DESIGN ANALYSIS OF THE ROLL CAGE FOR ALL - TERRAIN VEHICLE

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Abstract

We have tried to design an all terrain vehicle that meets international standards and is also cost effective at the same time. We have focused on every point of roll cage to improve the performance of vehicle without failure of roll cage. We began the task of designing by conducting extensive research of ATV roll cage through finite element analysis. A roll cage is a skeleton of an ATV. The roll cage not only forms the structural base but also a 3-D shell surrounding the occupant which protects the occupant in case of impact and roll over incidents. The roll cage also adds to the aesthetics of a vehicle. The design and development comprises of material selection, chassis and frame design, cross section determination, determining strength requirements of roll cage, stress analysis and simulations to test the ATV against failure.

***Keywords:** Roll cage, material, finite element analysis, strength*

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I. INTRODUCTION

The objective of the study is to design and develop the roll cage for All - Terrain Vehicle. Material for the roll cage is selected based on strength, cost and availability. The roll cage is designed to incorporate all the automotive sub-systems. A software model is prepared in Solid works software. Later the design is tested against all modes of failure by conducting various simulations and stress analysis with the aid of Ansys Software. Based on the result obtained from these tests the design is modified accordingly. After successfully designing the roll cage, it is ready for fabricated.

The vehicle is required to have a combination frame and roll cage consisting of steel members. As weight is critical in a vehicle powered by a small engine, a balance must be found between the strength and weight of the design. To best optimize this balance the use of solid modeling and finite element analysis (FEA) software is extremely useful in addition to conventional analysis. The following paper outlines the design and analysis of the roll cage design

2. DESIGN & DEVELOPMENT

The design and development process of the roll cage involves various factors; namely material selection, frame design, cross-section determination and finite element analysis. One of the key design decision of our frame that greatly increases the safety, reliability and performance in any automobile design is material selection. To ensure that the optimal material is chosen, extensive research was carried out and compared with materials from multiple categories. The key categories for comparison were strength, weight, and cost. The details of each step are given below.

2.1 Material Selection

While the rules set many factors of the material’s geometry, there are many other limitations. These limitations include the method of fabrication and industry standards for the material. The frame will be built using a bent tube construction and MIG welded joints. MIG welding becomes difficult at wall thicknesses less than 0.035 inches. The tubing bender that will be used for the fabrication can bend a maximum of 1.5 inch diameter tube with a 0.120 inch wall thickness. It also requires that the tube have a minimum wall thickness of 0.055 inches. The geometry is also limited by industry standards. It is important to utilize commonly available tubing sizes and materials. Tubing is available in standard fractional sizes to the 1/8th of an inch: 1, 1.125, 1.25, 1.375, and 1.5. The wall thickness is limited to: 0.035, 0.049, 0.058, 0.065, and 0.083 inches. The most commonly available material for this type of tubing is “ASTM 106 grade B Steel”.

The ASTM 106 grade B Steel has the same Modulus of Elasticity (E) and density as the mild steel, so using it does not affect the weight or stiffness in members with the same geometry.

After a careful study, based on the properties and cost and availability criteria, it was found that the following material with its properties given should be used.

Density (x 1000 kg/m3)	7.7-8.03
Poisson"s ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (MPa)	415
Yield Strength(MPa)	240
Elongation (%)	20
Reduction in Area (%)	48
Hardness (HRB)	100

Analysis was carried out on solid works Interface for these sections under three conditions:

- Compression test
- Tension test
- Bending test as simply supported

The pipe of 1" O.D and .12" thickness was selected for designing based on analysis result.

