER PROTECTIVE STRUCTURE OF AGRICULTURAL-WHEELED TRACTOR

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The main purpose of this study is to investigate the behaviour of four post Roll Over Protective Structure (ROPS) for agricultural wheeled tractor. The objectives are to assess the stresses and deflections in the ROPS of different cross-sections under different types of load conditions and compare the results to find out the most suitable type of cross-section. The ROPS is modelled by SolidWorks 2013 and analysed using ANSYS 14.0. Alloy steel is used as ROPS material. Three types of loadings are being investigated: rear loading, side loading, and vertical loading. Four types of cross-sections are being examined: square, circular, hollow square and hollow circular. This particular test is carried with accordance to SAE J2194 standard. This paper will present the stresses and deflections experienced by the ROPS.

Keywords: ROPS, Rollover, Solid works, ANSYS, SAE J2194 standard, Test conditions

INTRODUCTION

A rollover is a type of vehicle accident in which a vehicle tips over onto its side or roof. Tripped rollovers are caused by forces from an external object, such as a curb or a collision with another vehicle. Untripped crashes are the result of steering input, speed, and friction with the ground. All vehicles undergo rollovers to various extents. Generally, the higher the center of mass, the narrower the axle track, the more sensitive the steering, and the higher the speed, the more likely a vehicle is to roll over. The most common type of tripped rollovers occur when a vehicle is sliding sideways. In automobiles there are safety belts and airbags to help prevent injuries to passengers in the event of an accident. Despite these innovations, there are numerous deaths each year. However, these safety practices are not a substitute for ROPS

Tractor rollovers are the major type of accidents that do occur due to improper or poor working conditions of the tractor. ROPS is the structure developed to absorb the impact

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energy when tractor hits the ground during the time of rollover. Heavy vehicles having a high centre of gravity used in the agricultural field, construction, mining industries usually run on odd and inclined surfaces are capable to rollovers. ROPS is a frame attached to the operator's cabin for protection. The capability of the ROPS to protect the operator during the time of rollover made many researchers to conduct different experiments to evaluate its behaviour.

There are different ROPS designs with different specifications and regulations depending on the application. The ROPS design is based upon criteria like vehicle size, weight distribution, sub-system mounting, operator safety, ergonomics and analysis under various load conditions.

The continuous evaluation of ROPS consists of checking its performance under different loads, checking its behaviour if it is made of different materials, etc. Performing a experiment using ROPS involves in lot of cost, labour and time. Experiment on ROPS if conducted by involving the human beings may lead to his death. In order to avoid this, evaluation of ROPS on computer software is encouraged. Using computer modelling technology the designs are made and with the use of analysis software, the behaviour of ROPS at different loading conditions, behaviour of ROPS with different materials can be studied.

In this project the behaviour of the ROPS with different cross sections for same loading conditions is conducted as experiment using computer modelling and analysis technology. The stresses and deformations are observed for different cross sections.

Keeping above discussed factors in mind, it was decided to carry out the project with the following objectives:

1. Modelling of the Rollover Protective Structure using SolidWorks 2013.
2. Assess the stresses and deflections in the ROPS design using ANSYS14.0.

MATERIALS AND METHODS

To assure that the ROPS has been designed and tested properly, the ROPS should meet or exceed the performance standards established by the American Society of Agricultural Engineers (ASAE), the Society of Automotive Engineers (SAE), or the Occupational Safety and Health Administration (OSHA).

SAE J2194 is the ROPS standard for wheeled agricultural tractors. The SAE J2194 ROPS Standard is included with Static Testing and Dynamic Testing. The Static Test purpose is to simulate the loads applied in the unfortunate event of an overturn. The standard is prepared to set up definite guidelines in testing and performance of ROPS designed for wheeled agricultural tractors. This thesis is concerned with only the static testing of ROPS at ambient temperature, and this chapter will concentrate on how the research conducted.

STATIC TEST

SAE J2194 ROPS Standard significantly depends upon the energy measures. SAE J2194 Standard tells a mass, not less than the tractor mass shall be used for calculation of the force and energy inputs during the tests. If a number of tractor models form a family and use the same type of ROPS, the tractor having the heaviest mass shall be used as the reference mass (Mt). The static test is conducted to simulate the loads acted in the event of overturn.

TEST CONDITIONS

There are four types of loadings must be applied, if it can withstand the series of loadings we can say that ROPS is successfully passed the static part of SAE J2194. It should also be stated no adjustments or repairs can be made while testing, and if any fixture used for restraint purposes breaks or shifts, then the loading must be repeated.

As per the structural testing requirements of SAE J2194, specific order for loading must be followed. It must also be known whether the majority of the tractor mass rests on the rear wheels or the front wheels because the loading orders are different for each. For this research, it was determined that less than 50% of the tractor mass was on the rear wheels.

Rear Longitudinal Loading

First load to be applied to the ROPS was the rear longitudinal loading. The loading was applied until the energy requirement was met.

