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Design and Analysis of the Roll Cage of an ATV

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***Abstract*—The Roll cage is the most essential part of an ATV. It is like a 3-dimensional protection provided to the driver which is very crucial in determining the shape of the overall vehicle. It is the roll cage which bears the weight of all the systems like power terrain, suspension, steering and braking. The roll cage designed here is in accordance with SAE BAJA 2018 rulebook. Now SAE stands for society of automotive engineers and BAJA is their official competition where Engineering undergraduates try to design and build an ATV which is also market ready.**

Keywords— Roll cage designing, static structural analysis, structural tests, impact force calculation

INTRODUCTION

The roll cage acts as a support for attaching all the systems (braking, suspension etc) for the vehicle so it has to be strong. While designing the roll cage of an ATV the various factors to be considered which includes compact design, ergonomics, durability, ease while manufacturing and light weight. Now before starting the design it is important to consider the various possible failures. Aru et al., 2014[1],Noorbhasha,N., 2010[2] and Raina et al., 2015[3] have done static analysis for predicting the modes of failure of the roll cage. This paper includes all the possible crash condition and these conditions are analysed in static conditions. For dynamic conditions Bharat et all .,2016[4] have done analysis of roll cage in dynamic conditions.

In this paper we will begin with design and then we will go onto analysis of the roll cage. While designing all the key points will be mentioned along with the reasons for choosing the particular design. In analysis load is being calculated using usual energy theorems and no assumptions are taken while calculating the force on the roll cage in different conditions. The mesh used while analysis is of optimum size and is same for all conditions in the research.

1. Design

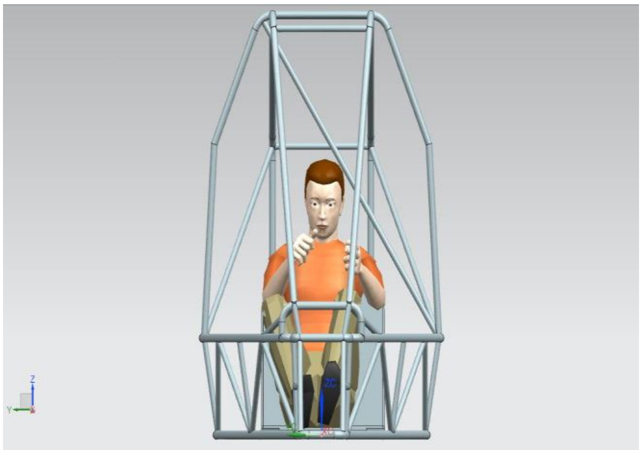
For designing the roll cage of the ATV several software's are available and it's up to you which software you choose. I used Siemens NX 10 software developed by Siemens. Before starting on the software I recommend sketching it on a rough paper. Get your team together and note down all the ideas that are floating in your mind. The key points while sketching your design could be as flows:

1)Avoid sharp edges as much as possible. Sharp edges have a higher stress concentration on its surface and this decreases the overall strength of the vehicle.
2) Check for the ergonomics of the driver as the whole body of the driver should always be inside the cage and sufficient spaces should be left to achieve that.

3)The vehicle shouldn't be too long. In our case we were building the ATV for a competition so we were given a maximum value.

Now once you are done with the sketching and have few sketches to design. Model them on the software. Always keep the weight is mind because the overall weight of the vehicle should be as low as possible. Now to keep the weight to a minimum we used variable thickness for the tubes. We kept the thickness of primary member as 4mm and secondary members had a thickness of 3mm. this way we reduced the weight and didn't compromise much on the strength of the vehicle. We also recommend working with triangles especially for side members. The advantage of using triangle shaped side members is that they are able to take more load than the usual straight or any other shaped side member. Always try to reduce space where ever you can this could help you in reducing the weight of the roll cage.
After several iterations my team and I came up with this final design.

