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Design and Analysis (Static) of the Roll Cage for an All-Terrain Vehicle (ATV)

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Abstract

This research paper deals with the design consideration and fabrication of the Roll Cage. Roll Cage designing is very important part of building an All-Terrain Vehicle (ATV). The vehicle must sustain all the stresses subjected on it in all types of terrain to give off-roading enthusiast the thrill he desires. Along with this the Roll Cage must be light in weight in order to increase the efficiency of the vehicle. Vehicle must be cost effective, so cost of designing, fabricating and rework is kept to minimum.

Keywords: *Roll-Cage, ATV, Design, Fabrication.*

1. Introduction

Roll Cage is the supporting structure of an ATV. Its prime function is to create a 3D protective space around the driver. It must have adequate strength to absorb impact stresses acting on it. Roll Cage must also provide mounting points for all other subsystems like Drive train and Suspensions. Proper material selection is of great significance in order to increase strength and reduce weight and cost of Roll Cage, eventually increasing efficiency of an ATV. Design and Analysis of the Roll Cage was done using Solidworks, 2016.

2. Literature Review

(R Bhandari et al, 2014) used AISI 1080 with Young's Modulus 210 GPa; yield strength is 365.5 MPa and Poisson's ratio 0.29. The density of material is 8000 kg/m3 with hardness (Brinell) of 126 HB. The Roll Cage is developed in ANSYS Multiphysics menu by plotting lines, keypoints, arcs. The element type selected is PIPE 16, a uniaxial element with torsion, tension and bending capabilities. G-Force method is used to calculate force.

(Khelan Chaudhari et al, 2013) considered factors like strength, bending stress, machinability, cost, availability, etc. while selecting material. After surveying they choose AISI 1026 as it is low in cost and also have good strength. A model is developed on Pro-engineer and tested in Autodesk Multiphysics. Newton's 2nd law of motion is used for Force calculation.

(Bharat Kumar et al, 2016) have chosen ERW2 steel pipes for fabrication of Roll Cage. They adopted it because of its high yield strength. Also considering the fact that it is easily available and low in cost compared to other materials. They designed the model in CATIA V5 and analysis in ANSYS 14.5. The main purpose of designing is to optimize to maximum strength and minimum weight. Work Done method is used for force calculation.

(Denish Mevawala et al, 2014) have selected the material ST-52 and used ANSYS for designing and analyzing. They have used the model to withstand the impact, torsion, roll-over conditions and provide a great amount of safety to the driver without subjected to deformation. G-Force method is used for Force calculation.

A prominent amount of literature which has been published and reports have been viewed for this topic. There have been about 190 technical papers since 1983 regarding fatal accidents caused while driving ATV.
In the year 2018, Insurance Business from Canada presented a breakdown of the 178 deaths. Among which, 44 of the deaths were caused due to the vehicle hitting the obstacle, 42 deaths due to vehicle

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rollover and 21 deaths occurs by the vehicle hitting another vehicle. Rest of the accidents took due to external factors such as bad weather, alcohol consumed, etc.
Delta-V Experts team worried on Simulation of quad bike in rollover circumstances in order to reduce number of accidents.

3. Design Methodology

Important steps for designing are as follows:

3.1 Prototype Construction:

We built the prototype of the Roll cage which satisfied all the rules and safety precautions laid down by the Society of Automotive Engineers. Prototype was constructed using the Polyvinyl Chloride (PVC) pipe. Body dimensions of the driver were also taken care off in order to provide him convenient exit from the vehicle incase of an emergency.

Fig.3.1: Prototype

3.2 Material Selection:

Material selection is very important factor as it directly affects total cost and weight of the vehicle. So, after extensive market survey considering our requirement, budget and availability we shortlisted following two materials:

Table 1: Materials

Properties	AISI 1018	AISI 4130
Density (gm/cc)	7.87	7.85
Young's modulus (GPa)	200	205
Tensile strength (MPa)	440	670
Yield Strength (MPa)	370	460
Elongation (%)	15	25.5
Strength to Weight ratio (KN-m/kg)	55 to 60	72 to 95
Brinell Hardness	140	200
Cost (Rs/m)	250	450

As the driver safety was the first priority, we chose AISI 4130 over AISI 1018. Though it was costly, it had better strength properties than AISI 1018, which compensated for its cost.