$E_r = 1.4 * M_t$(Joules),

E_r = Energy input to be absorbed during rear loading

M_t = Tractor mass in kg

The energy requirement in this case is 2,800 J (Joules). This was due to the reference tractor mass being 2,000 kg. But, $E_r = F_r * s$

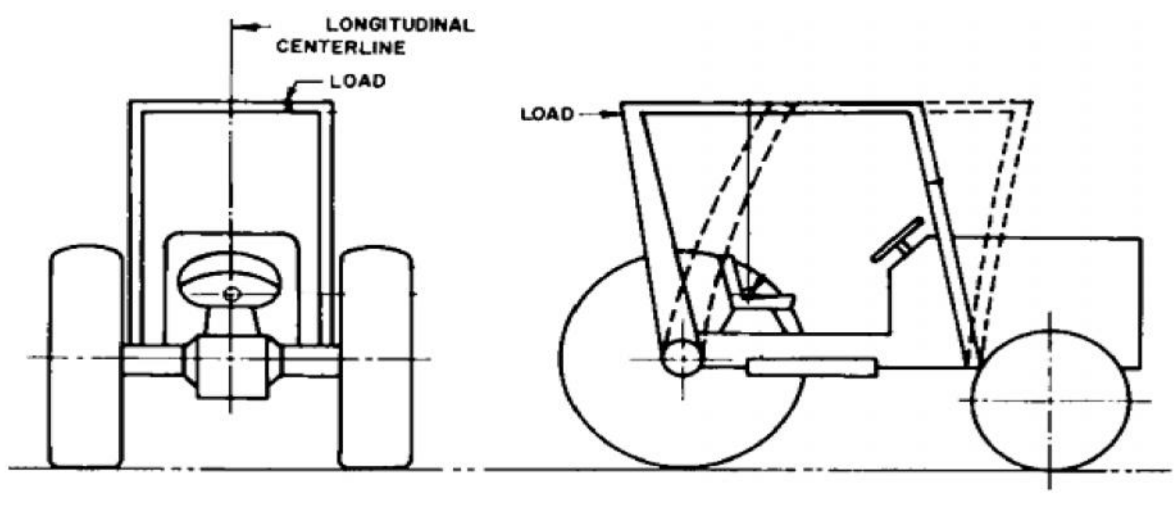
F_r = The force to be applied on the ROPS for rear longitudinal loading condition.

¢ = Maximum Displacement of the ROPS so that the deflection doesn't touch operator safety zone.

The Maximum Displacement value taken for our case is 20 cm. Therefore, calculated value of Force F_r is found to be 14,000 N. This force need to be applied for this test condition.

It is also important to state the loading was applied to the uppermost transverse structural member of the ROPS. This is the part of the ROPS, which would likely strike the ground first in the event of a rear overturn. It should also be

Figure 1: Typical Rear Load Application



stated the point of application of the loading was located at one-sixth of the width of the top of the ROPS inward from the outside corner.

Side Transverse Loading

The second load to be applied to the ROPS was the side transverse load. The loading was applied until the energy requirement was met.

$E_s = 1.75 * M_t$ (Joules),

E_s = Energy input to be absorbed during side loading

M_t = Tractor mass in kg

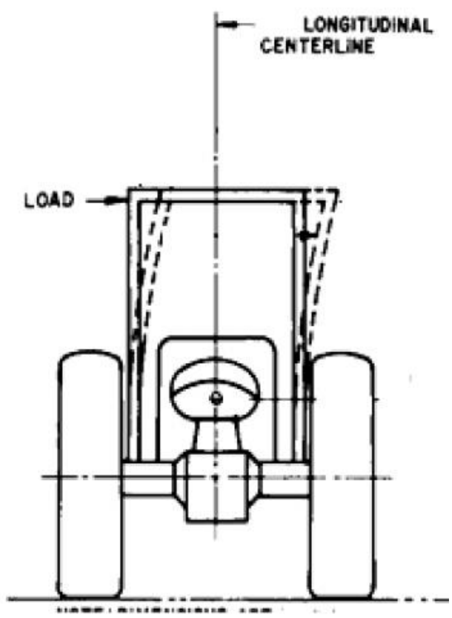
The energy requirement in this case is 3,500 J (Joules).

But, $E_s = F_s * ¢$

F_s = The force to be applied on the ROPS for side transverse loading condition.

The Maximum Displacement value taken for our case is 20 cm. Therefore, calculated value of Force F_s is found to be 17,500 N. This force need to be applied for test condition. The side transverse loading point of application was the part of the ROPS side, which will touch the ground first in the event of a sideways overturn.

