Design and Dynamic Analysis of Roll Cage for The Off-Road Vehicle

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Abstract*- A roll cage is a skeleton of an Off-Road Vehicle or the All-Terrain Vehicle. The roll cage not only forms the structural base but also a 3-D shell surrounding the driver which protects the driver in case of roll over incidents and all other impact conditions. The roll cage forms the main frame of the vehicle which contains other components like Engine assembly, Steering mechanism, Transmission assembly and the Driver. The roll cage also adds to the aesthetics of a vehicle. This paper deals with the Design, Development and Dynamic Analysis of Roll Cage for the off-Road vehicle. The roll cage model is designed with the help of SolidWorks software and Hyper Mesh is the software used for the Dynamic analysis. In the Dynamic analysis the different crash tests like front impact, side impact and head-on collision are carried out with the help of Hyper Mesh software for determining the optimum Factor of safety. By doing this analysis we can ensure the better strength as well as performance of the vehicle in various dynamic conditions.*

Keywords- roll cage, off-road, dynamic analysis, solid works, hyper mesh

I. INTRODUCTION

In modern engineering analysis it is rare to find a project that does not require various types of analysis for the behaviour of the model under certain specified conditions. The advantages of analysis are numerous and important. The frame contains the driver, engine, brake system, fuel system, and steering mechanism, and must be of adequate strength to protect the driver in the event of a rollover or impact. This roll cage is fully designed and developed under the all rules and regulations stated in the SAE Mini-Baja rule book.

Roll cage of a vehicle is usually designed with purpose to hold the load from the components of vehicle and mass from the driver. Roll cage need to satisfy a number of requirements whose aims partly conflict because of different operating conditions which are loaded and unloaded weight, acceleration and braking force, level or uneven road and straight running or cornering. Nowadays, most of the components of vehicle are in the stage of replacing with Steel and aluminium materials. This is due to the properties of material that can be designed freely to hold the load from any direction. The roll cage's light-weight property makes it possible to enlarge the performance of the car while maintaining low weight.

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 modelling and finite element analysis (FEA) software is extremely useful in addition to conventional analysis. The software model is prepared in SolidWorks software. Later the design is tested against the various types of failure by conducting various impact conditions and stress analysis with the aid of Hyper Mesh Software. After successfully designing the roll cage, it is ready for fabricated.

II. DESIGN AND DEVELOPMENT

The design and development process of the roll cage contains various factors which are material selection, cross section determination, frame design and the finite element analysis. The good design decision of our frame ensures the safety and reliability of the driver and better performance as well as efficiency of the vehicle which is achieved by the choosing the good material for the frame. To ensure that the optimal material is chosen, the extensive research was carried out and it is compared with the other materials from multiple categories. The key categories for comparison were considered as strength, weight, cost and the main important factor is the availability of that material in India.

A. Material selection and cross section determination

As the vehicle will be going to compete in various Mini-Baja design national competition carried out for the undergraduate students in India. So the criteria for material selection of the roll cage is strictly follows the all rules stated in the rule book which is given by the SAE India Baja. The material will be going to use for the construct of roll cage must be of steel tubes with the minimum 0.18% carbon percentage and should be of minimum 25.4mm outer diameter with the minimum of 1.57mm wall thickness for the primary members and should be minimum of 25.4mm outer diameter with the wall thickness 0.89mm for secondary members. After carried out the extensive research on the various factors like cost, quality, availability and weight of material, safety of driver and ease of manufacturing, AISI1018 and AISI4130 steel tubes are considered for the frame design. The AISI 4130 steel of aircraft grade is the material selected for our roll cage. Since the AISI4130 contains chromium and molybdenum as strengthening agents with the carbon content 0.28-0.33%. Also the AISI4130 have good weld ability as well as machinability, it also has the high ultimate tensile stress and yield stress.