Front View



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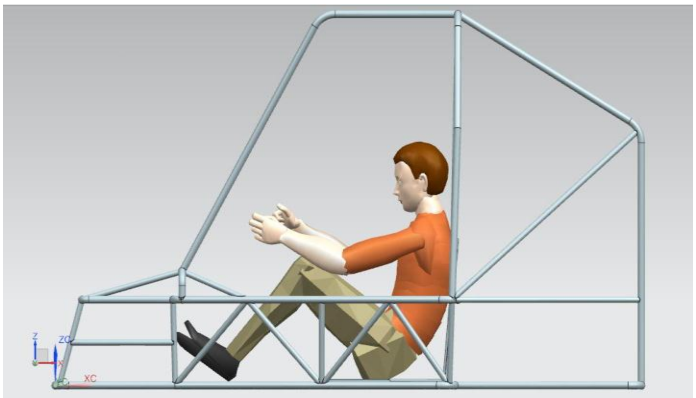
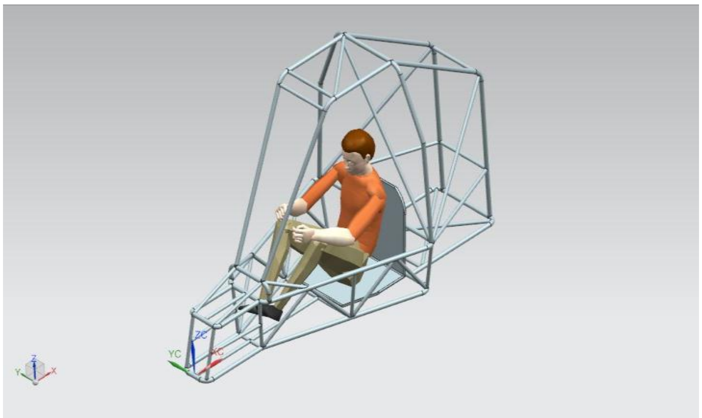
Side view



Isometric view



Basic dimension of the above shown frame are as follows:

Attributes	Values
Length	2250mm
Width	935mm
Wheelbase	2190mm
Weight(with driver)	249.5kg
Weight(Roll cage)	37kg
Height of CG	560mm
Height	1300mm

1. Material property

There are a number of materials available in the market which can be used for the material of the roll cage. These include AISI 1018, AISI1026, AISI1040 and AISI 4130. Following are the material properties for the above mentioned materials.

Property	AISI 1018	AISI 1026	AISI 1040	AISI 4130
Yield Tensile Strength	370 Mpa	415 Mpa	415 Mpa	440 Mpa
Ultimate Tensile Strength	440 Mpa	490 Mpa	620 Mpa	560 Mpa
Modulus of Elasticity	205 Gpa	210 Gpa	210 Gpa	190 Gpa
Poissions Ratio	0.290	0.300	0.300	0.290

You can select the material on the basis of Yield strength. Once you have sorted the material for the roll cage you can begin the analysis of the roll cage.

2. Analysis

The analysis of the roll cage can be done on various software's available so you can select by your own convenience but I would suggest you to choose either Ansys or Nastran. We used Ansys structural analysis and conditions were static. The tests which were conducted are as follows:

- Front impact test

  Few approximations were taken

  Weight=300kg

  v(initial)=16.67m/s

  v(final)=0

  Impact time=0.13sec

  Work done=|-0.5Mv|

  =|-0.5x300x(16.67)^2|

  =41683.33Nm

  Work done=Fxd

  d=t*v(initial)

  =0.13x16.67

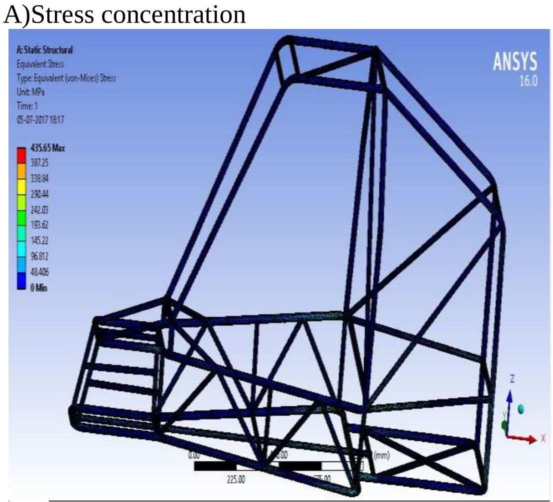
  =2.1671m

  F=41683.33/2.16

  =20841.66N

Now this is the impact force applicable on the front of the roll cage and by ansys we came with the following results:

A)Stress concentration



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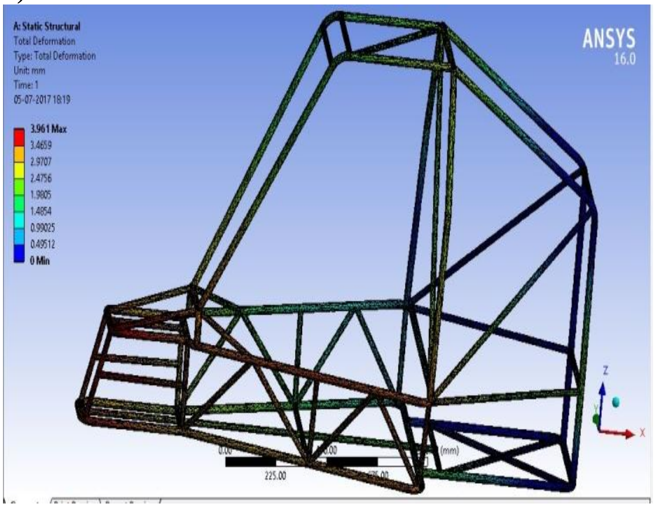
B) Total deformation