Report of Compression Test

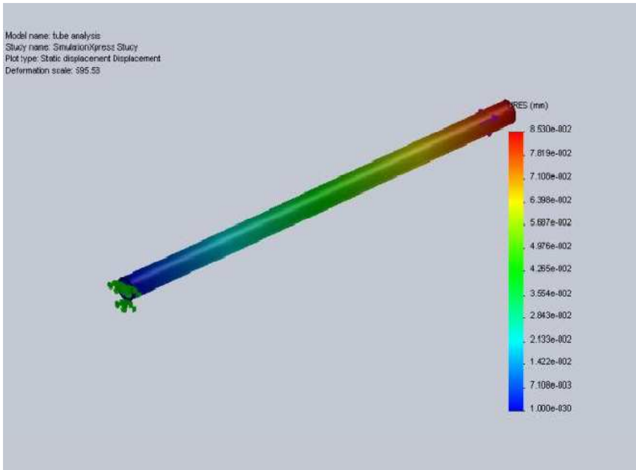

Fig-1 Compression test for tube sample

Fig2 Compression von-mises stress for selected pipe

Report of Tension Test

Fig-3 Tensile von-mises stress for selected pipe

Report of Pipe Bending

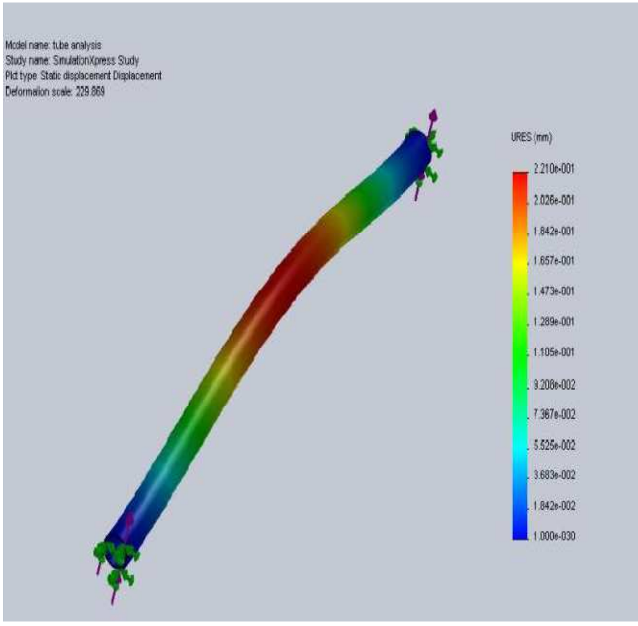

Fig-4 bending translational displacement for selected pipe

2.2 Frame Design

To begin the initial design of the frame, some design guidelines were required to be set. They included intended transmission, steering and suspension systems and their placement, mounting of seat, design features and manufacturing methods. It is also required to keep a minimum clearance of 3 inches between the driver and the roll cage members. It is also necessary to keep weight of the roll cage as low as possible to achieve better acceleration. It is necessary to keep the center of gravity of the vehicle as low as possible to avoid toppling. Mounting heavier components such as engine, driver seat etc. directly on the chassis is one way of achieving low center of gravity. Also it is imperative to maintain the integrity of the structure. This is done by providing bends instead of welds which in turn reduces the cost. A layout of the chassis within the given geometrical constraints is as shown in Fig.5