TABLE I. Material Properties

Class	AISI1018	AISI4130
Density	7.86 g/cm3	7.86 g/cm3
Ultimate Tensile Strength	460 MPa	750 MPa
Yield Tensile Stress	350 MPa	700 MPa
Bulk Modulus	140 GPa	140 GPa
Shear Modulus	80 GPa	80 GPa
Brinell Hardness	126	217
Poisson's Ratio	0.29	0.27-0.30
Elongation	15%	25.5%

B. Frame design

The design objective of the roll cage is to encapsulate all components of the vehicle, including a driver efficiently and safely. Principal aspects of the roll cage focused on during the design and implementation included driver safety, suspension and drive-train integration, structural rigidity, weight, and operator ergonomics. The intended fabrication is important due to the limitations of the abilities and skills of the build team as well as design directives. The objective is to minimize the number of welded joints on the frame in favour of bend members. Bending is less time consuming and when properly done show a much lower stress concentration.

The roll cage was design in the SolidWorks software by using weldments tool. Then the importing IGS file of the solid works model into the Hyper Mesh software, the 2D meshed model is created. First of all, the surfaces are generated of the roll cage and then 2-D quad type meshing is carried out with some quality index optimization for the meshing.

Fig1. SolidWorks CAD Model

C. 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 various impact conditions. The frame should be able to sustain all the impacts, torsion, roll over conditions and provide full safety to the driver without undergoing high stress and deformation.

Finite element analysis is a computerized method use by FEA Software for predicting how a product reacts to real-world forces, vibration conditions, and other physical effects acting on it. Finite element analysis shows whether a product will break, wear out, or work the way as it was designed. Here we divide the roll cage into small sizes known as element and collective elements on the model form a mesh. The computer analyses the elements and shows us a collective result. The material and structure of roll cage was finalized and then FEA was performed on it. It is tested whether the roll cage will be able to withstand the various conditions like torsion, impact, bump and vibrations.

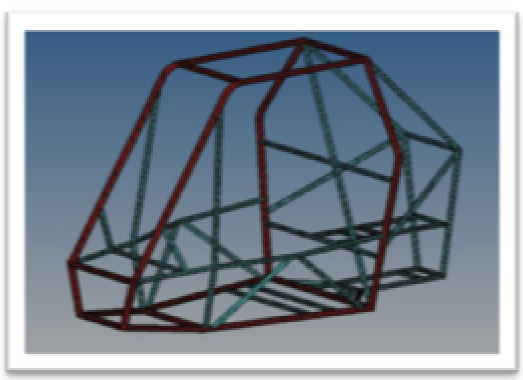

Fig 2. Hyper Mesh Model

III. DYNAMIC ANALYSIS

In dynamic analysis the vehicle is considered to be in state of motion and it is given maximum possible velocity and allows it to hitting the wall, vehicle as per corresponding different impact conditions. For the dynamic analysis Hyper Works 13 software is used. For meshing we choose the 2-D surface meshing for its appropriate result. The mid surface is generated of roll cage pipe and then this mid surface is meshed in quad type 2-D meshed. The 2-D meshing is used because it is preferred for pipes and also the time required for analysis is less compared with others. As the dynamic analysis required very much time as compared to static analysis, the average element size for meshing is selected. For general industrial practises the mesh size between 3.5mm to 5mm is selected for element. So we select the 7mm mesh size for meshing our roll cage model and other quality index criteria is also preferred for better optimization of mesh element so as the result comes are being appropriate. The dynamic analysis is carried out for the following conditions for the optimum factor of safety.

- Front Impact Analysis
- Side Impact Analysis
- Head on collision

In Hyper mesh the Radioss solver is used for the dynamic analysis. The other quality index criteria are used for meshing for an element are given in the table.

