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Research Article

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Finite Element Analysis of Rollover Protective System on a Three-wheeler's Chassis

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Abstract

Rollover Protective System (ROPS) is one of the key components that is included in the chassis framework for the safety of the driver. The density and the Young's modulus of the material of ROPS need to be carefully considered for performing Finite Element Analysis (FEA) to minimize deformation and stress concentration near joints. The deformation, von Mises stress and strain contours are obtained for ROPS under static structural loading conditions simulating the dynamics of vehicular rollover and toppling in ANSYS. It was observed that the maximum deformation was obtained on the part of ROPS that came into contact with ground headfirst. Changes were made in the weldment material assignment till the deformation was reduced to permissible levels for both the cases, i.e., toppling and rollover. The modified deformation contour for toppling force produced a 64.5002% decrease in the deformation from 13.237 m to 4.6991 m. The modification in the material of the ROPS, specifically the use of default structural steel for reproducing the rollover force, has brought about a 64.5005% decrease in the deformation due to the rollover force from 12.163 m to 4.3178 m.

Keywords

Finite element analysis, Three-wheeler, Rollover protective system, Structural analysis

Introduction

Three-wheelers are beneficial in terms of fuel consumption rate and road traffic over the four-wheelers as they possess lightweight and narrowed track [1]. However, three-wheelers are more prone to rollover due to its reduced wheel and narrower track [1]. The National Highway Traffic Safety Administration, Department of Transportation, US has released Traffic Safety Facts annual report for the year 2020 which covers the data which indicates that 88,874 crashes out of 116,022 non-collision type accidents were occurred due to rollover [2]. Given the proclivity of three-wheelers to rollover and the role of the rollover factor in road accidents, it is critical to protect three-wheeler passengers from rollovers.

ROPS is a protective structure that is extended beyond the torso of the driver and is a part of the chassis geometry. A ROPS is included in the framework to account for the possibility of vehicular rollover and protect the driver from a fatal injury. These protective systems are especially required under challenging terrains like farmlands or mountains; and in vehicles that specialize traversal in these terrains i.e., tractors or SUVs.

FEA involved the use of breaking down complex geometrical figures into simple 2D planes called meshes and applying the required testing variables on each of these meshes individually to simulate the behavioral traits of the entire geometry. Wang et al. [3] and Yu et al. [4] have been referred for carrying out

finite element analysis of the ROPS I this work using student version of Ansys 2021 R2.

A systematic review of finite element analysis of a Three-wheeler chassis by Shukla et al. [5] revealed several static as well as dynamic loading conditions. Another study pertaining to the analysis of a Three-wheeler electric rickshaw for weight reduction revealed that by providing a rib at the neck ring can minimize stress concentration significantly and thereby effectively reduce the cost associated with the chassis [6].

The 3D computer-aided design model should be selected after careful inspection and failure analysis in ANSYS. Moreover, the ROPS should be made of a thicker weldment coupled with a higher factor of safety [7]. The chassis should employ proper corner treatment to minimize structural weight [8]. The node-to-node triangulation law should be followed for proper shock absorption by the weldment structure in case of accidents [9].

Experimentation

This section presents the geometry creation, meshing, and finite element analysis of the ROPS for two different scenarios. They are toppling and rollover of the vehicle.

Geometry creation and meshing

A Three-wheeler's SolidWorks model made by Kharatmul [10] was adopted for performing toppling and rollover analysis of the ROPS installed on the chassis using Finite Element Modeling.

The element of mesh model is of hexahedron type. The number of nodes and elements of the mesh are 40946 and 5585 respectively. Figure 1 shows the mesh model.

Boundary conditions

In this work, two different scenarios are considered for the analysis of the ROPS. They are toppling of the vehicle and rollover of the vehicle. Based on which the boundary conditions are given and discussed in this section.

Toppling instance analysis

AFor a static structural analysis, contours for total deformation, von Mises stresses and von Mises strain are analyzed for a uniformly distributed load of 4500N acting on the ROPS as shown figure 2 in case of a toppled vehicle.

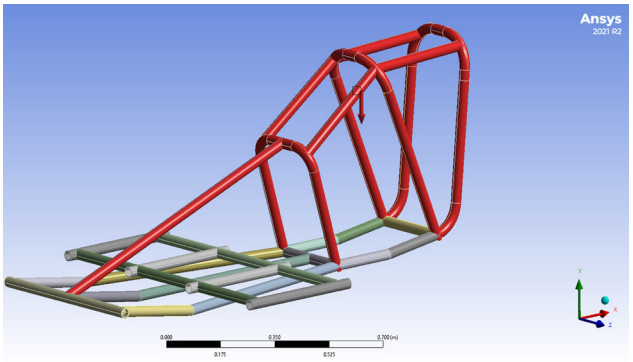

Figure 2: Toppling force on ROPS and adjoining elements.