3.3 CAD Model:

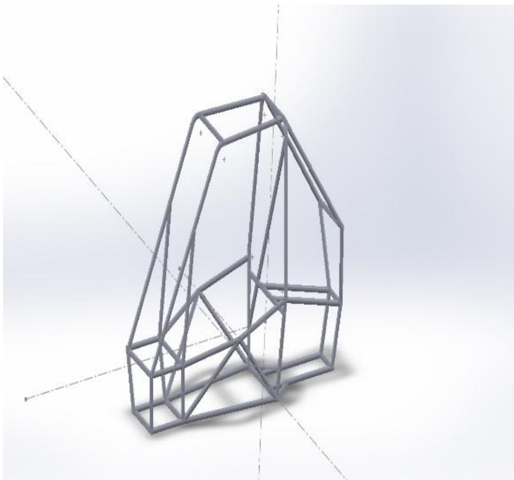

Fig.3.3.1: Design of Roll Cage on CAD

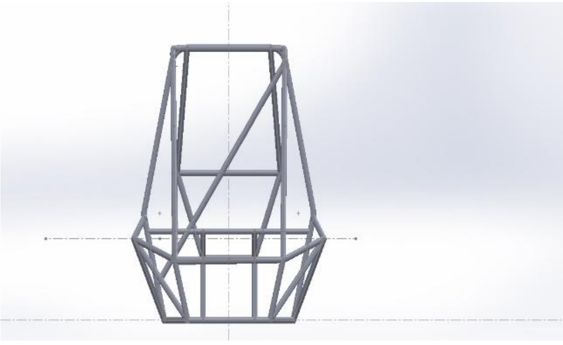

Fig.3.3.2: Front View of Roll Cage

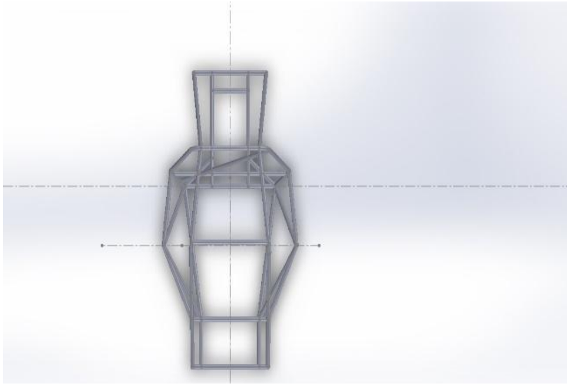

Fig.3.3.3: Top View of Roll Cage

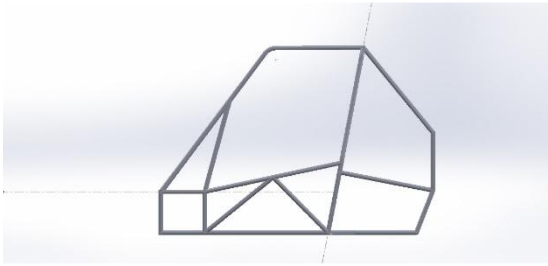

Fig.3.3.4: Side View of Roll Cage

3.4 Impact Test [Calculation, Analysis Images and Result]

3.4.1 Front Impact Test

Most of automotive fatal injuries and death took place due to head long or frontal crashes. So, to reduce this to happen again, every automobile must go under Frontal Impact Test. This test assured us how well protected is the occupant in head on collision. The Analysis Test is done in Solidworks,2016.

3.4.1.1] Impact Force Calculation

For perfectly inelastic collision, we use Work-done Method.

Work (W) = Kinetic Energy (KE)

Work done during Impact is equal to change in Kinetic Energy.

W = Δ KE
W= $KE_{Final} – KE_{Initial}$

Now, KE_{Final} = 0
Since Velocity after impact is V_{Final}= 0 m/s.
Hence W=$|KE_{Initial}|$= 0.5 * m * $v_{Initial}^2$
where m= mass of vehicle = 270 kg
$V_{Initial}$=60 km/hr =16.67 m/s.
Hence, Work-done = 37515.005 J.

Displacement = Impact time * velocity
Impact time = 0.15 sec
Displacement(s) = 2.5005m.
Force = W/s
Hence Force = 15000N.

3.4.1.2] Front Impact Analysis

CONSTRAINTS: Rear corners suspension mountings.

