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Procedural Layout of Designing a SAE Baja Roll Cage

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Abstract:

This paper deals with the study of design of a roll cage for an All-Terrain Vehicle (ATV) in accordance with the rulebook of BAJA given by SAE (Society of Automobile Engineers). A roll cage is a skeleton of an ATV as it forms the basic structure and gives stability to a vehicle. 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. An all-terrain vehicle (ATV) as defined by the American National Standards Institute (ANSI) is a vehicle that travels on low pressure tires, with a seat that is straddled by the operator, along with handlebars for steering control. The design comprises of material selection, chassis and frame design according to the constraints given in the rule book, cross section determination, determining strength requirements of roll cage.

Keywords — Roll cage, AISI, ATV, SAE, Rule book, bending strength, bending stiffness and DFMEA.

I. INTRODUCTION

The study of design of a roll cage for an All-Terrain Vehicle (ATV) in accordance with the rulebook of BAJA given by SAE (Society of Automobile Engineers) is done .Material for the roll cage is selected based on strength, cost, availability and total weight of the roll cage. The roll cage is designed considering, the automotive sub-systems and constraints given in the BAJA rule book. The design factor contains safety, easy manufacturing, durability & maintenance of the frame and a compact, lightweight & ergonomic design. A software model is prepared in a designing software (CREO or SOLID WORKS).

II. DESIGN AND DEVELOPMENT

The classification of roll cage members as given in the SAE BAJA rule book

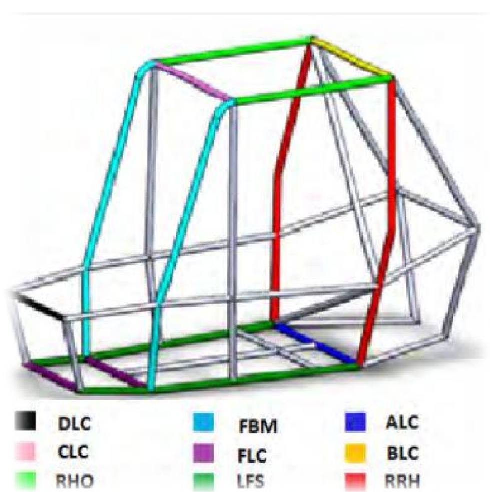

Figure 1. Primary Members of Roll Cage

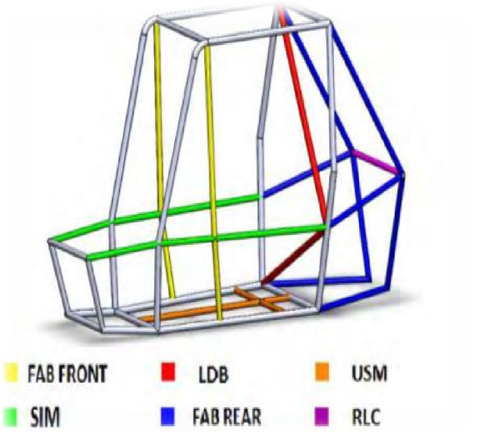

Figure 2. Secondary Members of the roll cage

Primary Members of Roll Cage

- Rear Roll Hoop (RRH)
- Roll Hoop Overhead (RHO)
- Front Bracing Member (FBM)
- Lateral overhead Cross Member (BLC)
- Front Lateral Cross Member (FLC)
- Upper lateral cross member (ULC)
- Lower frame side member (LFS)

The secondary Members of the roll cage

- Lateral Diagonal Bracing (LDB)
- Fore /Aft bracing member (FAB)
- Side Impact Member (SIM)
- Under Seat Member (USM)
- Rear lateral cross member (RLC)
- Tubes used for mounting safety belts

Important rules and dimensional constraints given in the SAE BAJA rule book.