For simulating explicit dynamics of vehicle crash test in Static Structural available in Ansys workbench, fixed vertices or fixed supports (at the base of chassis), must be provided in conjunction with uniform loading force [11]. Seven fixed supporting vertices are provided as shown in figure 3.

Rollover instance analysis

Another static analysis involving the application of force to the faces on the ROPS that come directly into contact with the ground to simulate the instance of rollover was reproduced with a uniformly distributed load of 5000 N acting in the positive z-direction as shown in figure 4.

Similar to the case of toppling of the vehicle, in this case too, the seven vertices have been made fixed as shown in figure 3.

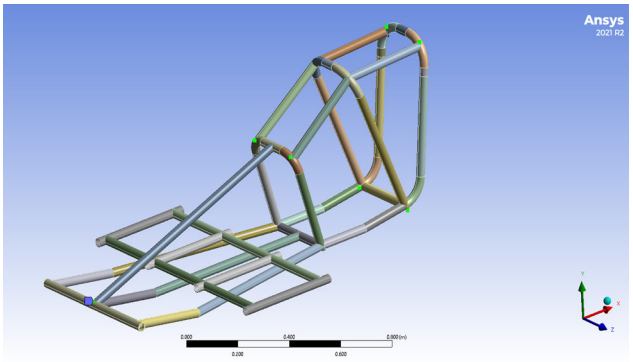

Figure 3: Fixed support vertex element variable for toppling analysis.

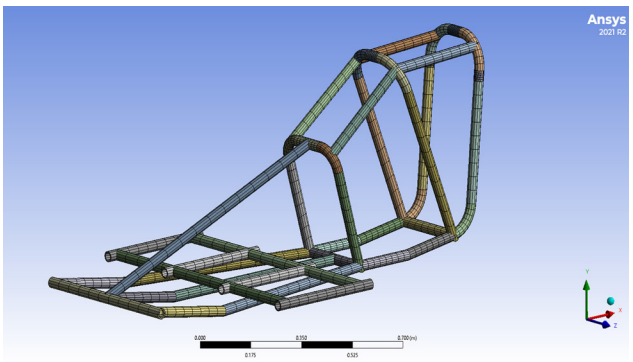

Figure 1: Mesh mode of chassis of the three-wheeler.

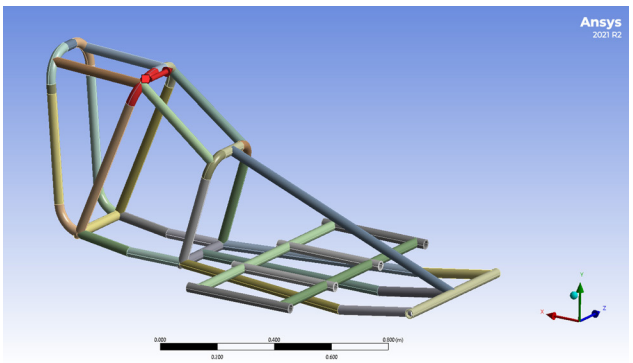

Figure 4: Rollover force on the contact interface of ROPS.

Results and Discussion

This section discusses the results obtained in terms of different parameters for two cases of analysis of the ROPS analysis. The cases analyzed were toppling of the vehicle and rollover of the vehicle. The parameters analyzed were deformation, von Mises stress, and von Mises strain.

Mesh convergence report

Mesh convergence has been performed for the given vehicle chassis by analyzing the total deformation for both the instances of toppling and rollover as shown in figure 5a and 5b. The figures show that as the number of nodes increases, total deformation gets converged.

Table 1 shows the number of nodes, number of elements, and total deformation for both the cases discussed in section on boundary condition corresponding to the different solution number shown in the first column of the table. As can be seen in the table, the difference between successive solutions after solution number four is significantly decreased. The mesh specification corresponding to solution number five is selected for further analyses.

Toppling of the vehicle

The force of 4500 N produced visible deformation on the ROPS installed on the three-wheeler as shown in figure 6a. The region of the ROPS that comes head-first into contact with the ground has undergone the most deformation.

As shown in figure 6b and 6c, respectively, the von Mises stresses and elastic strains, the contours developed a slight discoloration on the weldments attached to the base of the chassis. This is due to the strong reactive force at the base of wheels that results in the toppling of the vehicle.