Loading: F = 12000N on Front Corner.
Boundary Conditions:
Symmetry (Plane normal to Z-axis)
Suspension Mounting Points U_y=U_z=0
Rear Corner Points
All DOF=0

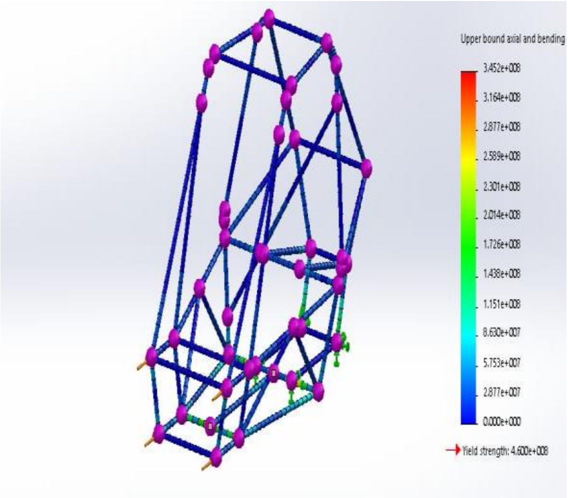

Fig 3.4.1: Front Impact Analysis

Result:

Maximum Deformation: 5mm and it is within the permissible limit.
Maximum Stress Induced = 345.5 MPa
Incorporated FOS = σ_{yt}/σ_{max}
= 460/345.5
= 1.33.

3.4.2 Rear Impact Test

A rear end collision took place mostly during traffic where a vehicle collides violently into the vehicle in front of it.
Factors that led to this collision include driver's distraction or due to sudden fear.
3.4.2.1] Impact Force Calculation

Work done during Impact is equal to change in Kinetic Energy.

W = Δ KE
W= $KE_{Final} – KE_{Initial}$

Now, KE_{Final} = 0
Since Velocity after impact is V_{Final}= 0 m/s.
Hence W=$|KE_{Initial}|$= 0.5 * m * $v_{Initial}^2$
where m= mass of vehicle = 270 kg
$V_{Initial}$=60 km/hr =16.67 m/s.
Hence, Work-done = 37515.005 J.

Displacement = Impact time * velocity
Impact time = 0.15 sec
Displacement(s) = 2.501m.

Force = W/s
Hence Force = 15000N.

3.4.2.2] Rear Impact Analysis

CONSTRAINTS: Front corners suspension mountings.

Using the projected vehicle/driver mass of 270kg, the impact force was calculated based on a G load of 4. Hence,

4G=4*m*a=4*270*10=10800N
Take F=11000N.

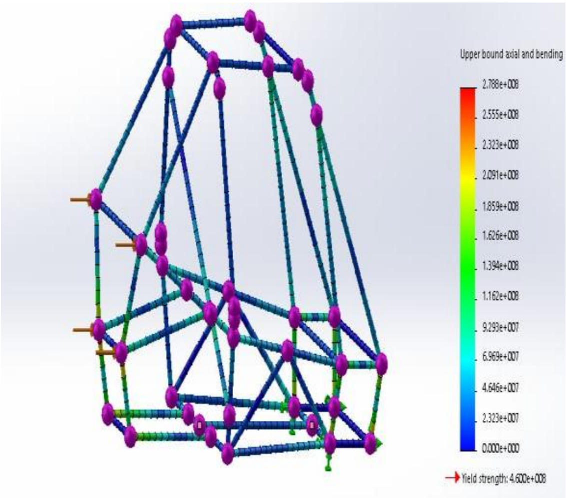

Fig 3.4.2: Rear Impact Analysis

Result:

Maximum Deformation: 6.58mm and it is within the permissible limit.
Maximum Stress Induced = 278.8 MPa
Incorporated FOS = σ_{yt}/σ_{max}
= 460/278.8
= 1.64.

3.4.3 Side Impact Test

Side collision occurs when other vehicle clash to the side of the vehicle from front or rear resulting a 'T' shape. The problem concerns about the vehicle and the occupant. Both may undergo serious issue.

3.4.3.1] Impact Force Calculation

Work done during Impact is equal to change in Kinetic Energy.