The rules and regulations given in the SAE BAJA rule book need to be followed while designing the roll cage. The clearance and dimensional limitations are the main design specifications that will checked by the technical inspection team in the BAJA event. The constraints are as follows:

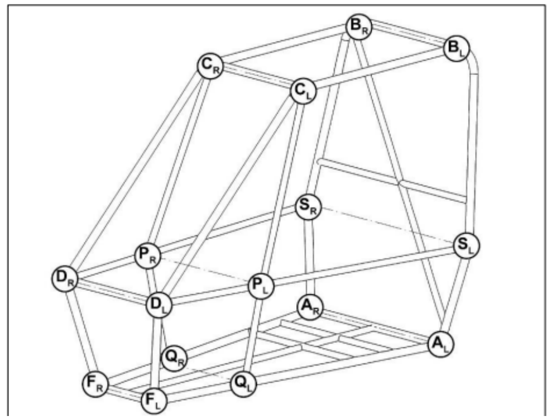

Figure 3. Roll Cage, Named Roll Cage Points, Rear Braced Frame. (Normal model)

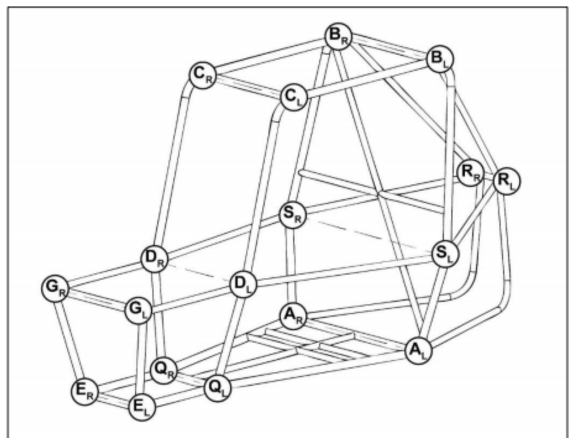

Figure 4. Roll Cage, Named Roll Cage Points, Rear Braced Frame (Nose model)

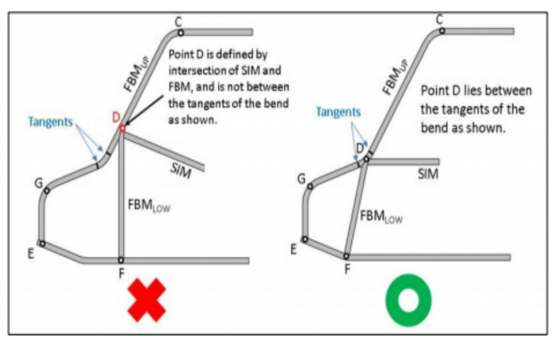

Figure 5. Intersection of the SIM member and FBM (Point D)

- The intersection point D shown in the Figure 5 need to be properly designed as shown in the image.
- Dimensional requirements of the roll cage member material:

  Wall thickness : 3.05mm

  Outer diameter : 25.4mm

  With carbon content at least 0.18%
- The above given dimensions is for AISI 1018, if you are not using AISI 1018 then we have to select a material such that it should have the bending strength and bending stiffness at least equal to AISI 1018.
- If we are using different material other than AISI 1018 then the wall thickness should be at least 1.57mm.

  With carbon content at least 0.18%.
- Dimensions given in the rulebook are measured between centerlines.
- Length of the straight member must not exceed 40 inches between the named points.
- Bends must not have a bend greater than 30 degrees and should not exceed 28 inches between the named points.
- Small bend radii 6 inches and terminate at named points
- Named points must lie between the tangents of the bend.
- **Lateral Cross Member**:
  - Lateral cross members cannot be less than 8 in. long.
  - LC's cannot have a bend; however, they can be a part of a larger, bent tube system but the length constraints need to be considered.
  - Only the RLC is fabricated with secondary material.
  - ALC member minimum length requirement should be of 18in. & does not fall under above clause of 8in. requirement.