Front impact	21000N
FOS	1.90
Total deformation	3.9978mm
Maximum stress	437.61/2=218.80Mpa

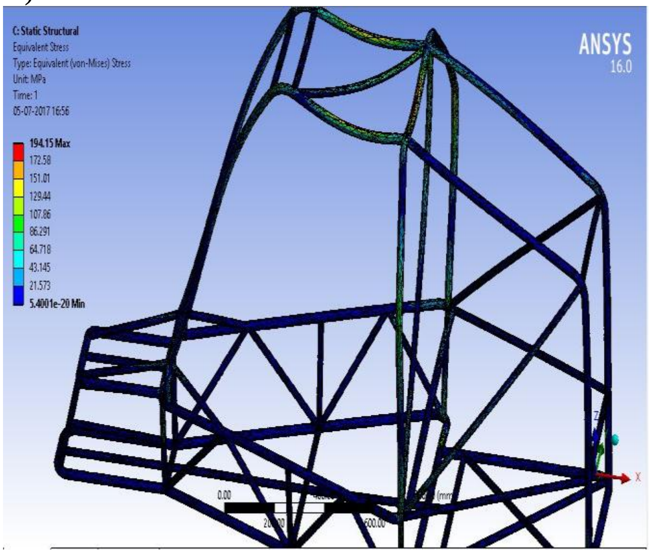
FOS stands for factor of safety and it's suitable to have a FOS of 1.5 or above. We took impact force as 21000N and got a max stress concentration of 218.80Mpa. We took the tube material as AISI 1026 so all the calculations are done with respect to that.

FOS=yield strength of the material/max stress
=415/218.80
=1.90

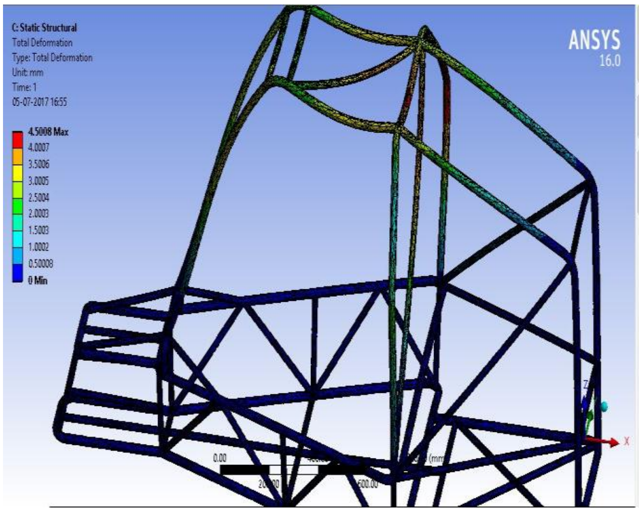
- Roll over test

Here we basically test how much stress the roll cage can take in an inverted fall. During fall the overall potential energy will be converted into kinetic energy hence;
M*g*h=0.5*M*(v^2)
v=$\sqrt{(g)} \times h \times 2$
assuming the height of the fall to be 10 feet
10ft=3.048m
v=7.733m/s
Just substitute this v in the work done equation and find out work done.
Work done=8969.59J
impact time(t)=0.13sec
d=t*v
d=1.005m
Now follow the same steps as in front impact test and find out F.
F=8925.26
F≅9000N

A)Maximum stress concentration



B) Total deformation



Impact	9000N
FOS	2.1375
Maximum stress	194.15Mpa
Total deformation	4.008mm

The FOS of this case is also calculated by following the same steps as in case of front impact test.

- Side impact test

Here we will test how much stress the roll cage can take from sideways.

Impact time (t) =0.30sec
Velocity(v)=16.67m/s
Again by same method we have calculated the work done.
Work done=41683.335J
d=v*t
d=5.001m
F=work done/d
F=8335N
F≅9000N