TABLE II. Mesh Quality Index Parameters

Sr. No.	Parameter	Value
1	Min Size	4mm
2	Max Size	10mm
3	Warpage	20
4	Aspect Ratio	10
5	Quad Min Angle	20
6	Quad Max Angle	140
7	Trias Min Angle	10
8	Trias Max Angle	140
9	Jacobian	0.4

A. Front Impact Analysis

For worst condition in front impact of vehicle, it is assumed to hit a wall at velocity of 60 km/h. Hitting a wall will give maximum possible stress as wall is non-deformable body and impact time will smaller. The dynamic crash analysis has been performed in Hyper Mesh 13.0 using RADIOSS Block 120 solver. Impact analysis is used to verify the safety of the driver. In this analysis condition, it is assumed to be the vehicle hits the wall at the speed of 60km/h. The material type is selected for the analysis is the elasto-plastic.

Result and Discussion

As the impact happens the internal energy goes on increasing and kinetic energy goes on decreasing as the impact time increase. When the kinetic energy is absorbed in the structure, then roll cage starts to bounce back after the impact happens i.e. the penetration stops and impact is said to be complete.

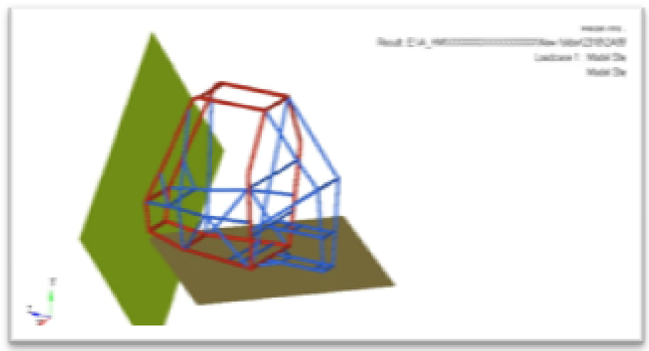

Fig 3. Front Impact Condition

By doing the front impact dynamic analysis we found out the following parameters are as follows

- As the graph shows between the internal energy, kinetic energy and total energy vs time, the impact was happening at the time around 0.0032 seconds.
- The Displacement in roll cage observed was 19.9cm.
- Maximum Von misses stress developed is 554.41 MPa.
- Factor of Safety = Syt / Von Misses stress

= 700 / 554.41
= 1.26
(Since FOS above 1 is good for dynamic analysis)
Here both the design of roll cage and driver are safe.

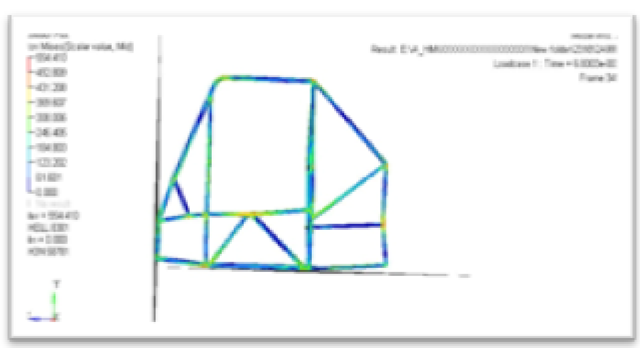

Fig 4. Von-Misses Stress distribution for Front Impact

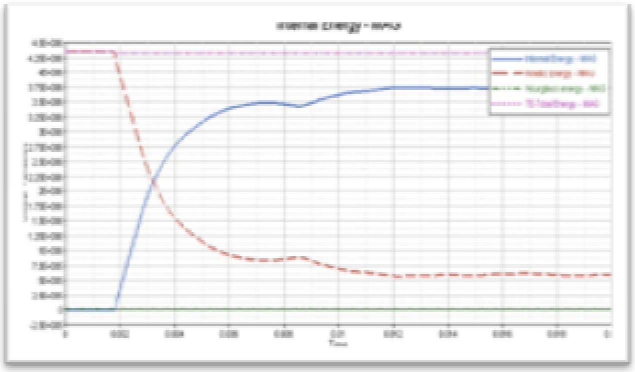

Fig 5. Energies Vs Time Graph for Front Impact

B. Side Impact Analysis

The Side Impact Dynamic analysis is done in order to find out the amount of stress generated and deformation in the roll cage if the roll cage is gets impact by the side by any object. For worst case scenario in case of side impact, it is assumed that, one vehicle is in motion with the speed of 60km/h and it is going to be hitting at the side of other similar type of vehicle which is initially at rest. This analysis is carried out by using hyper works 13 radioss with block 120 solver.

