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Design and Analysis of a 3-Wheleer Integrated Monocoque Chassis

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Abstract: In this project, the design and development of integrated chassis of three wheeler prototype vehicle chassis is done, to convert the three wheeler passenger vehicle chassis into a load carrier chassis with the aim of reducing the tooling cost and increasing the rate of production. For this, The analysis is carried out by using Finite Element Analysis (FEA). The parameters checked in the analysis are the displacement of the chassis structure and stresses under static condition. The modeling of new chassis is done by using PRO-E and FEA by using ANSYS. Specifications of materials selection become a priority in order to construct the new chassis, based on the results of FEA we selected CRS-D grade (Cold Rolled Steel) of thickness 1.6mm. The best design with minimum self-weight, maximum load capacity and minimum deflection under static loading was then identified based on the results obtained through FEA.

Keywords: FEA, CRS-D, Monocoque.

I. INTRODUCTION

Chassis is a French term and was initially used to denote the frame parts or basic structure of the Vehicle. It is the back bone of the vehicle. A vehicle without body is called Chassis. The components of the vehicle like power plant, transmission System, axles, wheels and tires, suspension. Controlling Systems like braking, steering etc., and also electrical system parts are mounted on the Chassis frame. It is the main mounting for all the components including the body, so it is also called as "Carrying Unit". Since we are using two different chassis for passenger and load carrier vehicles, the tooling cost will be higher. The concept was aimed to make one chassis for both types with simple modifications. This was built from passenger vehicle chassis by adding some material at required locations but it serves the function of carrier vehicle. Hence, it will definitely decrease the tooling cost and also helps in increasing the production rate.

II. TYPES OF CHASSIS

- Backbone chassis
- Body on frame
- Space frame
- Monocoque

A. Backbone Chassis

Backbone tube chassis is a type of an automobile construction chassis that is similar to the body-on-frame design. Instead of a two-dimensional ladder type structure, it consists of a strong tubular backbone (usually rectangular in cross section) that connects the front and rear suspension attachment areas. A body is then placed on this structure.

Advantages:

- The half-axles have better contact with ground when operated off the road. This has little importance on roads.
- The vulnerable parts of drive shaft are covered by thick tube. The whole system is extremely reliable.
- Modular system is enabling configurations of 2, 3, 4, 5, or 6-axle vehicles with various wheel bases.

B. Body-On-Frame (Ladder)

Body-on-frame is an automobile construction method. Mounting a separate body to a rigid frame that supports the drive train was the original method of building automobiles, and its use continues to this day as shown in Fig.1. The original frames were made of wood (commonly ash), but steel ladder frames became common in the 1930s. It is technically not comparable to newer monocoque designs, and almost no modern vehicle uses it (other than trucks).

Advantages:

- Easier to design, build and modify (less of an issue now that Computer-Assisted Design (CAD) is commonplace, but still an advantage for coach-built vehicles).
- Quieter, because the stresses do not pass into the body, which is isolated from the frame with rubber pads around the attachment bolts. Less significant lately, but earlier bodies would squeak and rattle, ever more as they rusted, lubricants drained, and fasteners loosened. Isolated bodies had a lesser degree of these modes of aging.
- Easier to repair after accidents. This is crucial for taxicabs, because damaged bolt-on fenders can be replaced in the firm's own garage - for petty cash, with the cab returned to earning status immediately - whereas

a monocoque body would require straightening by paid specialists on machine expensive to rent - with the cab laid up for repair longer. Grand-Am allows tubular space frame cars to replace their monocoque counterparts, as the cars can easily be repaired with new clips.

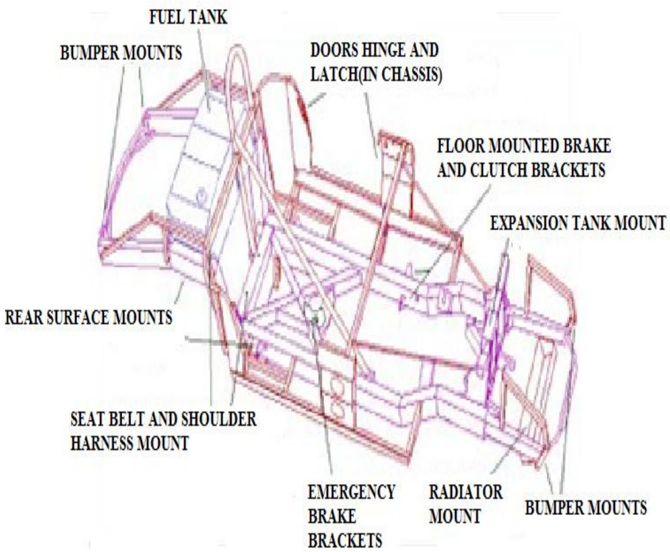

Fig.1. Body on frame ladder chassis[1].

