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Design and Optimisation of Roll Cage of a Single Seated ATV

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Abstract: *An all-terrain vehicle (ATV), also known as a quad, quad bike, three-wheeler, or four-wheeler, is defined by the American National Standards Institute (ANSI) as a vehicle that travels on low-pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control[1]. Roll cage is the skeleton that encapsulates the driver and serves as a protection. It becomes mandatory for manufacturers to ensure customers' safety, which in turn is dependent on a robust and sturdy construction of the roll cage. Physical prototyping done to ensure this was costly and hence cleared way for virtual prototyping which involves computer aided design and analysis. This does not involve manufacturing prototypes and hence reduced the cost. Constraints and loading conditions are applied at locations as per the standards and the analysis results are used for determining the real life performance of the roll cage. Though there are several constraints in designing, some of the dimensions are left to the mercy of the designer. In this paper, two of such dimensions are taken and analyzed to arrive at the optimum dimension and checked for final feasibility.*

Keywords:*Finite Element Method, Linear Static Analysis, Stress analysis, Structural Analysis, Vehicle Chassis*

I. Introduction

The preliminary design was started keeping in mind, the constraints laid by BAJA SAEINDIA. The BAJA SAEINDIA Rulebook 2015 was taken into account for designing the roll cage. Cylindrical pipes are used for designing all members of the roll cage. The roll cage was designed in CATIA V5 R19 wherein the pipes were represented by their centre lines. The geometries of cross sections weren't taken into account for the initial design in CATIA. The base model was finalized and it was subjected to different tests in CAE software Altair HyperWorks. For simplicity's concerned, 1D static analysis was performed until the design is finalized and the finalized design was subjected to 2D static analysis with similar loading conditions as that of the 1D static analysis, and the difference between them being the fact that it takes into account, the cross sectional dimensions of the roll cagemembers directly thus giving more accurate results than the former.The dimensions which are not constrained directly or indirectly are iterated and the design with the lowest deformation and stresses is selected as the optimum design. The finalized design is then converted to 3D representation as cylinders in SolidWorks 2013 software and checked for weight constraints given in BAJA SAEINDIA 2015 Rulebook.

II. Design Constraints

The following constraints were given in the BAJA SAEINDIA Rulebook and the values we have taken have been tabulated against the constraints for verification purposes.

Primary Constraints

Member	Parameter	Rulebook constraint[2]	Actual Values taken
ROLL CAGE (PRIMARY)	Tube Outer Diameter	Minimum 25.4 mm	25.4 mm
	Tube thickness	Minimum 3 mm	3 mm
ROLL CAGE (SECONDARY)	Tube Outer Diameter	Minimum 25.4 mm	25.4 mm
	Tube thickness	Minimum 0.89 mm	0.89 mm
Total Length		Maximum 274 cm	217.9 cm
Total Width		Maximum 162 cm	88.9 cm

Table 1

Secondary Constraints

Member	Parameter	Rulebook Constraint[2]	Actual Values
Lateral Cross Member (LC)	Length	Minimum 203.5 mm	330.2 mm
Rear Roll Hoop (RRH)	Width 686 mm above seat bottom	Minimum 736 mm	750.451 mm
	Inclination	Maximum 20 degree	10 degree
Rear Roll Hoop Lateral Diagonal Bracing (LDB)	Intersection at the top	Maximum 127 mm from the top	100.056 mm
	Intersection at the bottom	Maximum 127 mm from the bottom	100.056 mm
Angle between LDB and RRH		Greater than or equal to 20 degree	38.696 mm
Side Impact Member (SIM)	Height from the Seat's upper surface	203 mm to 356 mm	330 mm
Front Bracing Member (FBM)	Angle with Vertical	Maximum 45 degree	35.786 degree