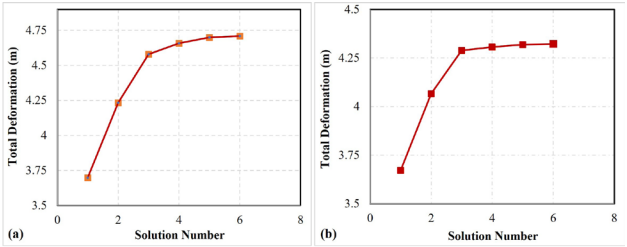

Figure 5: (a) Convergence graph for toppling analysis with modified ROPS deformation contour analyzed over Toppling force application and **(b)** Convergence graph for rollover analysis with modified ROPS deformation contour analyzed over Rollover force application.

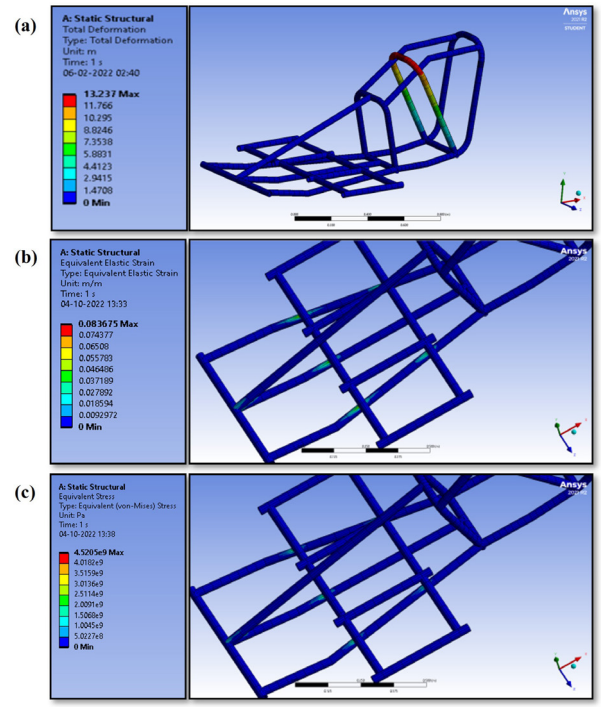

Figure 6: (a) Total deformation contour of ROPS in response to toppling force, **(b)** von Mises strain contour showing the strains at the base of chassis, and **(c)** von Mises stress contour showing the stresses at the base of chassis.

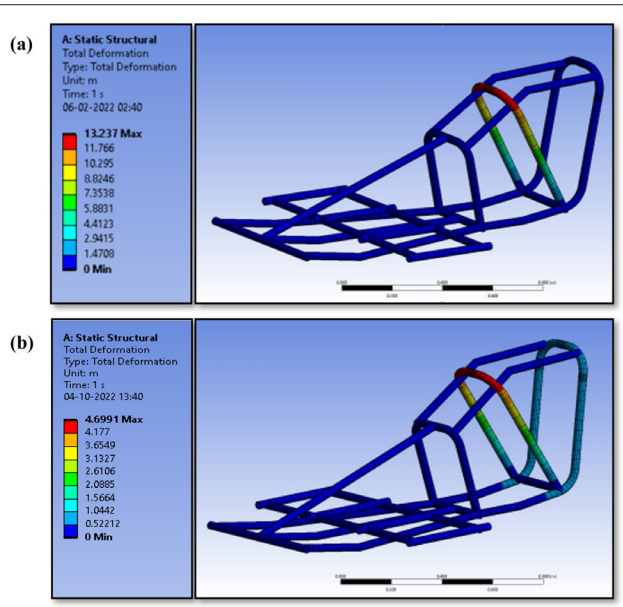

Figure 7: (a) Unmodified ROPS deformation contour and **(b)** Modified ROPS deformation contour analyzed over toppling force application.

Table 1: Data related to mesh convergence for the cases of both toppling and rollover.