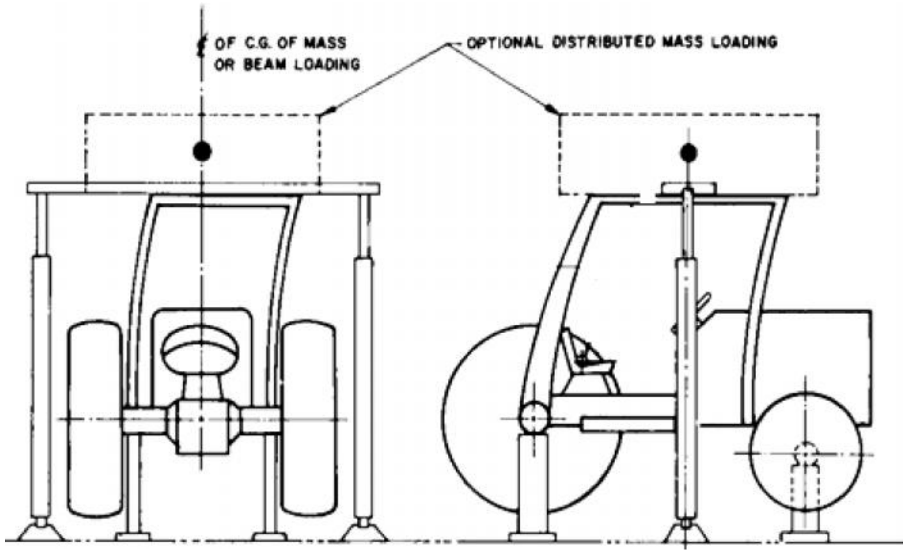
Figure 2: Typical Side Load Application



Vertical Crush Loading

The third load to be applied to the ROPS was the vertical crush load. Unlike the first two load applications, the third load is not based upon

Figure 3: Vertical Crush Load Application



an energy requirement. To the contrary, this load is applied to ensure the ROPS does not buckle and have a catastrophic failure. The ROPS must be able to withstand a force of F_v.

$F_v = 20 * M_t$(N),

F_v = Force to be withstand during vertical crush loading

M_t = Tractor mass in kg

The Force requirement in this case is 40,000 N (Newton). This force has to be applied for this test conditions. Load must be applied to the rear upper most structural member(s) of the ROPS. Using a rigid beam positioned on topof the ROPS typically does the load application, and the loading is applied through the beam. Of course, the rigid beam must be secured to the ROPS and not allowed to slip.

Frontal Loading

The fourth and final load to be applied to the ROPS was the second longitudinal load. The load must be applied in the opposite direction to and at the corner furthest from the point of application of the first longitudinal load. Again, the point of application of the load was located at one-sixth of the width of the top of the ROPS inward from the outside corner.

$E_f = 0.35 * M_t$(Joules)

E_f = Energy input to be absorbed during frontal loading

M_t = Tractor mass in kg

The energy requirement in this case is 700 J (Joules).

But, $E_f = F_f$ * ¢

F_f = The force to be applied on the ROPS for frontal loading condition.

The Maximum Displacement value taken for our case is 20 cm. Therefore, calculated value of Force F_f is found to be 3,500 N. And this force need to be applied for this test conditions.

After each of the four loads are applied, failure is determined by whether the Occupant Clearance Zone has been intruded upon by the deformed ROPS, or if the three point ground plane intrudes upon the zone. Success means the ROPS was able to absorb the prescribed amount of energy or force without intrusion upon the zone. This means the determination of the Occupant Clearance Zone an important process. Each class of tractor uniquely determines every zone. The first step in creating the zone depends upon the seat reference point, and the seat reference point can be determined by ISO 3462 standard with the seat to its uppermost and rearmost position (1987). Once the seat reference point is known, the zone can be successfully represented and modelled.

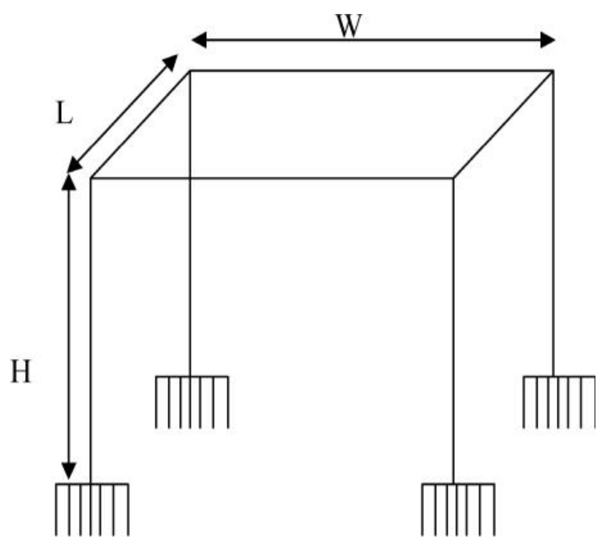
ROPS MATERIAL

Steel is preferred to be used as ROPS material. Carbon steels, alloy steels, stainless steels and tool steels are the available steels. Among these, alloy steels are the most preferable type as it has the better mechanical properties compared to other materials. Hardness is the major criteria to select ROPS material as it is a property which enables the material to resist against deflection under different loading conditions. For our thesis work, alloy steel is used.

DIMENSIONS OF ROPS

The measurements taken are commonly used ROPS dimensions for tractors.