Table 2

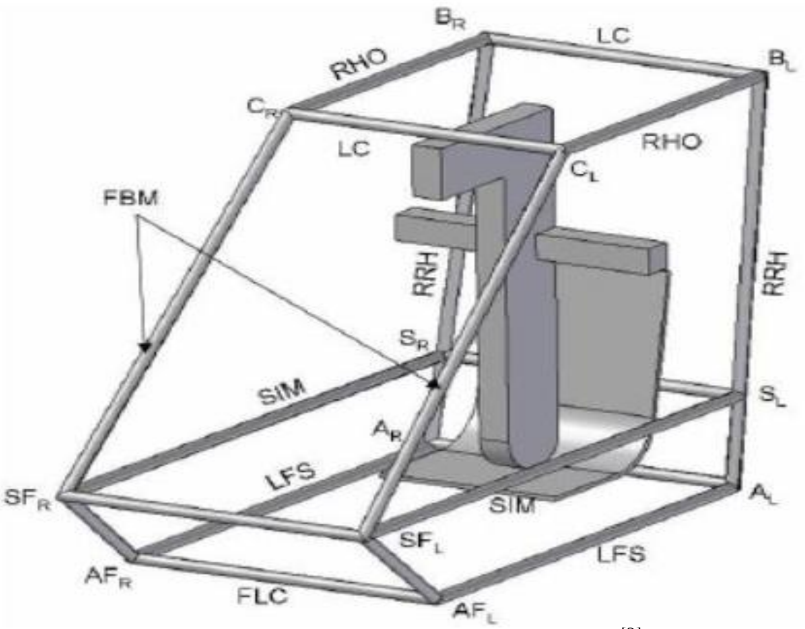


Fig 1 Base Template given in the rulebook [2]

Design of Roll Cage

With the above constraints in mind, the base model was designed in CATIA V5R19. The centre lines are used to represent the member which will later be converted to proper 3D representation in SolidWorks 2013.

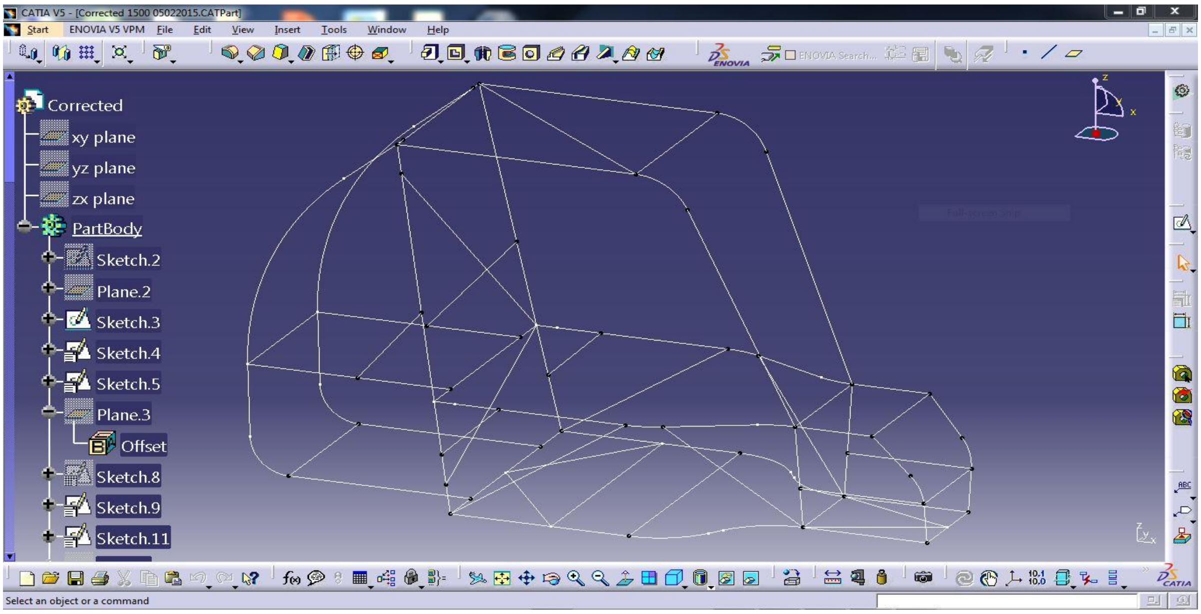


Fig 2

This line data was imported into Altair HyperWorks 12 and was analysed for deformation and stresses under different loading conditions as follows.

III. Analysis Of Roll Cage

The initial analyses were performed on 1D elements which neglects the cross section dimensions and is hence less accurate. So, 2D static analyses were performed on the same roll cage with tria and quad elements in Altair HyperWorks.

3.1 Analytical calculation for frontal Impact

The required force that is to be applied is calculated as follows
Assuming mass of roll cage, m= 300Kg
Initial velocity before collision =60kmph=16.66m/s[2]
Final velocity after collision=0m/s
Collision time=0.1s
The change in kinetic energy D.K.E=Work done W= Impact force× displacement ...(1)
Change in kinetic energy: D.K.E=$^1/_2$×m $[v^2 - u^2]$=41633.34 J ...(2)
Impact force= D.K.E/Displacement ...(3)
Displacement: $s = ut + {}^1/_2 at^2$ ...(4)
From v=u +at, a=-166.6m/s^2 , s =0.8327m ...(5)
Impact force = 41633/0.8327
Impact force= 49,998 N
Force imposed on one node= 12,500N

3.2 Preprocessing in CAE software

To perform 2D static analyses, mid surface was drawn above the centre lines that were drawn earlier.