C. Space Frame

In architecture and structural engineering, a space frame or space structure is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern. Space frames can be used to span large areas with few interior supports as shown in Fig.2. Like the truss, a space frame is strong because of the inherent rigidity of the triangle; flexing loads (bending moments) are transmitted as tension and compression loads along the length of each strut.

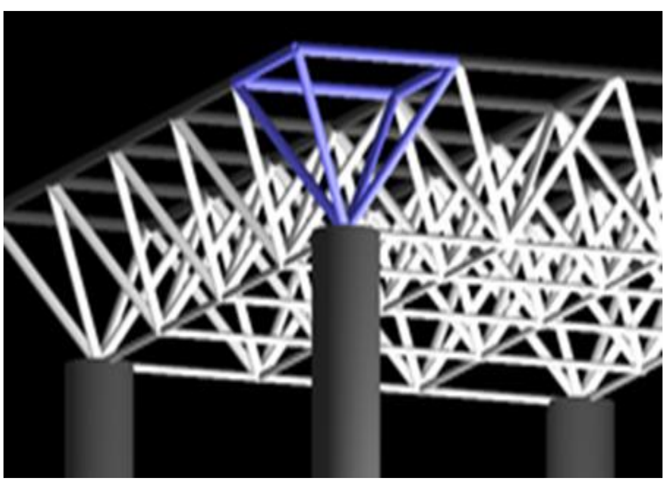

Fig. 2. Space frame chassis[2].

Simplified space frame roof with the half-octahedron highlighted in blue. The simplest form of space frame is a horizontal slab of interlocking square pyramids and tetrahedral built from aluminum or tubular steel struts. In many ways this looks like the horizontal jib of a tower crane repeated many times to make it wider. A stronger form is composed of interlocking tetrahedral in which all the struts have unit length. More technically this is referred to as an isotropic vector matrix or in a single unit width an octet truss. More complex variations change the lengths of the struts to curve the overall structure or may incorporate other geometrical shapes.

D. Monocoque

The word monocoque comes from the Greek for single (mono) and French for shell (coque).The technique may also be called structural skin or stressed skin. Alternatives to the monocoque structure are the truss structure, geodetic structure, unibody, inflatable, and semi-monocoque. The semi-monocoque is a hybrid of a mutually reinforcing tensile shell and compressive structure. A common aircraft has longerons (ribs or frames) and stringers. Most car bodies are not true monocoques; instead modern cars use unitary construction which is also known as unit body, unibody, or Body Frame Integral construction. This uses a system of box sections, bulkheads and tubes to provide most of the strength of the vehicle, to which the stressed skin adds relatively little strength or stiffness.

III. DESIGN OF CONCEPT MODEL CHASSIS

This study includes study of design, load criteria and analysis under static conditioning. It will help in understanding about the factors that will play vital role in designing. This study was done by designing and analyzing the components using PRO-E and ANSYS softwares. Here we are basically discussing the idea of designing passenger automotive vehicle chassis which is totally different from carrier automotive chassis basically used to carry loads.

Passenger: The passenger chassis has the following parts:

- Rear long member
- Riser member
- Front long member
- Cross member
- Horizontal tunnel
- Vertical tunnel

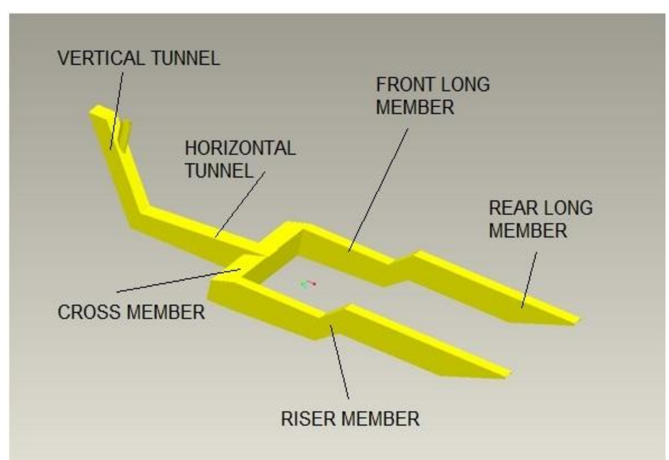

Fig.3. Different parts in passenger chassis.