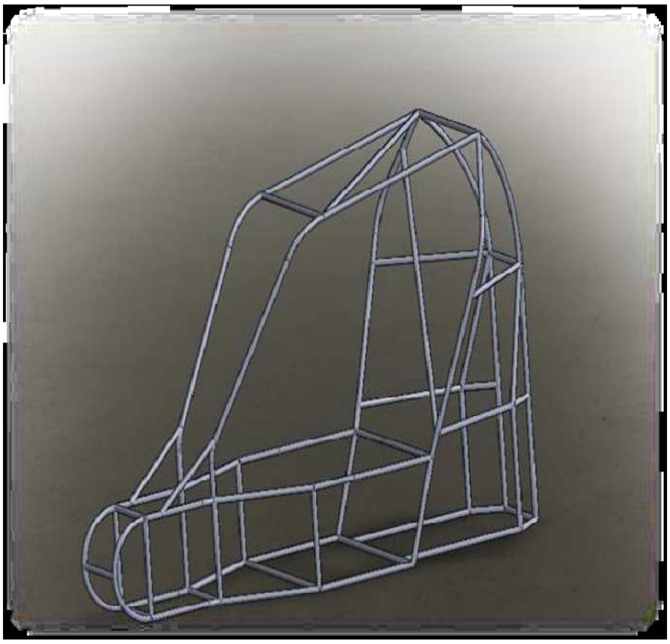

Fig-4 Solid modeling of ATV Roll Cage

3. FINITE ELEMENT ANALYSIS

After finalizing the frame along with its material and cross section, it is very essential to test the rigidity and strength of the frame under severe conditions. The frame should be able to withstand the impact, torsion, roll over conditions and provide utmost safety to the driver without undergoing much deformation. Following tests were performed on the roll cage.

- Front impact
- Side impact
- Rear impact

3.1 Front Impact Test

Front Impact Test was carried out assuming a vehicles having 300 kg mass and travelling with velocity of 60km/h colliding head on with a stationary wall. The impact force was calculated using the kinetic energy transfer theory.

Impact energy = (1/4) x M x (velocity)^2

Work done= force x displacement

Front Impact Test

Loading= 7500 N on front corner

Boundary Conditions:

1. Symmetry (Plane normal to Z-axis)
2. All DOF are fixed at rear corner points.

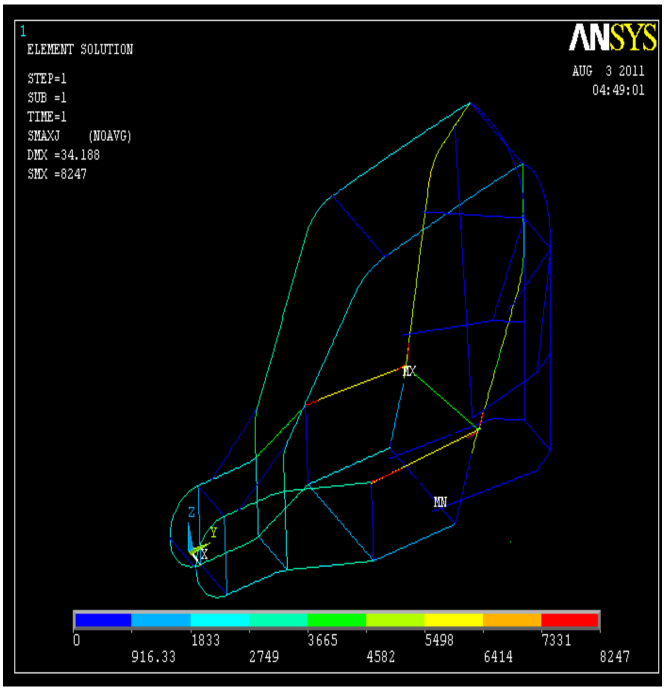

Fig. 5: Vonmises Stress plot

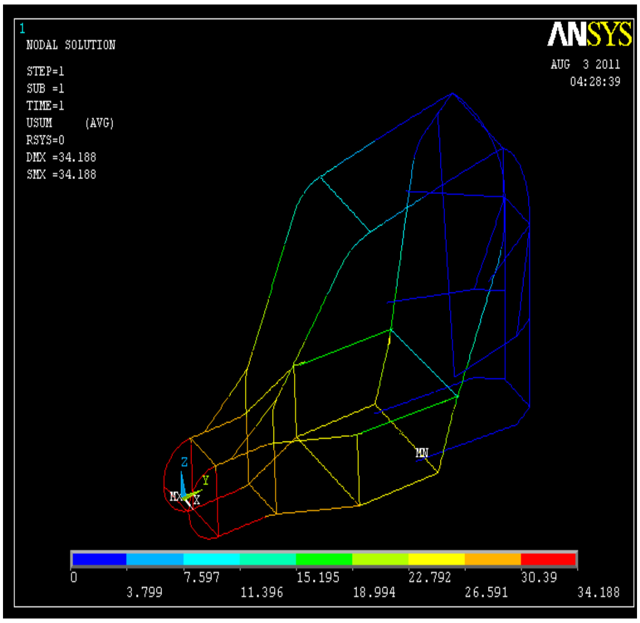

Fig. 7: Displacement plot

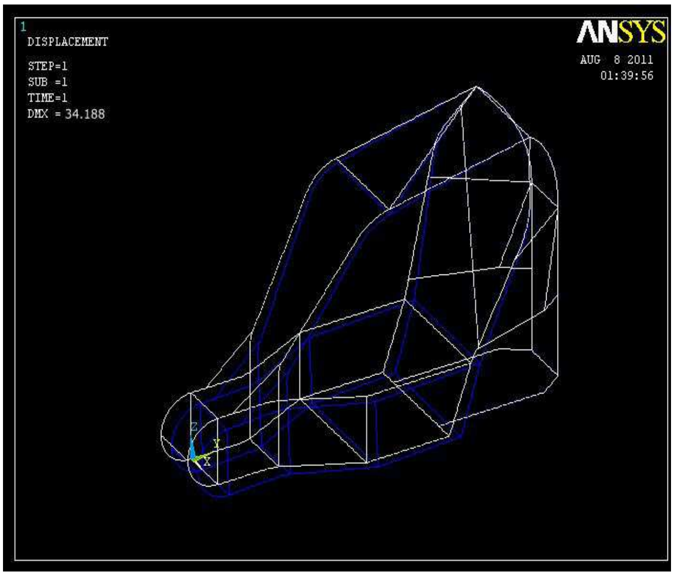

Fig 8: Deformation plot

Results:

Maximum VonMises Stress= 56 MPa
Incorporated Factor of Safety= σ_{yt}/σ_{max}
= 386/56
= 6.89
As factor of Safety for automobiles goes up to 8, hence design is safe against specified stress.

3.2 Rear Impact Test

Loading= 6850 N on rear corner
Boundary Conditions:
1. Symmetry (Plane normal to Z-axis)
2. All DOF are fixed at front corner points.