Figure 4: ROPS Dimensions Showing Length, Width, Height



Height = 150 cm

Length = 140 cm

Width = 116 cm

Experiments were carried out for different cross-sections. The dimensions of the cross-sections are:

Squared Tube: 5 x 5 cm^2

Hollow Squared Tube: 5 x 5 cm^2, Thickness = 1 cm

Circular Tube: Radius = 3 cm

Figure 5: Solid Square Section

Figure 6: Solid Circular Cross Section

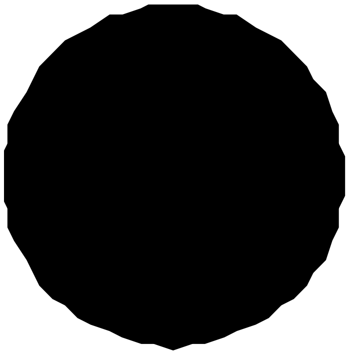
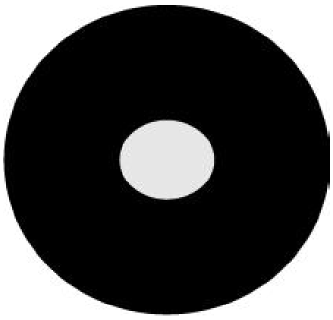


Figure 7: Hollow Square Cross Section

Figure 8: Hollow Circular Cross Section



Hollow Circular: Radius = 3 cm,

Thickness = 1 cm

MODELLING OF ROPS IN SOLIDWORKS

1. The sketch is drawn in the selected plane with the required dimensions.

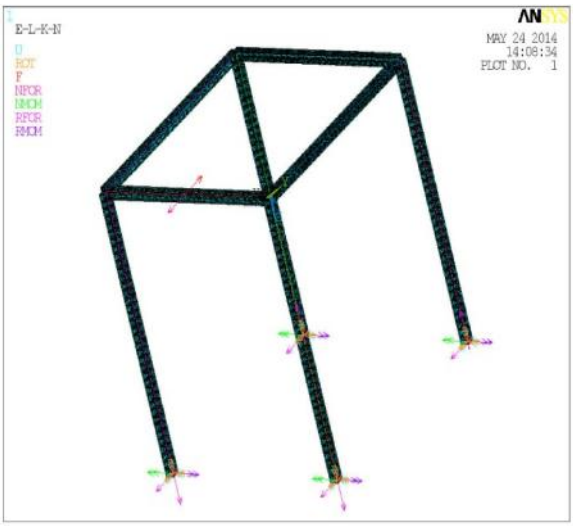
2. Next the 2D sketch is converted into 3D with the help of 'Features' tab which consists of Extrude, Extrude cut, etc.
3. After getting a 3D model again plane is selected to draw sketch on existing model and with the help extrude option the desired model is made.
4. Similarly the other structures with Hollow Square, Circular, Hollow Circular cross sections can be modelled with the same procedure done for the modelling of the square cross section structure.
5. Once the required structures with different cross sections are modelled then next step is to make analysis to study their behaviour.

ANALYSIS IN ANSYS

Boundary Conditions

The four legs of the structure is fixed as ground since the structure is mounted on to the tractor with the help of bolt joints. During the analysis the bolt joints are taken as ground. Boundary conditions were applied all loading conditions.

Figure 9: Boundary Conditions for Rear Loading of Circular Cross Section



Material

The material of the structure is selected as alloy Steel.

Load Applied

The structure was subjected to three types of loading one at a time namely.

- Side transverse load 17.5 Kilo-Newton
- Rear longitudinal load 14 Kilo-Newton
- Vertical load 40 Kilo-Newton

RESULTS AND DISCUSSION

When structures with different cross sections are subjected to rear loading, side loading, vertical loading and analysed by ANSYS software, the results are as follows:

Circular Cross-Section

Rear Loading

Figure 10: Stresses in Circular Cross Section When Subjected to Rear Loading

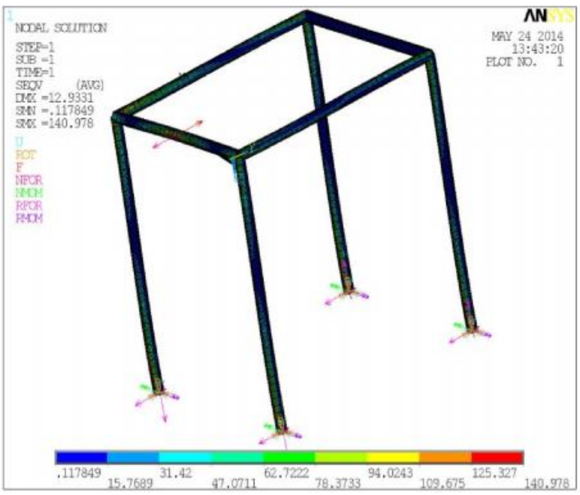
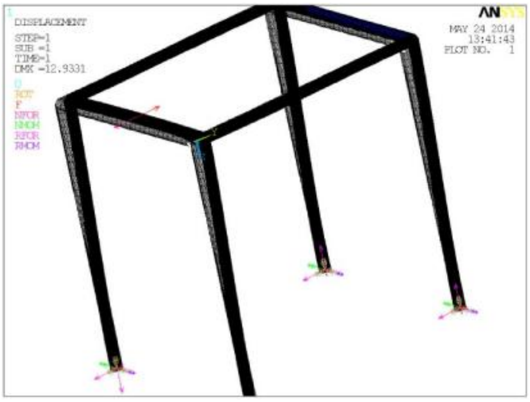