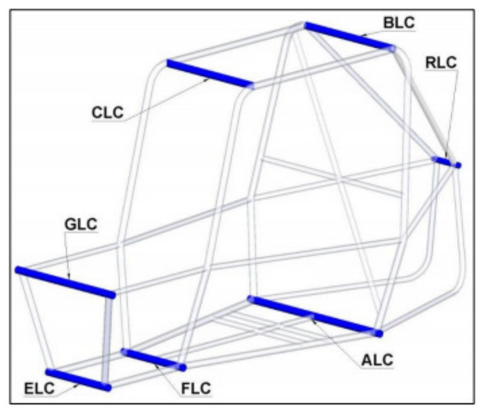

Figure 6. Lateral cross members of the Roll Cage

- RRH (Rear Roll Hoop):
  - The RRH should be fabricated as a continuous tube and the maximum length constraints of members is not applicable to RRH.
  - The minimum width of the RRH, measured at a point 27 in. above the inside seat bottom, is 29 in. In addition

to this, minimum width of the RRH measured 14 in above the inside seat bottom should be minimum 32 inch.

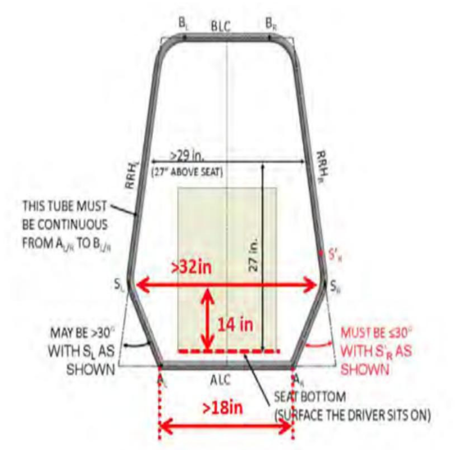

Figure 7. RRH of the roll cage

- ➢ The S is the named point in which the bend is given above 14 in. from the seat bottom and it should meet the angle constraints that is mentioned in the Figure.7.

- ▪ LDB Lateral Diagonal Bracing:

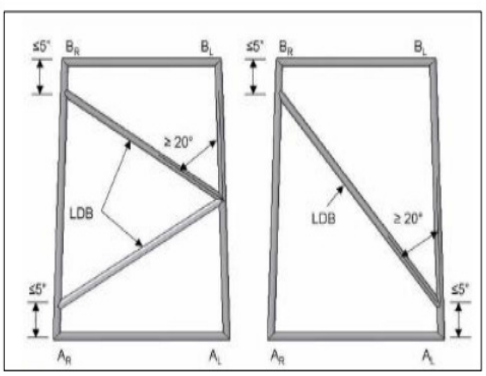

Figure 8. LDB of the roll cage

- ➢ The top and bottom intersections of the LDB members and the RRH vertical members must be no more than 5 in. from points A and B as shown in the Figure.8.
- ➢ The angle between the LDB members and the RRH vertical members must be greater than or equal to 20 deg.
- ➢ A single straight LDB is exempt from the maximum length in straight member requirements.

- ▪ RHO Roll Hoop Overhead Members:
  - ➢ CLC, BLC and RHO members must all be coplanar and bends at the aft (rearward) ends of the RHO members are not permitted.

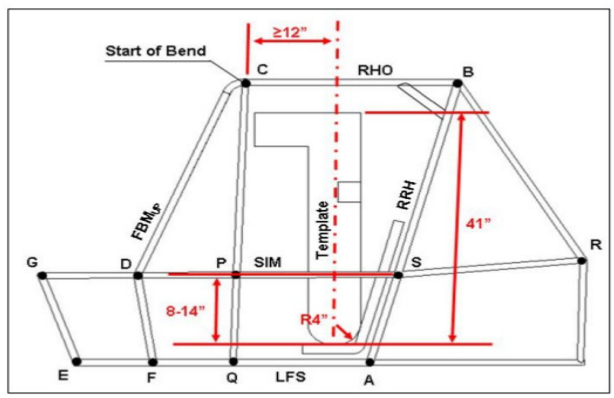

Figure 9. Side view of the design constraints of the roll cage

  - ➢ Points CR and CL must be between at least 12 in. forward of a point, in the vehicle's side view, defined by the intersection of the RHO members and a vertical line rising from the aft end of the seat bottom. This point on the seat is defined by the seat bottom intersection with a (4 in.) radius circle which touches the seat bottom and the seat back. The top edge of the template is exactly horizontal with respect to gravity.