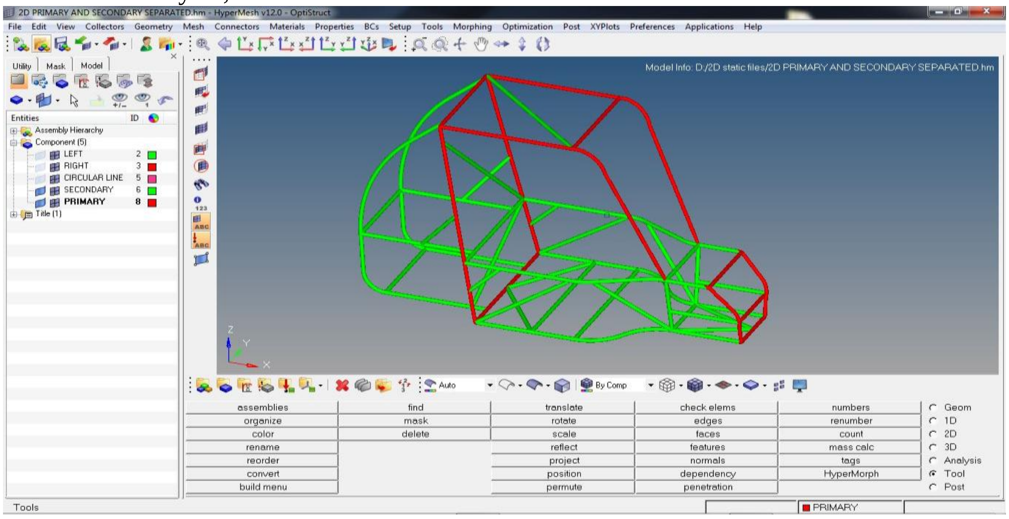


Fig 3

The different colours indicate different cross sectional dimensions, with the red coloured pipe being thicker than the green one as presented in Table 1. This surface is meshed with a mesh size of 3 and using mixed elements (trias and quad)

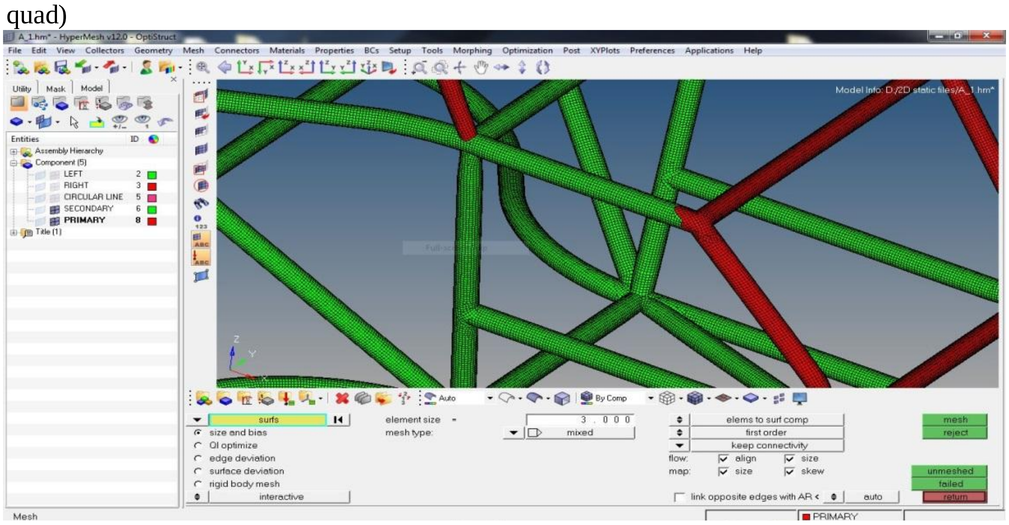


Fig 4

IV. Results of Analysis

Following are the results of the analyses performed. The picture on the left indicates the loading condition and the constraints applied and the picture on the right indicates the result of the respective analysis.