Figure 11: Displacement in Circular Cross Section When Subjected to Rear Loading



Vertical Loading

Figure 12: Stresses in Circular Cross Section When Subjected to Vertical Loading

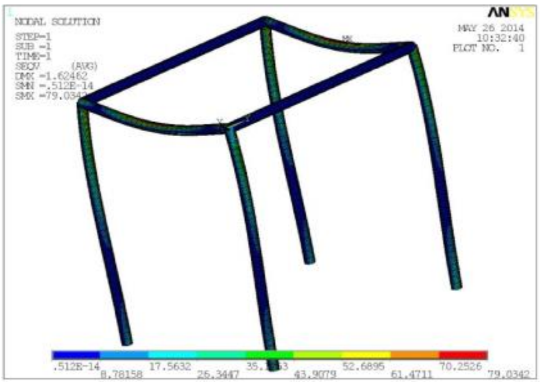
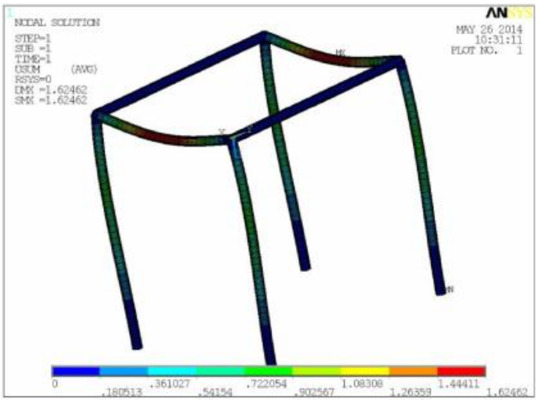


Figure 13: Displacement in Circular Cross Section When Subjected to Vertical Loading



Side Loading

Figure 14: Stresses in Circular Cross Section When Subjected to Side Loading

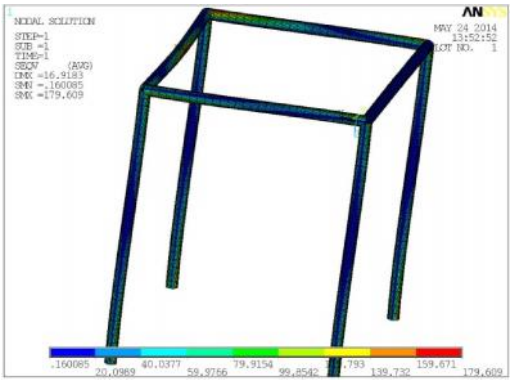


Figure 15: Displacement in Circular Cross Section When Subjected to Side Loading

Hollow-Circular Cross Section

Rear Loading

Figure 15: Displacement in Circular Cross Section When Subjected to Side Loading

Figure 16: Stresses in Hollow Circular Cross Section When Subjected to Rear Loading

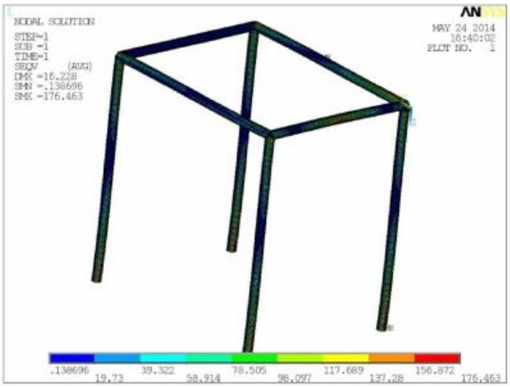


Figure 17: Displacement in Hollow Circular Cross Section When Subjected to Rear Loading

Vertical Loading

Figure 18: Stresses in Hollow Circular Cross Section When Subjected to Vertical Loading

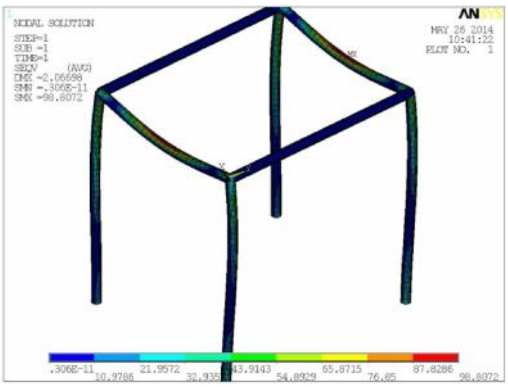
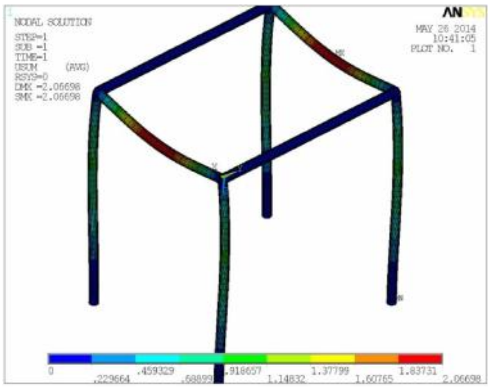


Figure 19: Displacement in Hollow Circular Cross Section When Subjected to Vertical Loading



Side Loading

Figure 20: Stresses in Hollow Circular Cross Section When Subjected to Side Loading