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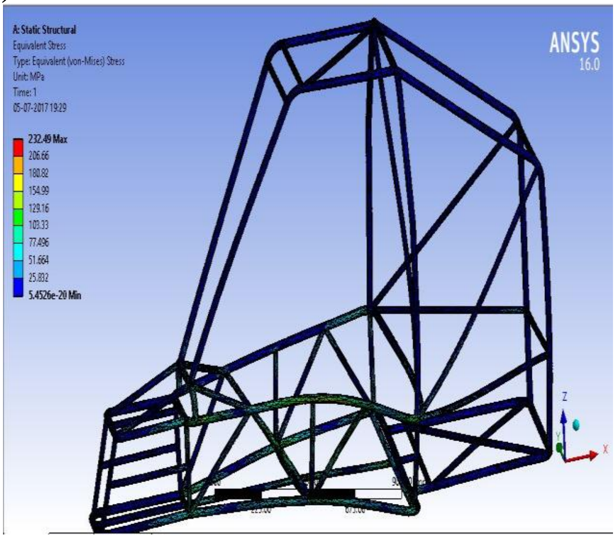
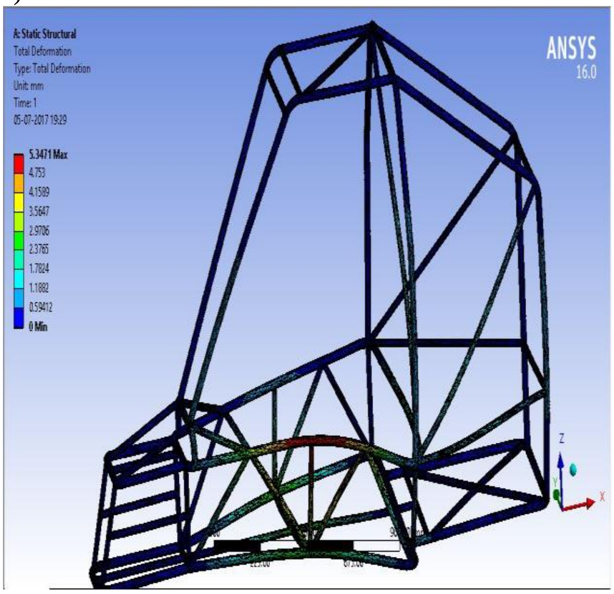
A) Maximum stress concentration



B) Total deformation



Side impact	9000N
FOS	1.78
Maximum stress	232.48Mpa
Total deformation	5.374mm

The steps for calculation of the FOS are again the same.

- Rear impact test

Here we test how much stress the rear part of the roll cage can take.

Impact time(t)=0.30sec

v=16.67m/s

work done is again calculated y same method and is 41683.33N

d=t*v

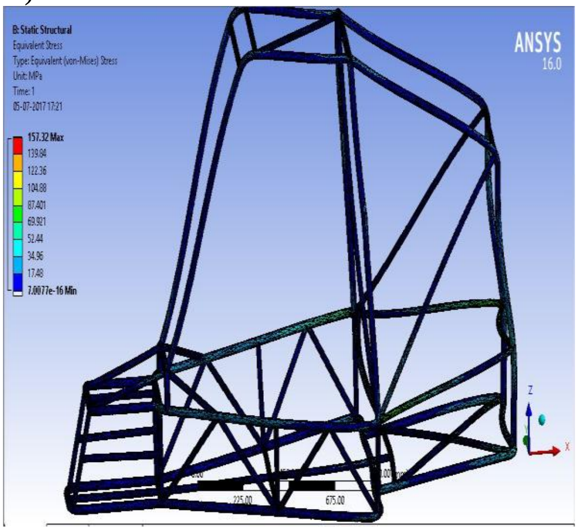
d=5.001m

F=work done/d

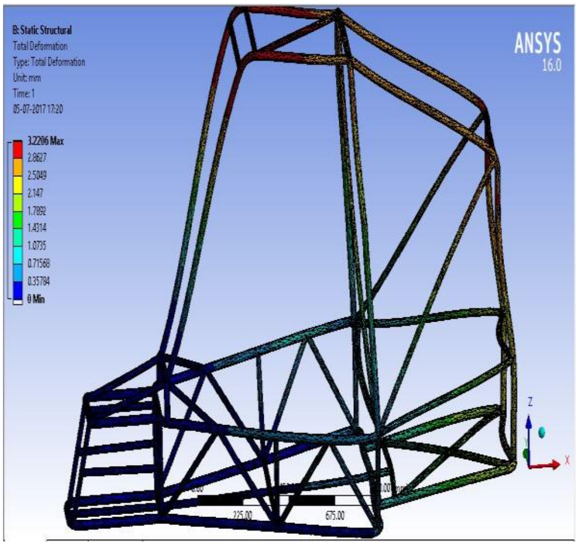
F=8335N

F≅9000N

A)Maximum stress concentration



B)Total deformation



Rear impact	9000N
FOS	2.63
Maximum stress	159.32Mpa
Total deformation	3.22mm

The FOS calculation method remains the same.

3. CONCLUSION

This paper explores the ways of designing the roll cage of an all terrain vehicle and also sheds on possible key points kept in mind for designing. You can also find analysis results in this paper along with their respective results and formulae used. During the static analysis of the roll cage the design of the roll cage was changed several times in order to obtain a higher FOS. A higher value of factor of safety insures the durability of the roll cage in the most extreme conditions and hence makes the roll cage safe in terms of production.

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