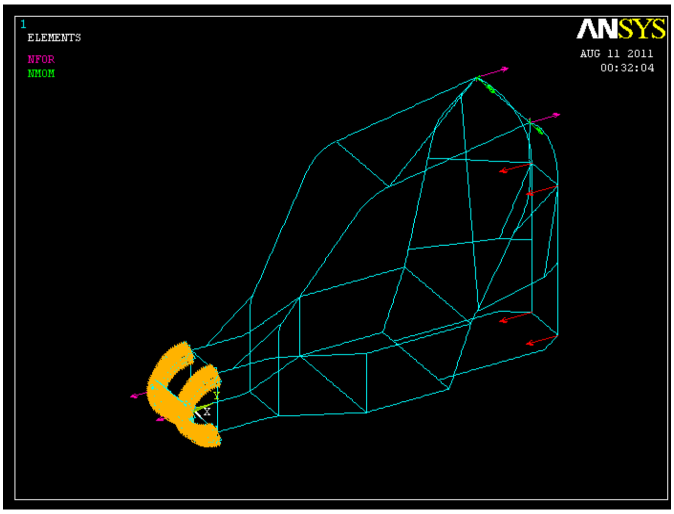

Fig. 9: Boundary conditions

Fig. 10: Vonmises stress plot

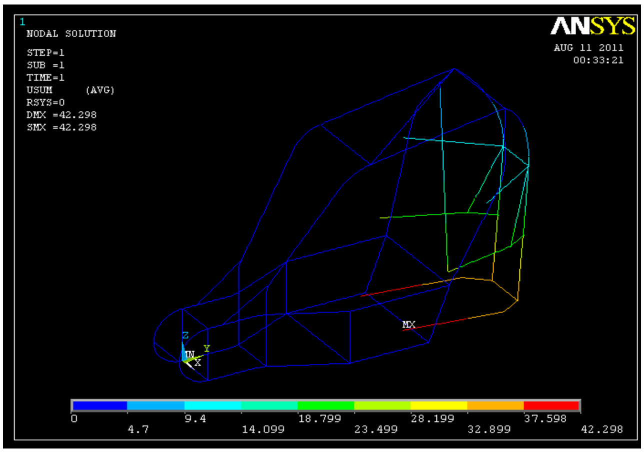

Fig. 11: Displacement plot

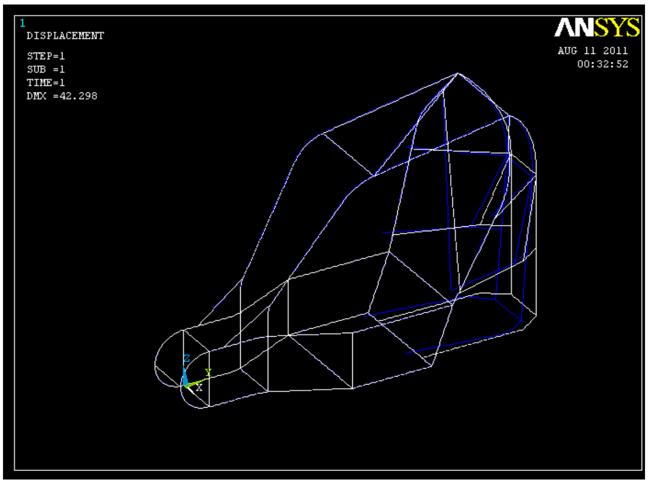

Fig. 12: Displacement plot

Results:

Maximum Von Mises Stress= 74 MPa
Incorporated Factor of Safety= σ_{yt}/σ_{max}
= 386/74
= 5.21
Hence design is safe against specified stress.

3.3 Side Impact Test

Loading= 6500 N on left side impact member.
Boundary Conditions:
1. Symmetry (Plane normal to Z-axis and along Y-axis)
2. All DOF on SIM are fixed.