W = Δ KE
W= $KE_{Final} - KE_{Initial}$

Now, $KE_{Final} = 0$
Since Velocity after impact is $V_{Final}= 0$ m/s.
Hence W=$|KE_{Initial}|= 0.5 * m * v_{Initial}^2$
where m= mass of vehicle = 270 kg
$V_{Initial}$=60 km/hr =16.67 m/s.
Hence, Work-done = 37515.005 J.

Displacement = Impact time * velocity
Impact time = 0.3 sec
Displacement(s) = 5.01 m.

Force = W/s
Hence Force = 7500 N.

3.4.3.2] Side Impact Analysis

CONSTRAINTS: Opposite SIM members.

Using the projected vehicle/driver mass of 270 kg, the impact force was calculated based on a G load of 3. Hence,

3G=3*m*a=3*270*10=8100N.

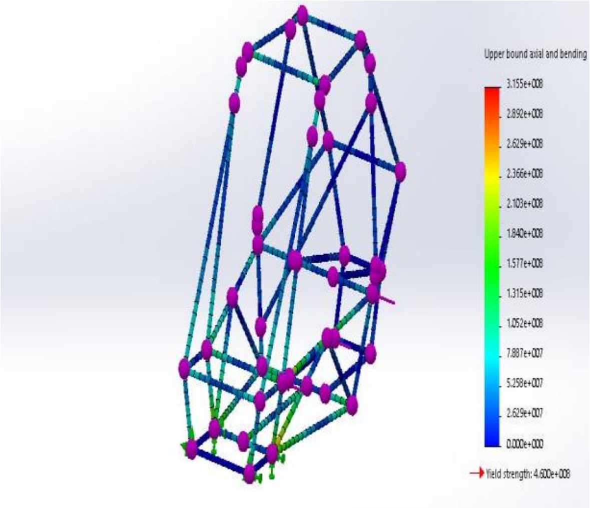

Fig 3.4.3: Side Impact Analysis

Result:

Maximum Deformation: 7.55mm and it is within the permissible limit.
Maximum Stress Induced = 315.5 MPa
Incorporated FOS = σ_{yt}/σ_{max}
= 460/315.5
= 1.5.

3.4.4 Roll-Over Impact Test

Roll-over crash categorized as tripped and untripped. Tripped roll-overs crashes happen due to the force from another vehicle. Untripped roll-overs crashes took due to speed, steering input, etc.

3.4.4.1] Roll-Over Analysis

CONSTRAINTS: Front and Rear suspension joints.

Using the projected vehicle/driver mass of 270 kg, the impact force was calculated based on a G load of 3. Hence,

3G=3*m*a=3*270*10=8100N.

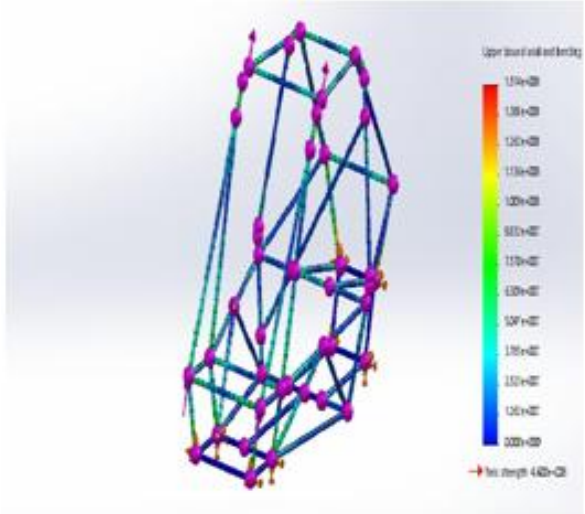

Fig 3.4.4: Roll-Over Analysis

Result:

Maximum Deformation: 6.33mm and it is within the permissible limit.
Maximum Stress Induced = 151.4 MPa
Incorporated FOS = σ_{yt}/σ_{max}
= 460/151.4
= 3.

4. Conclusion

The objective of designing of ATV Roll cage by performing structural analysis on ATV frame considering mainly the safety of the driver during any crash or accident seems to be achieved. Engineering principles and design process are used to make sure and generate a vehicle with less weight but rigid and compact structure. The design process includes the use of Solidworks,2016 software to model, simulate and assist in the analysis of the completed vehicle. Other automotive systems like transmission, suspension, steering and brakes get integrated with the roll cage to form an All-Terrain Vehicle (ATV).

Acknowledgement

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