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Roll-Cage Analysis in Car Design

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ABSTRACT

This paper deals with the aspect of Roll-cage design in cars. Different static analysis and bending strength calculations depicts that the safety and robustness such designs offers to the structure, is immense . But usage of such cages are restricted to special needs of racing and all-terrain competitions (like SAE Baja) .

KEYWORDS Roll-cage , Impact analysis ,impulse momentum theorem, Bending strength, Stiffness

Introduction

Roll-Cage is a frame of pipes providing a rigid structure and robust design to the vehicle.

They can be used either as the only-frame (like in ATVs) or as the inner supporting structure in the conventional vehicles to provide strength against impacts.

Here at the institute we designed and manufactured our roll-cage and impact analysis were done using ANSYS.

Figure 1- SAE Baja Roll-Cage

Our Roll-cage

Various Metals and their alloys can be used for frame construction , but we chose AISI 4130 for design and manufacturing of our roll-cage , as it contains relatively higher carbon %(0.28%-0.33%) and hence relatively higher tensile strength than some other possible alternatives.

Material properties-

Table 1-Material Properties

Class	AISI 4130
Density	7.85g/cm³
Ultimate Tensile strength	560MPa
Yield tensile strength	460MPa
Shear modulus	80GPa
Bulk modulus	140GPa
Brinell Hardness	217
Poisson Ratio	0.27-0.30
Melting point	1432°C
Elongation	25.5%

Impact Analysis of a roll cage

We made an above shown roll cage(fig.1) using AISI 4130 steel. Welded using the filler material ER20S2 through TIG. It weighs 40kg and is fully capable of taking the weight of all the essential components. Following are the impact force analysis on this chassis which can be treated as the general method of impact analysis on any given roll-cage.

Calculation methodology-

All the calculations are done using impulse momentum theorem. i.e.

$$\text{Force} = \frac{(Mass\ of\ the\ vehicle\ )\ X\ (\ Vehicle\ Change)}{Impulse\ Time}$$

$$\text{G Force} = \frac{Maximum\ Force}{(Mass) X\ (Acceleration)}$$

Table 2- Assumptions

Velocity of impact	12m/s
Final Velocity	0m/s
Impulse Time	0.2s
Mass of the vehicle	280kg

According to the calculation-
Maximum Impact Force = 16800N
G Force = 6G

Table 3-Loading Condition

Force Applied on	Front two Members joining FBM
Fixed Supports	Front and rear suspension all mounting points.

Table 4- Results

Max. Deformation	0.73mm
Equivalent Stress	255.2MPa
Factor of safety	1.80

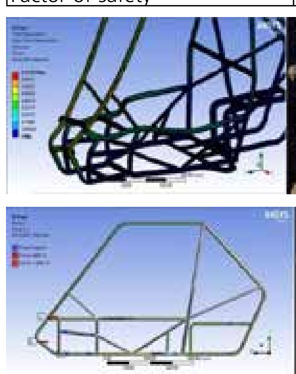

Figure 2 - Front Impact

Rear impact

Assumptions are same as in front impact.
According to the calculation-
Maximum Impact Force = 16800N
G Force = 6G

Table 5-Loading Condition

Force Applied on	Both Mid Fore Aft Bracing members
Fixed Supports	Front & rear suspension mounting tabs

Table 6- Results

Max. Deformation	1.49mm
Equivalent Stress	219.1MPa
Factor of safety	2.10

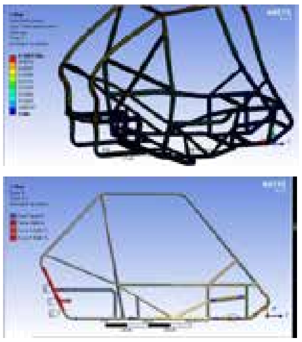

Figure 3 - Rear Impact

Side Impact

Table 7-Assumptions

Velocity of impact	4m/s
Final Velocity	0m/s
Impulse time	0.2s
Mass of vehicle	280kg

According to the calculation-
Maximum Impact Force = 5600N
G Force = 2G

Table 8-Loading Condition

Force Applied on	Side Impact member and truss of trailing arm
Fixed Supports	Only lower mounting points of suspensions

Table 9- Results

Max. Deformation	4.12mm
Equivalent Stress	346.8MPa
Factor of safety	1.33

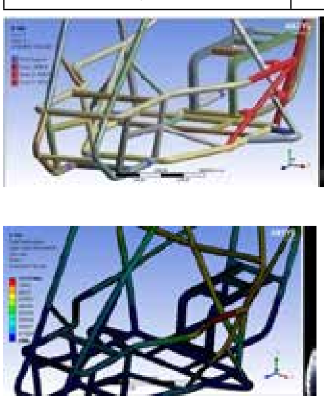

Figure 4 - Side Impact

Side Roll-Over

Table 10-Assumptions

Velocity of impact	5m/s
Final Velocity	0m/s
Impulse time	0.25s
Mass of vehicle	280kg

According to the calculation-
Maximum Impact Force = 5600N
G Force = 2G

Table 11-Loading Condition

Force Applied on	One Side of Rear Roll Hoop & Front Bracing Member at an angle of 45^0
Fixed Supports	Front & Rear Suspensions

Table 12- Results

Max. Deformation	4.12mm
Equivalent Stress	346.8MPa
Factor of safety	1.33

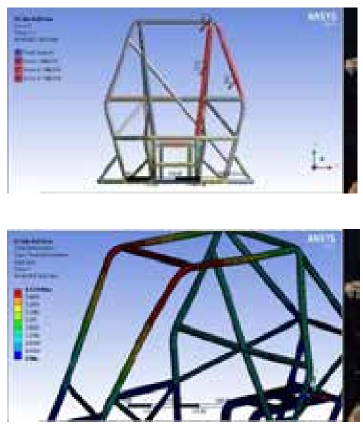

Figure 5 - Side Roll-Over

Bending strength

Bending strength also known as modulus of rupture, Flexural strength or Fracture strength, is a material property, defined as the stress in material just before it yields in a flexure text. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross section is bent until fracture or yielding, using a three point flexural test technique.

Bending strength is given by: $\frac{S_y \times I}{C}$

Where:
Sy - Yield strength (365 MPa for AISI 1018 steel, 460MPa for AISI 4130 steel)
C - Distance from neutral axis to extreme fiber.

Bending stiffness

The Bending Stiffness (K) is the resistance of a member against bending deformation. It is a function of elastic modulus (E), the area moment of inertia (I) of the beam cross section about the axis of interest, length of the beam and beam boundary condition.

Bending stiffness is considered to be proportional to the product EI where:

E - Modulus of elasticity (205 GPa for all steels)
I - Second moment of area for the structural cross section

Incorporation in modern vehicles

Figure 6 - Roll-cage incorporation in conventional cars. Image courtesy - Wikipedia

As seen above ,if a roll-cage is used as the only structure for the vehicle , it is fully capable of taking various loads and can ensure the high-level safety to the occupants. But still the usage of such designs in modern vehicles is not common .

Even as the installed frame passenger have to compromise most of the inner car space and it inhibits the access to the car if cross-members comes in the doorway.

Conclusion
According to the test conducted above , the proposed vehicle design is suitable for all terrain challenges.

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