The most important aspect of the vehicle design is the chassis or frame as shown in Fig.3. The frame contains the operator, engine, brake system, fuel system, and steering mechanism, and must be of adequate strength to protect the operator in the event of a rollover or impact. The chassis must be constructed of steel, with minimum dimensional and strength requirements. All members are made of cold rolled steel (E = 205GPa, ν = 0.30). All members are of 1.6mm wall thickness to realize the transmission and processing of data in distance. In this example, we will use ANSYS to investigate the response of the frame (e.g., stresses and deflections) under static loading. The applied forces are obtained by considering loads due to passenger's weight, engine mountings, fuel tank weight, other accessories weight and also the self-weight of the chassis. The loading is simulated by restricting displacements at certain locations, and applying discrete forces at various points on the frame where the weight is concentrated.

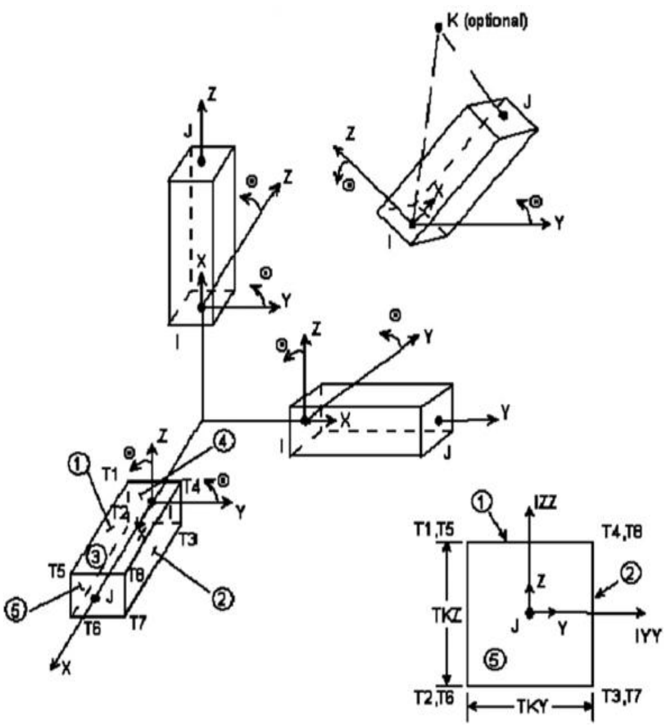

Fig.4. Beam element[3].

The BEAM4 element (shown below) requires the following cross-sectional properties to be calculated and entered as Real Constants: cross-sectional area, area moment of inertia about the z-axis (I_{zz}), area moment of inertia about the y-axis (I_{yy}), thickness along the z-axis (outer edge-to-edge), and thickness along the y-axis (outer edge-to-edge) as shown in Fig.4.

III. DESIGN OF PASSENGER CHASSIS

A. Analysis Of The Concept Model Chassis

The static analysis of the passenger chassis have done by constraining the front and rear wheels at desired locations and applied loads at front and rear positions as shown in Fig.5. By considering all the parameters like driver, passengers engine, fuel tank, self-weight of chassis.

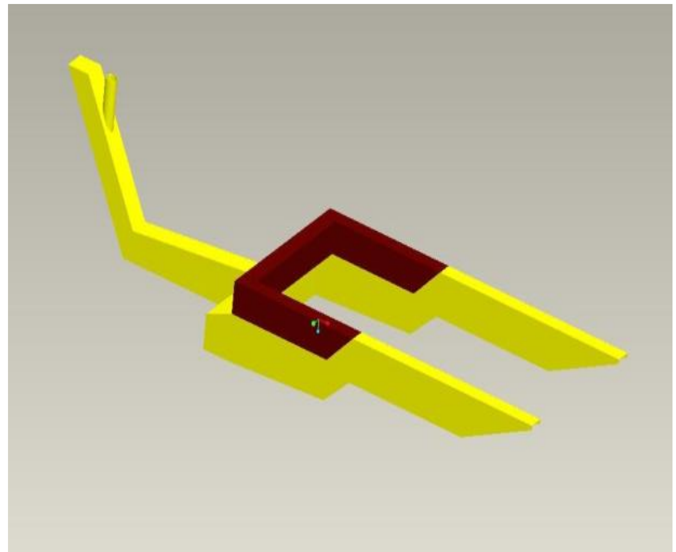

Fig.5.Prototype model in PRO-E.