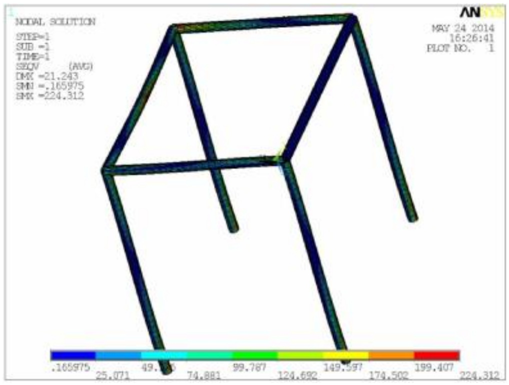
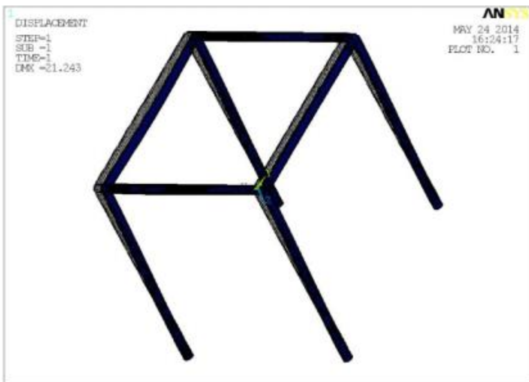


Figure 21: Displacement in Hollow Circular Cross Section When Subjected to Side Loading



Square Cross Section

Rear Loading

Figure 22: Stresses in Square Cross Section When Subjected to Rear Loading

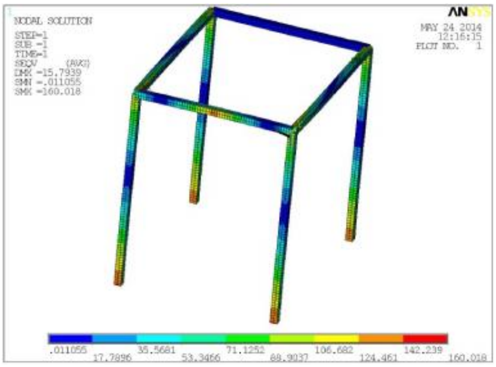


Figure 23: Displacements in Square Cross Section When Subjected to Rear Loading

Vertical Loading

Figure 24: Stresses in Square Cross Section When Subjected to Vertical Loading

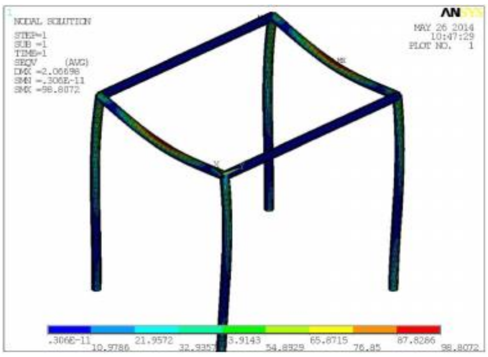
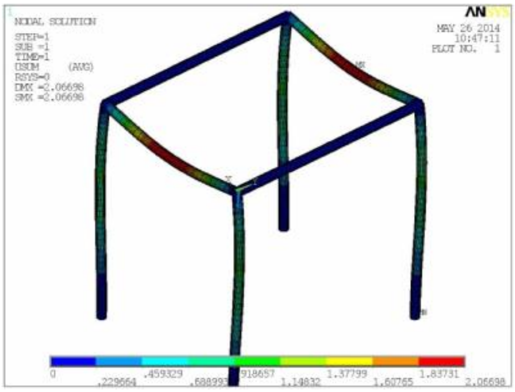


Figure 25: Displacement in Square Cross Section When Subjected to Vertical Loading



Side Loading

Figure 26: Stresses in Square Cross Section When Subjected to Side Loading

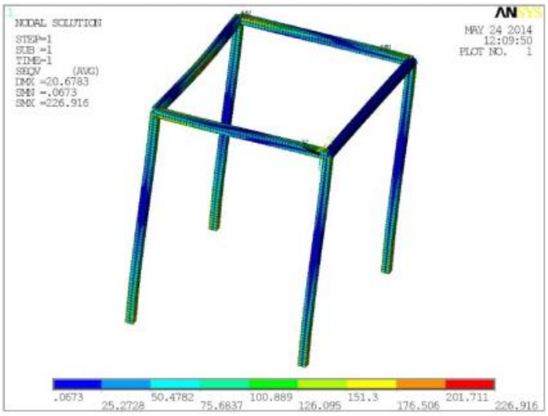
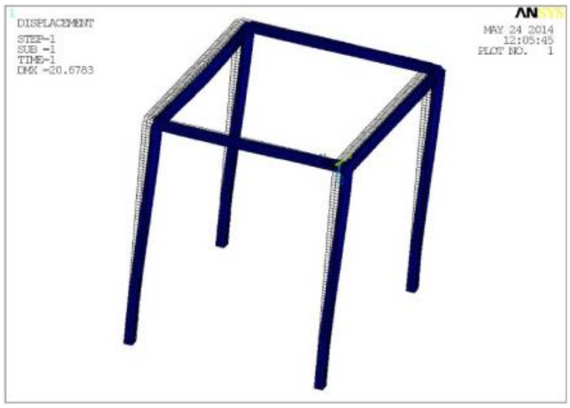