- Points CR and CL and Points BR and BL must also be no lower than the top edge of the template, 1041.4 mm (41 in) above the seat, as shown in the Figure 9.

- LFS – Lower Frame Side Members:
  - These members are joined to the bottom of the RRH at Point A and extend generally forward, at least as far as a point forward of every driver's heels, when seated in normal driving position.
- SIM – Side Impact Members:
  - The SIM members must be between 8 in. and 14 in. above the inside seat bottom at all positions between points S and D. In 'Nose' designs, the SIM extends forward to Point G, and is joined by a lateral cross member GLC. In this case, DLC may be omitted if GLC provides adequate protection for the driver's toes.
- USM – Under Seat Member:
  - The two LFS members must be joined by the Under Seat Members. The USM must pass directly below the driver.
  - The ALC and FLC members must be joined longitudinally by the Under Seat Member. The USM must and pass directly below the driver where the template intersects the seat bottom.

- FBM Front Bracing Members:
  - The angle between the FBM UP and the vertical must be less than or equal to 45 deg.
  - The upper Front Bracing Members (FBM UP) must join points C on the RHO to point D on the SIM. The lower Front Bracing Members (FBM LOW) must join point D to point F.
- Bracing:
- FAB – Fore - Aft Bracing

  The RRH must be restrained from rotation and bending in the side view by a system of triangulated bracing. Bracing must either be front bracing or rear bracing.
- Rear Bracing - directly restrain both points B from longitudinal displacement in the event of failure of the joints at points C.
- Front Bracing - restrain both points C from longitudinal and vertical displacement, thus supporting points B through the RHO members.
- A better design will result if both front and rear bracing are incorporated. Members used in the FAB systems must not exceed 1016 mm (40 in.) in unsupported length. Triangulation angles (projected to the side

view) must be at least 20 deg. between members.

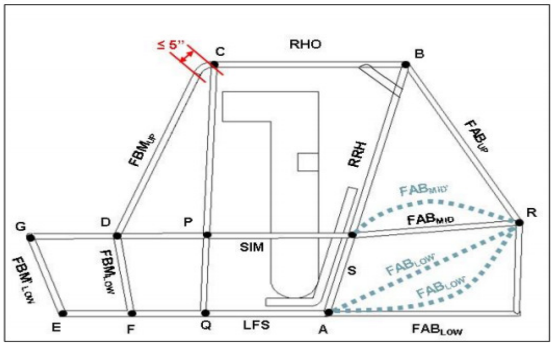

Figure 10. FAB System of the Roll Cage

III. MATERIAL CALCULATION

As per the constraint given in the SAE BAJA rulebook, the roll cage material must have at least 0.18% carbon content. After an extensive market survey the material which can be used for the roll cage is shortlisted, the comparative study of these shortlisted materials is done on the basis of strength, availability and cost. The shortlisted materials are as follows.

1. AISI 1018
2. AISI 4130
3. AISI 1026

IV.ROLL CAGE EQUIVALENCY CALCULATIONS

Bending Strength Comparison

Definitions: E=Modulus of elasticity

I=Area moment of inertia about the weakest axis

Required tubing specifications:

Diameter : 25.4mm (1 in)

Wall thickness: 3.05 mm (0.120 in)

Material: 1018 steel

From tubing geometry:

Modulus of elasticity, E_x =205 GPa

Outer diameter, Do = 25.4mm

Thickness, t = 3mm

Inner diameter, Di =19.4mm

Area Moment of Inertia,

$I_x = [\pi*(Do^4-Di^4)]/64$

$I_x = \pi*(25.44^4-19.44^4)/64$

I_x =13478.63 mm^4

Yield strength, Sy_x= 365MPa

Distance to the extreme fibre,

C=25.4/2= 12.7mm

Sy_x*I/C = (365*13478.63)/12.7

= 387.377Nm

Bending Stiffness (Required)

= E_xI_x

= 205*10^3*13478.63

= 2763.11Nm^2

Now the material we select for fabricating the roll cage should meet the above specified requirements or should exceed. In selecting the material we should also keep in mind the weight density per meter length of the material chosen.