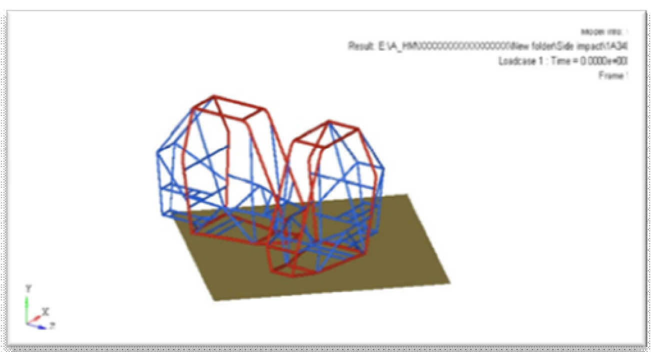

Fig 6. Side Impact Analysis condition

Result and Discussions

As the impact happens the internal energy goes on increasing and kinetic energy goes on decreasing as the time increase. The kinetic energy is absorbed in the other vehicle, the penetration stops and impact is said to be complete. The following parameters are obtained by the side impact analysis.

- As the graph shows between the internal energy, kinetic energy and total energy vs time, the impact was happening at the time around 0.0038 seconds.
- The Displacement in roll cage observed was 14.2 cm.
- Maximum Von misses stress developed is 300 MPa.
- Factor of Safety = Syt / Von Misses stress

= 700 / 300

= 2.33

Here both the design of roll cage and driver are safe.

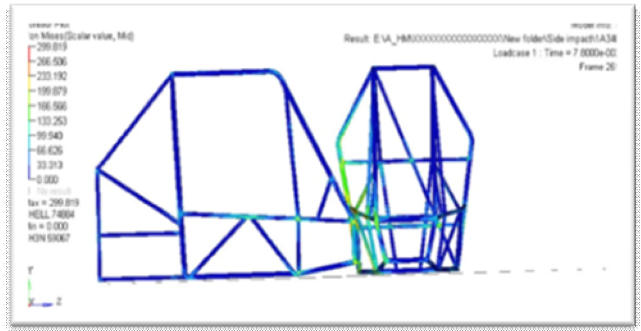

Fig 7. Von-Misses stress distribution in Side Impact analysis

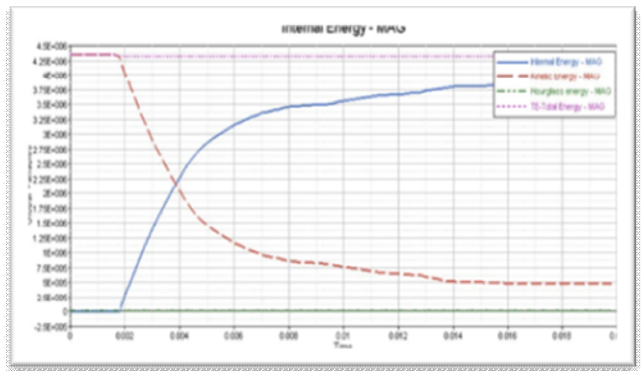

Fig 8. Energies Vs Time Graph for Side Impact

C. Head-on Collision

The Head on collision of two similar vehicles will be the worst condition at event site for vehicle. In head on collision two similar vehicles are allows to be hitting on each other with maximum possible velocity. So, for head-on collision analysis the roll cage of two Similar off-Road vehicles are allows hitting on each other with velocity of both vehicle is 60 km/h.