Figure 27: Displacement in Square Cross Section When Subjected to Side Loading



Hollow Square Cross Section

Rear Loading

Figure 28: Stresses in Hollow Square Cross Section When Subjected to Rear Loading

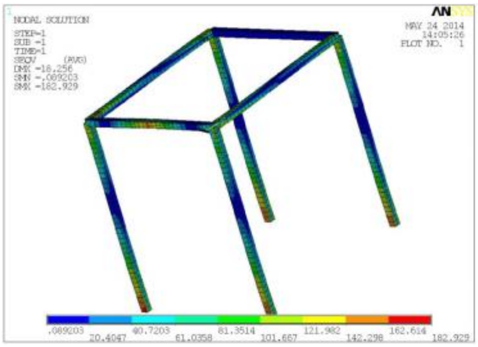
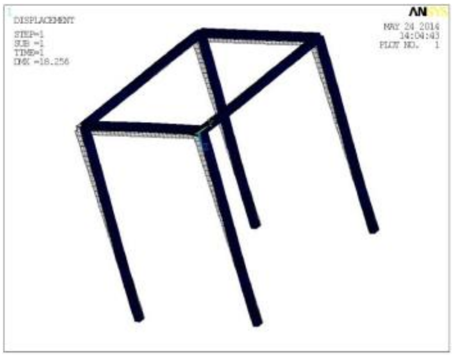


Figure 29: Displacement in Hollow Square Cross Section When Subjected to Rear Loading



Vertical Loading

Figure 30: Stresses in Hollow Square Cross Section When Subjected to Vertical Loading

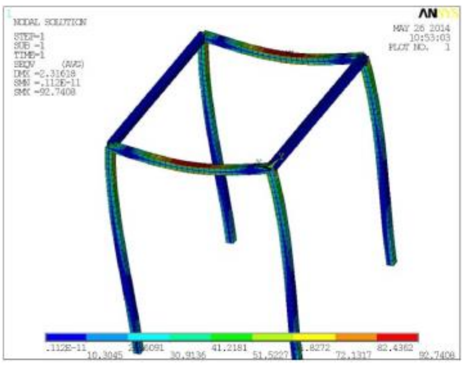
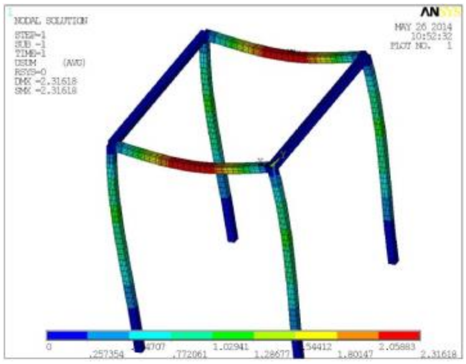


Figure 31: Displacement in Hollow Square Cross Section When Subjected to Vertical Loading



Side Loading

Figure 32: Stresses in Hollow Square Cross Section When Subjected to Vertical Loading

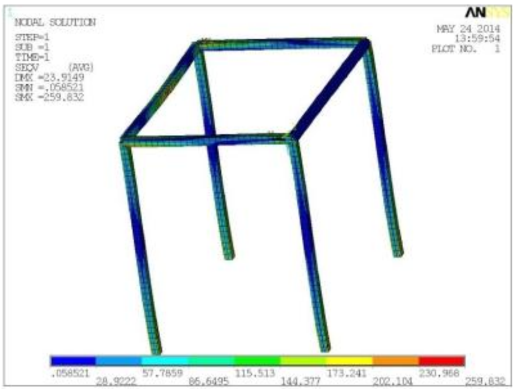
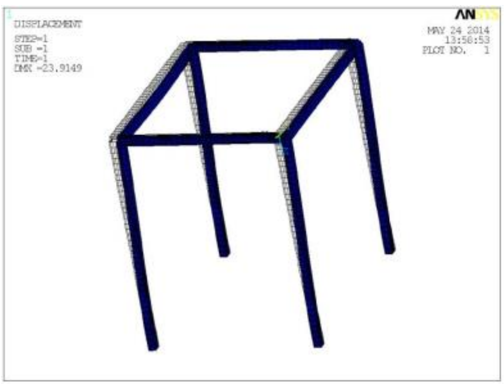


Figure 33: Displacement in Hollow Square Cross Section When Subjected to Side Loading



When circular cross section ROPS was subjected to different loadings the Displacement and Stresses are as follows:

Table 1: Displacement and Stresses of Circular Cross Section

Type of Loading	Displacement (mm)	Stresses (MPa)	
		Min	Max
Rear Loading	12.9331	0.1178	140.978
Vertical Loading	1.624	$0.512*10^{-14}$	79.0342
Side Loading	16.9183	0.160085	179.609

When Hollow-circular cross section ROPS was subjected to different loadings the displacement and stresses are as follows:

Table 2: Displacement and Stresses of Hallow-Circular Cross Section

Type of Loading	Displacement (mm)	Stresses (MPa)	
		Min	Max
Rear Loading	16.228	0.1386	176.463
Vertical Loading	2.316	$00.112*10^{-11}$	92.7408
Side Loading	21.243	–224.312	221.883