Example calculations of desired tubing material:

Tubing specifications of chromoly AISI 4130:

Diameter: 31.75mm (1.25”)

Wall thickness: 1.6mm (0.062”)

Material: 4130 steel

From tubing geometry:

Modulus of elasticity, E_y= 210GPa

Outer diameter, D_o= 31.75mm

Thickness, t = 1.6mm

Inner diameter, D_i =28.55mm

Area Moment of Inertia,

$I_y= [\pi*(D_o^4-D_o^4)]/64$

$I_y=\pi*(31.754^4 - 28.554^4)/64$

$I_y=17268.83mm^4$

Yield strength,

Sy_y=714.85MPa

Distance to the extreme fibre,

C =31.57/2 =15.875mm

Sy_y*Iy/C = (714.85*17268.83)/15.87

= 777.85Nm

Bending Stiffness (Desired)

= E_yI_y

=205* 10^3*17268.83

=3540.11Nm^2

Percent difference = 100*(EI desired – EI required)/EI desired

= 21.99%

This percentage increase is the desired one which we can use for the roll cage fabrication.

V. STEPS FOR DESIGNING THE ROLL CAGE

1. Start by reading the rulebook issued by SAE BAJA. You should be thorough with all the terms, constraints and rules mentioned in the rulebook.
2. Consider the tallest member of the team as the driver and make him to sit in driving position with this in reference start making a chalk diagram of the belly pan.
3. Take inputs from all departments for mounting of suspension arms, engine, gearbox, seat, braking components. The Track width, Wheel base and the Driver constraints should be the first factor that need to be considered. This should always be maintained in the design of the roll cage.
4. The Rear Roll Hoop (RRH) should be the first feature need to be designed. It can be angled at 90 degrees to 75 degrees the air drag need to be considered while deciding it as the RRH of the roll cage decides the frontal area of the vehicle.
5. Working forward, the front end should be designed according to suspension mounting points which need to be predetermined already by the suspension team. Members were drawn

to accommodate the dual A-arms of the front suspension as well as a shock mounting point. The space for the brake reservoirs and the new constraints for brake pedal and acceleration pedal should be considered during the front part design as shown in the Figure 11. While fixing the length of the LFS and SIM we should be careful that in the normal seated position the Knee of the driver should not 3 in. above the SIM as shown in the Figure 12.

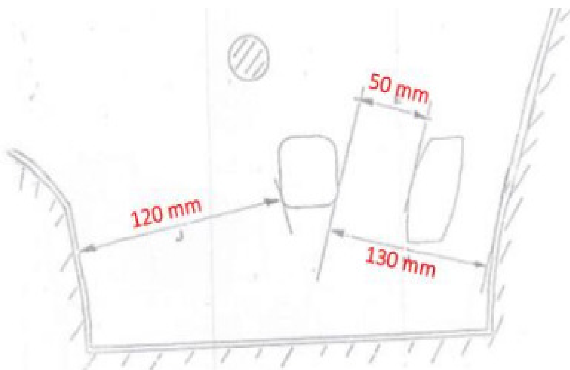

Figure 11.Brake pedal and Accelerator pedal constraints.

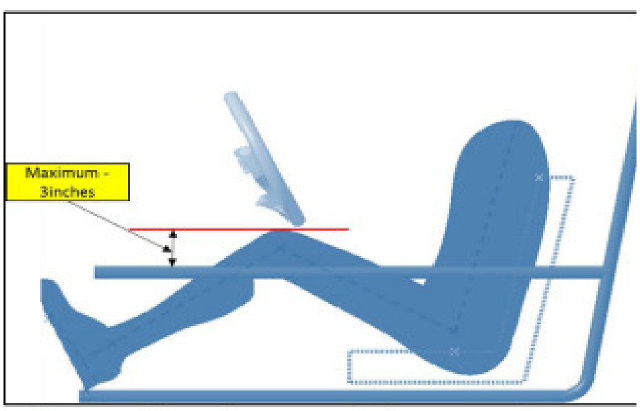

Figure 12. The SIM and Knee constraint (Maximum 3inches)