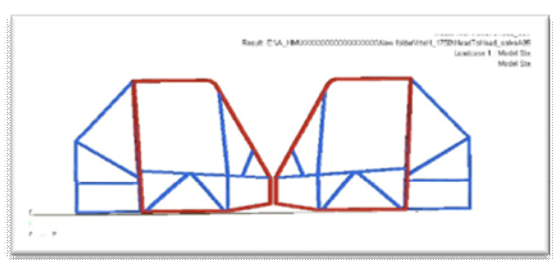

Fig 9. Head-On collision condition

Result and Discussion

As the impact happens the internal energy goes on increasing and kinetic energy goes on decreasing as the time increase. The kinetic energies of respective vehicles are get absorbed in the other vehicles and we observed the bounce back effect. The penetration stops and impact is said to be complete. The following parameters are obtained by the Head-on collision analysis.

- As the graph shows between the internal energy, kinetic energy and total energy vs time, the impact was happening at the time around 0.0025 seconds.
- The Displacement in roll cage observed was 22.6 cm
- Maximum Von misses stress developed is 391.91 MPa.
- Factor of Safety = Syt / Von Misses stress

= 700 / 391.91

= 1.78

So here also both the driver and design is safe.

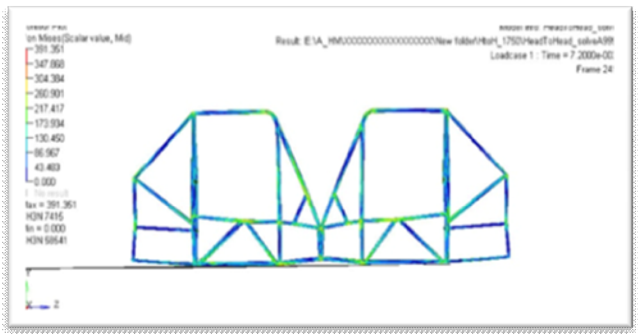

Fig 10. Von-Misses stress distribution for Head-On Collision

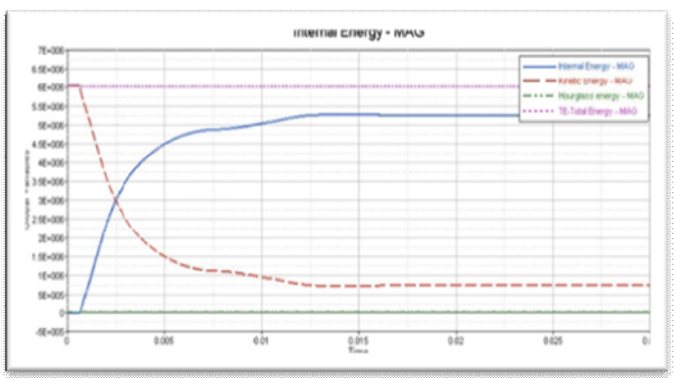

Fig 11. Energies Vs Time Graph for Head-On collision

IV. CONCLUSION

The study of this paper explores concepts of various analysis of dynamic impact conditions and selection of mesh size as well as mesh method in finite element analysis. The main aim of the study was to obtain optimum factor of safety in various dynamic impact conditions. During the study of roll cage for an off-road vehicle was analyzed and optimized for the design and optimum factor of safety is obtained in dynamic analysis which ensures that the roll cage of off-road vehicle will be safe in all conditions. Greater values of factor of safety for various conditions in dynamic analysis ensure the enhancement in results which is important. The FEA Analysis was shows that the vehicle can sustain in various condition and all the stress values in dynamic impact conditions are within the permissible limits. The basic need of the off-road vehicle, which is less weight to strength ratio, was also satisfied by the roll cage. Keeping the manufacturing in mind, the design of the roll cage was kept very simple. Thus it can be concluded that this roll cage demonstrates good strengths in all dynamic tests.

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