When Square cross section ROPS was subjected to different loadings the displacement and stresses are as follows:

Table 3: Displacement and Stresses of Square Cross Section

Type of Loading	Displacement (mm)	Stresses (MPa)	
		Min	Max
Rear Loading	15.7939	0.0110	160.018
Vertical Loading	3.82785	$0.25*10^{-14}$	157.333
Side Loading	20.678	–226.916	223.417

When Hollow-Square cross section ROPS was subjected to different loadings the displacement and stresses are as follows:

Table 4: Displacement and Stresses of Hollow-Square Cross Section

Type of Loading	Displacement (mm)	Stresses (MPa)	
		Min	Max
Rear Loading	18.256	0.0892	182.929
Vertical Loading	2.316	$0.112*10^{-11}$	92.7408
Side Loading	23.919	0.160085	179.609

CONCLUSION

1. The four post ROPS for Agricultural wheeled tractor is modelled with the dimensions taken from existing design and analysed with the help of finite element analysis in ANSYS software.
2. The maximum deflection of the ROPS is taken 20 cm and calculated the loads to be applied in side loading, rear loading, and vertical loading.
3. ROPS was modelled with different cross sections for the same dimensions and analysed with the calculated forces.
4. The behaviour of the ROPS with different cross sections when subjected to calculated forces is observed in the form of Stresses and deflections.
5. The one with the less deflection and less stress is found to be the safe structure which will have the generated stresses in the range of yield point stress of the material.

RECOMMENDATIONS

1. This particular topic can be extended by analysing the different cross sections made up of different materials.
2. The constraints given to the structure can be changed to ball joint and analyse the behaviour when loads are applied.

3. Different types of complex structures which can resist high impact energy can modelled and analysed.

ACKNOWLEDGMENT

I owe my profound gratitude to my project guide Dr. Ashish Kumar Shrivastava, Mechanical Engineering Department, RGUKT-Basar who took keen interest on my project work and guided me all along, till the completion of my project work by providing all the necessary information.

REFERENCES

1. ASABE (2006), "Roll Over Protective Structures (ROPS) for Wheeled Agricultural Tractors", ASAE S383.1 FEB04 (SAE J2194 MAY89).
2. Ayers P, Davis G, Yantis J and Kerrigan S (2012), "Improving ROPS Designs for Agricultural Tractors", International Conference RAGUSA SHWA, September 3-6, Ragusa-Italy.
3. Carol Lehtola J, Charles Brown M and William Becker J (February 2008), "Roll Over Protective Structures (ROPS) for Tractors Used in Agricultural Operations", OSHA Standard 1928.51.
4. Dennis J Murphy and Dennis Buckmaster R (2003), "Roll Over Protection for Farm Tractor Operators", *Agricultural and Biological Engineering*.
5. Edward Fritz A, Case J I and Switalski William G (August 1992), "Small Agricultural Tractor ROPS – New Operator Protective Zone", SAE Techinical Paper Series 911782.
6. Gattamelata D, Laurendi V, Pirozzi M, Vita L, Puri D and Fargnoli M (2012), "Development of a Compact Roll Over Protective Structure for Agricultural Wheeled Narrow Track Tractors", International Conference RAGUSA SHWA, September 3-6, Ragusa-Italy.
7. Gillispie M Adam (2000), "Optimization of a Roll Over Protective Structure (ROPS) Using Nonlinear Finite Element Analysis".
8. Iyers D Paul (1997), "Roll Over Protective Structure (ROPS) Design for Pre-ROPS Tractors", *Journal of Agro Medicine*.
9. John Etherton, McKenzie E A Jr, Tim Lutz, Doug Cantis and Tsui-Ying Kau (2004), "An Initial Farmer Evaluation of a NIOSH Auto ROPS Prototype", *International Journal of Indurstrial Ergonomics*, Vol. 34, pp. 155-165.
10. OSH (2001), "Approved Code of Practice for Roll Over Protective Structures on Tractors in Agricultural Operations".
11. Saini Amandeep Singh (November-December 2013), "To Study Weld Strength and Strain Energy Absorption of Roll Over Protection Structure of an All Terrain Vehicle", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*.
12. Scarlett A J, Reed J N, Semple D A, Seward P C, Stockton A D and Price J S (2006), "Operator Roll Over Protection on Small Vehicles", Research Report 432.
13. Silleli Hasan (2007), "Research on Applying an Anchor Mechanism to Orchard and Vineyard Tractors Produced in Turkey", *Turk. J. Agrik. For.*, Vol. 31, pp. 389-398.

14. Stockton A D, Neill D H O and Hampson C J (2002), "Methods for Optimising the Effectiveness of Roll Over Protective Systems".

15. Thambiratnam D P, Clark B J and Perrera N J (2009), "Performance of Roll Over Protective Structure for a Bulldozer", *Journal of Engineering Mechanics*.

16. UMTRI-98-53 (November 1998), "The Dynamics of Tank – Vehicle Roll Over and the Implications for Roll Over – Protection Devices".