6. Consideration was made for minimum head clearance for driver safety. The vertical portion of the roll cage has been designed to maintain a large vertical clearance and forward clearance from the rear seat bottom considering the clearance constraints and drivers comfort. The constraints given in the Figure 13 and Figure 14 need to be considered while designing the horizontal design of the vehicle.

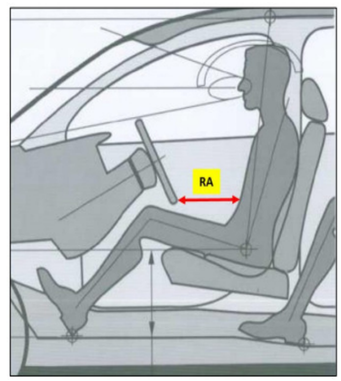

Figure 14. Minimum clearance between the Steering wheel and abdomen of the driver (RA= Minimum 200mm)

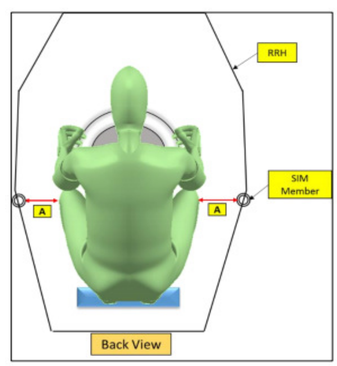

Figure 16. The lateral clearance between the driver and roll cage members. (A = Minimum 3 inches)

7. The vehicle's rear end has been designed with consideration for the engine size and orientation. Gearbox and rear suspension

mounting points has been considered and decided. The Figure 16 engine constraints need to be considered in the rear design.

8. The extra support members were added according to the post pilot analysis report to withstand the impact forces and few were added for mounting purposes.

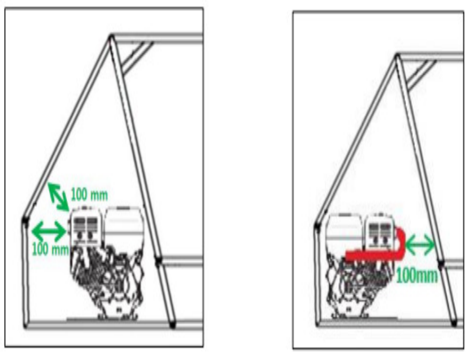

Figure 17 Engine and roll cage member clearance.

8. The material was selected on the basis of cost, availability, performance and weight of material. The external and internal diameter of the primary and secondary member need to be found out. The member's dimensions were selected after calculating the bending stiffness and bending strength.

VI. DFMEA (DESIGN FAILURE MODE AND EFFECTIVE ANALYSIS)

- Part: Roll cage
- Potential failure modes: Cracks and bends in the members and nodes of the roll cage.
- Potential Failure Causes: When the welding is improper, material used is not properly selected and improper impact analysis.
- Potential Failure Effects: May lead to total collapse and vibration in the vehicle.
- Severity : 10
- Occurrence: 8
- Detectance : 1
- Risk Priority : 80 Number
- Actions Taken: Proper material selection, welding and impact analysis should be done properly.
- Severity : 10
- Occurrence: 2
- Detectance : 1
- Risk Priority : 20 Number

For every part that is designed and fabricated the DFMEA should be done to identify the accidents and problems that can occur and find out what are the possible solutions and measures to overcome it.

VII. CONCLUSION

The Procedural layout of designing the roll cage is stated here in this paper successfully considering the rules and constraints mentioned in the BAJA SAE India rule book and the DFMEA is done. 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.

VIII. REFERENCES

[1] BAJA SAE INDIA Rule book, 2019.
[2] Automobile Engineering, Kirpal Singh.