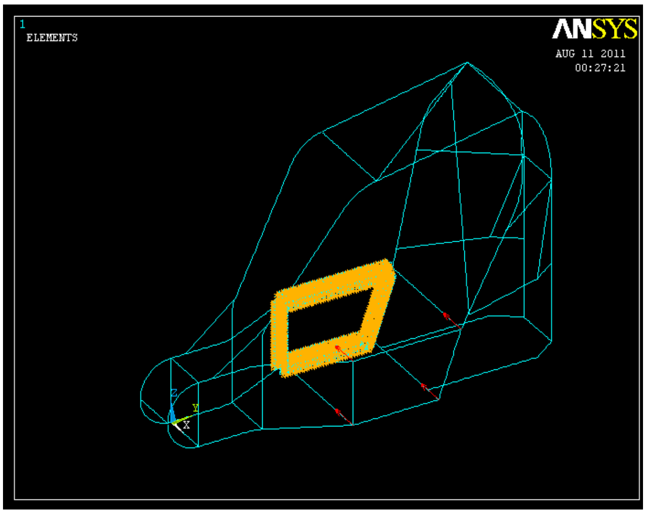

Fig. 13: Boundary condition

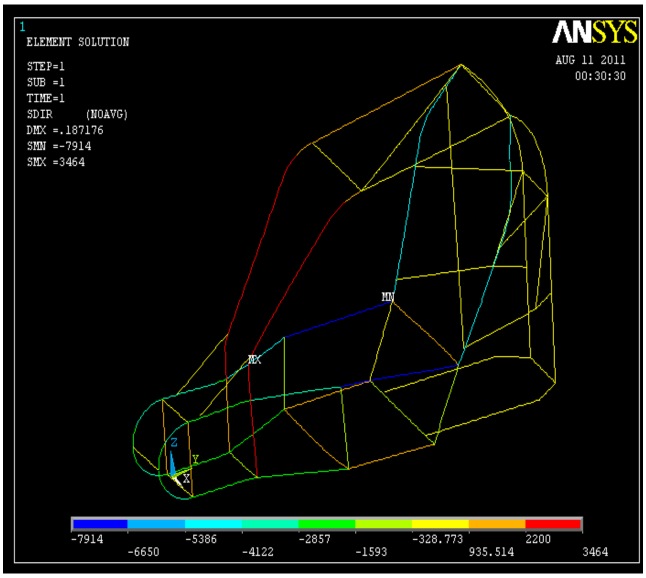

Fig. 14: Vonmises stress plot

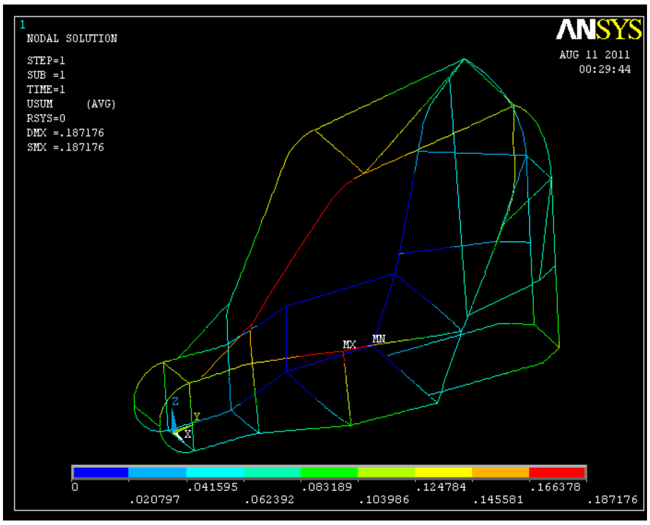

Fig. 15: Displacement plot

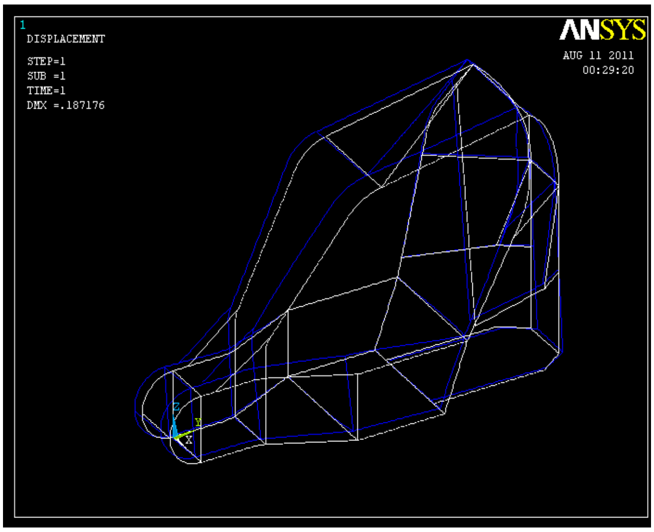

Fig. 16: Deformation plot

Results:

Maximum VonMises Stress= 77 MPa
Incorporated Factor of Safety= σ_{yt}/σ_{max}
= 386/77
= 5.01
Hence design is safe against specified stress.

CONCLUSIONS

The FEA analysis demonstrated the structural superiority while maintaining a lower weight to strength ratio. The customers' needs were given the topmost priority as they are our ultimate goal. The vehicle demonstrated satisfactory dynamic stability while maneuvering rough terrains. The design of the vehicle is kept very simple keeping in view its manufacturability. Thus at this point of time our vehicle design can be predicted to heading in correct direction. There is a lot of future work which is essentially required to fine tune the performance. The design, development and fabrication of the roll cage is carried out successfully. The roll cage is used to build an ATV by integrating all the other automotive systems like transmission, suspension, steering, brakes and other miscellaneous elements.

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