4.1 Front Impact test

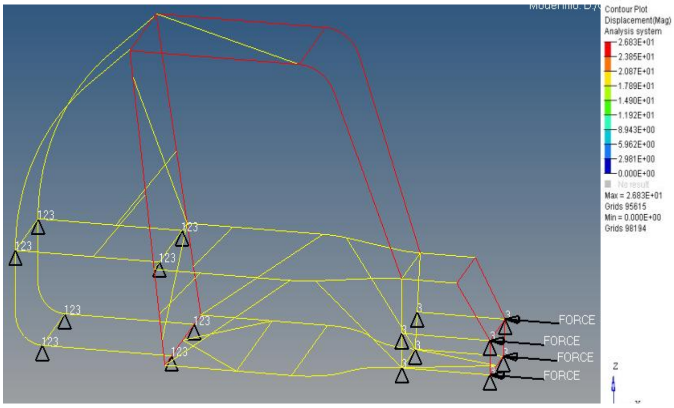


Fig 5

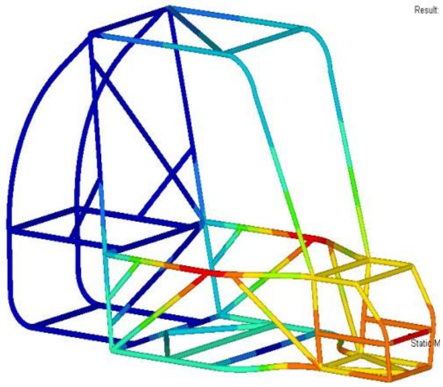


Fig 6

4.2 Torsion Test

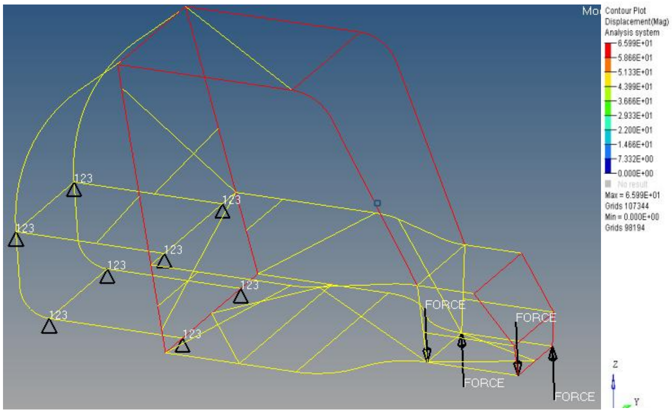


Fig 7

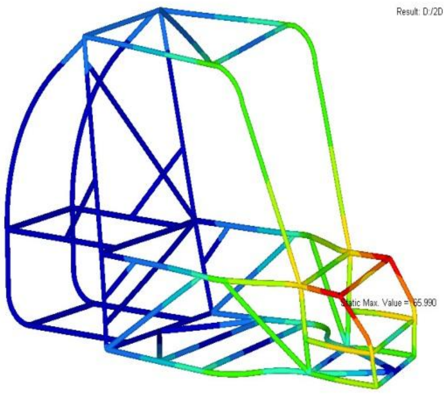


Fig 8

4.3 Front Bump Test

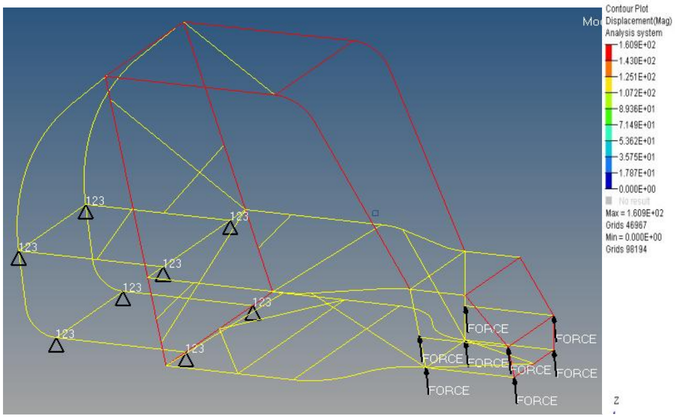


Fig 9

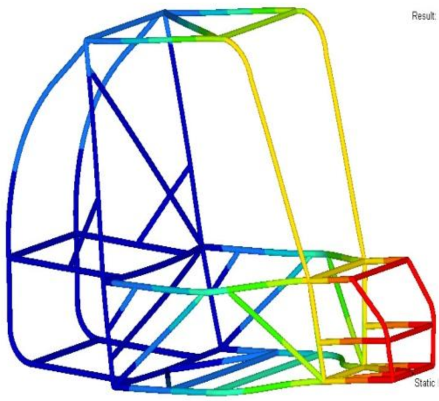


Fig 10

4.4 Roll Cage Roll Over Test

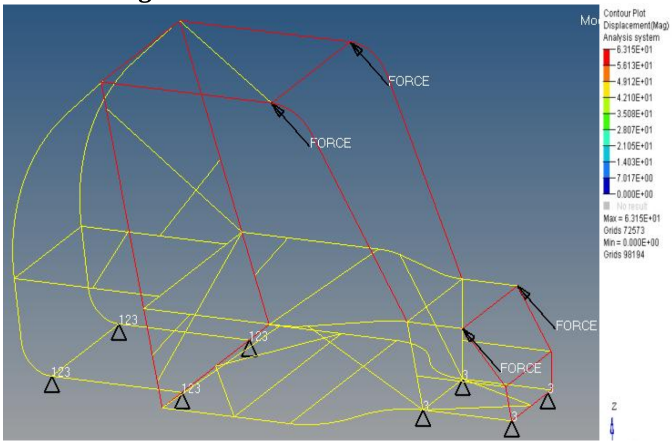


Fig 11

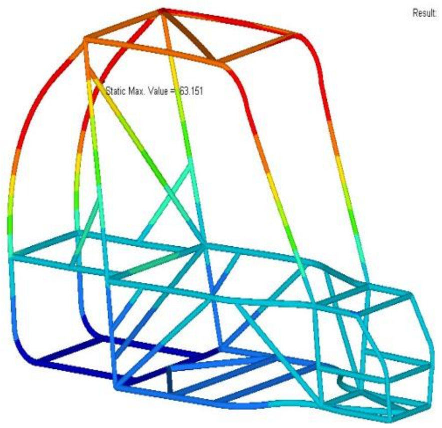


Fig 12

4.5 Side Impact Test