Solution No.	Nodes	Elements	Total Deformation for the case of toppling (m)	Total Deformation for the case of rollover (m)
1	976	112	3.6991	3.6722
2	3561	486	4.2325	4.0658
3	10377	617	4.3788	4.2885
4	35250	2336	4.6169	4.3066
5	40946	5585	4.6991	4.3178
6	43994	5613	4.7084	4.3212

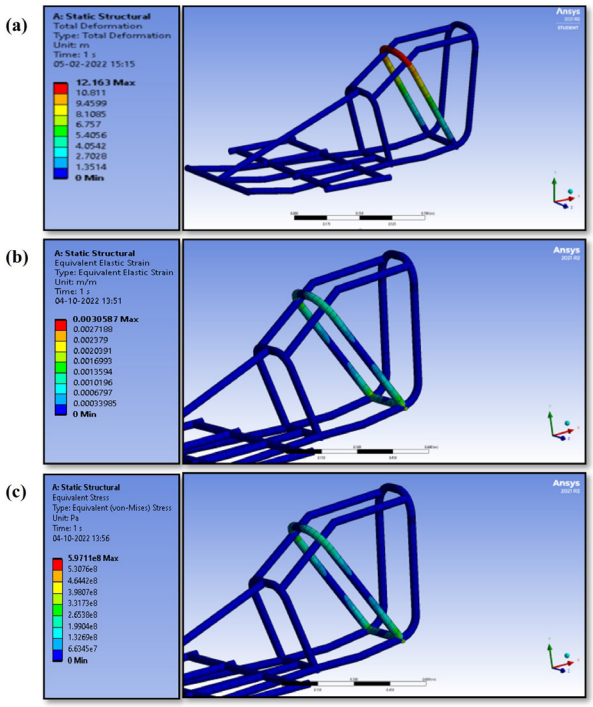

Figure 8: (a) Total deformation contour of ROPS in response to rollover force, **(b)** von Mises strain contour showing the strains developed on ROPS due to rollover, and **(c)** von Mises stress contour showing the stresses developed on ROPS due to rollover force.

In order to reduce the deformation of the ROPS, the part used on ROPS was altered to the default structural steel that is available in Ansys. The Young's modulus of the material is 2 x 1011 Pa and a mass density is 7850 kg/m^3 which is much higher than that of standard military grade MIL-HDBK-5H handbook aluminum alloy.

The modified deformation contour makes it evident that the toppling force produced a 64.5002% decrease in the deformation from 13.237 m to 4.6991 m. The deformation has become more distributed to other parts of the chassis, putting lesser load on ROPS and minimizing the risk of failure.

Rollover of the vehicle

A visible deformation was produced on the ROPS during the application of the Rollover instance force of 5000N that simulated Rollover condition. This deformation is a critical outcome that needs to be minimized for the safety of the driver.

As discussed previously, the material is changed to reduce the deformation of the ROPS.

As shown in figure 8a there is significant deformation on the ROPS as a result of vehicular rollover with the deformation contour showing a distinct red zone. Figure 8b and 8c, respectively show light discoloration of the ROPS weldment during the result evaluation of rollover parameters since most of the von Mises stress and strain are dissipated as reaction forces on the base of wheels.

Figure 9a shows the deformation contour after making the modifications along with the maximum deformation. As compared in figure 9a and 9b the modification in the material has brought about a 64.5005% decrease in the deformation due to the rollover force from 12.163 m to 4.3178 m.

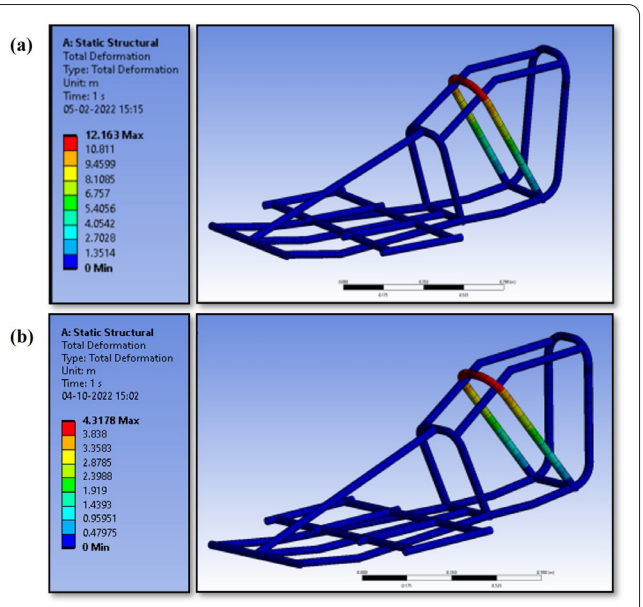

Figure 9: (a) Unmodified ROPS deformation contour analyzed over rollover force application and **(b)** Modified ROPS deformation contour analyzed over rollover force application.

Acknowledgements

None.

Conflict of Interest

We know of no conflicts of interest associated with this publication.

Credit Author Statement

Sudeep Nair: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft preparation; Ankitkumar Dandiwala: Conceptualization, Methodology, Writing - review and editing, Supervision; Debashish Chakravarty: Supervision; Basab Chakraborty: Supervision. All the authors read and approved the manuscript.

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