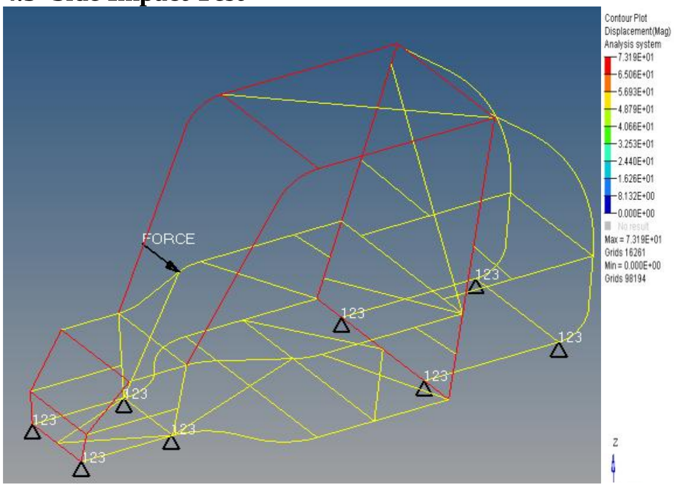


Fig 13

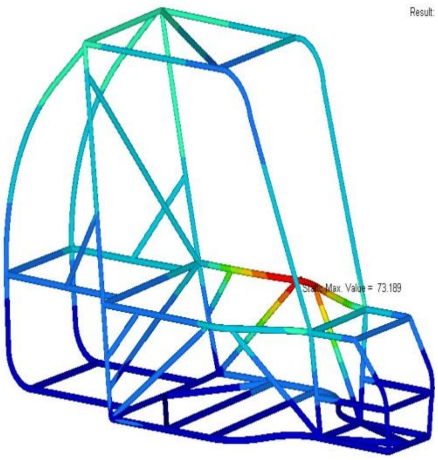


Fig 14

4.6 Tabulation of results

The results of the analyses were interpreted and is represented in the following table

Test	Applied load (N)	Maximum Deformation(mm)	Maximum Stress (MPa)	Yield Stress of material (AISI 1018 steel)
Front Impact Test	50,000	26.828	227.308	370 MPa[3]
Side Impact Test	15,000	73.189	129.449	
Roll Cage Roll Over Test	50,000	63.151	146.461	
Bump Test	15,000	160.854	170.394	
Torsion Test	50,000	66	190	

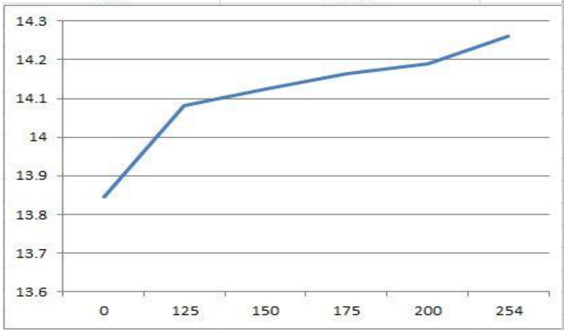
Table 3

V. Optimisation

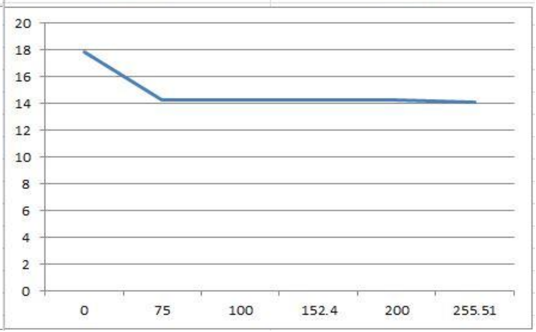
Though, there are several constraints for the design of the roll cage, some of the dimensions are left to the mercy of the designer. Two such parameters were taken for optimization. One is the radius of the Front Impact member and the other is the radius of the side impact member. Repeated analyses were performed by subsequently reducing the radius from the maximum possible radius to the minimum possible radius and the deformation is plotted against the radius. By this way, the optimum radius is selected.

Radius in SIM (mm)	Front Impact Deformation (mm)
0	13.846
125	14.081
150	14.123
175	14.164
200	14.191
254	14.26

Front Radius	Front Imapact Deformation
0	17.829
75	14.272
100	14.277
152.4	14.26
200	14.236
255.51	14.124



Graph 1



Graph 2

VI. Mass Property And 3DRepresentation

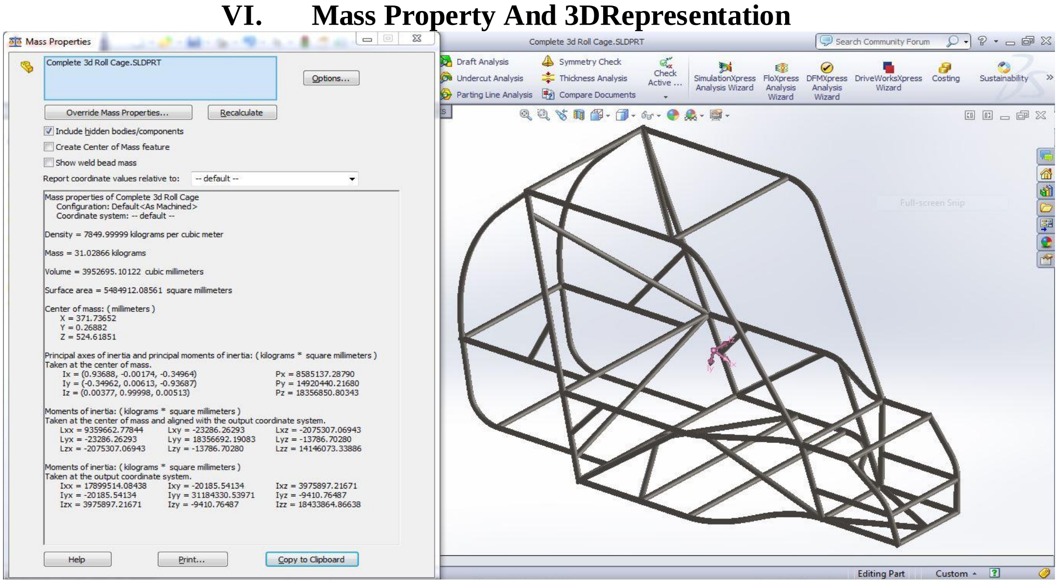


Fig 15

VII. Conclusion

The roll cage was designed and analysed and for the dimensions which are not constrained, the optimum dimension for minimum deformation and stresses are calculated with the help of analysis results from the CAE software. The following results were obtained

1. Reducing the radius in the Side Impact Member (SIM) meant reduction in deformation for the given load.
2. The radius present in the Front Impact Member does not matter much unless there is a sharp edge. The sharp edge in front impact member increases the deformation value and the presence of radius itself, however small may it be, reduces the deformation considerably

References

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