B. Load Calculations for Passenger Chassis

Side bar of the chassis are made from "C" Channels with 165mm x 70 mm x 1.6 mm

Wheel Base (b) = 1720 mm

Overall length of the vehicle = 2800mm

Material of the chassis is CRS D Grade

Young's modulus, E= 205 GPa

Poisson's ratio = 0.3

Radius of gyration = 165/2 = 82.5

Capacity of the vehicle = 555kg = 5445N

Weight of the body and engine = 440kg = 4316.4N

Total load acting on the chassis in normal load condition

= capacity of the vehicle +weight of the body

= (5445+4316.4)N

= 9761.4N

Total load of the vehicle with 1.5% over load = 12484N Chassis has two beams. So load acting on each beam is half of the total load acting on the chassis. Load acting on single beam = 12484/2 = 6242N.

IV. FINAL LOADS ON WHEELS

After taking moment about centre of gravity of the vehicle into consideration we can conclude that

- Static load on the front wheel under normal load condition= 230kg.
- Static load on each of rear wheel under normal load condition =765/2=382.5kg.

- Static load on the front wheel under overload condition= 345kg.
- Static load on each of the rear wheel under overload condition=574kg.

A. Calculation For Reactions At Supports [4]

Chassis is simply clamp with Shock Absorber and suspension Spring. So Chassis is a Simply Supported Beam with uniformly distributed load. Load acting on Entire span of the beam is 6242 N. Length of the Beam is 2800 mm

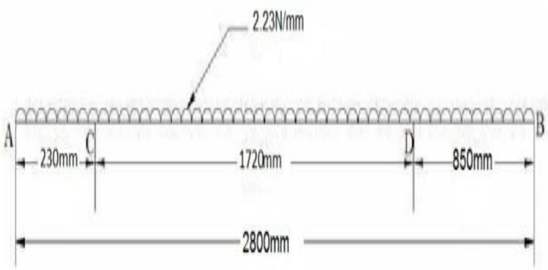

Fig.6.

Reaction at C,

$$Rc = \frac{wl(l-2c)}{2b}$$

$$= \frac{2.23 \times 2800 \times (2800 - 2 \times 850)}{2 \times 1720}$$

= 1997 N.

Reaction at D,

$$Rd = \frac{wl(l-2a)}{2b}$$

$$= \frac{2.23 \times 2800 \times (2800 - 2 \times 230)}{2 \times 1720}$$

= 4247 N.

B. Calculation Of Shear Force And Bending Moment

Shear Force:

Shear force at A, $V_A = w \times a$
$= 2.23 \times 230$
= 513 N

Shear force at B, $V_B = w \times c$
$= 2.23 \times 850$
=1896N

Shear force at C, $V_C = Rc - V_A$
= 1997-513
= 11484 N

Shear force at D, $V_D = Rd - V_B$
=4247-1896
=2351N

Bending Moment:

Bending moment C, $M_C = -\frac{wa^2}{2}$

$$= -\frac{2.23 \times 230^2}{2}$$

= -58983 N-mm.

Bending moment D, $M_D = -\frac{wc^2}{2}$

$$= \frac{2.23 \times 850^2}{2}$$

= -805587 N-mm.

Bending moment A, $M_A = -Rc(\frac{Rc}{2w} - a)$

$$= -1997(\frac{1997}{2 \times 2,23} - 230)$$

= -434862 N-mm.

Bending moment A, $M_B = -Rd(\frac{Rd}{2w} - c)$

$$= -4247(\frac{4247}{2 \times 2.23} - 850)$$

= -434222N-mm.

Calculation For Stress Generation:

M_{max}= Maximum of (M_A ,M_B ,M_C ,M_D)
=805587N-mm.

Moment of inertia about X-X axis is

$$I_{XX} = \frac{bh^3}{12} - \frac{(b-2t)(h-2t)^3}{12}$$

$$= \frac{70 \times (165+125)^3}{12} - \frac{(70-2 \times 1.6)((165+125)-2 \times 1.6)^3}{12}$$

= 10948627.42 N-mm^4

Section Modulus:

Section modulus about X-X axis

$$Z_{XX} = \frac{bh^3}{6h} - \frac{(b-2t)(h-2t)^3}{6h}$$

$$= \frac{70 \times (290)^3}{6 \times 290} - \frac{(70-2 \times 1.6)(290-2 \times 1.6)^3}{6 \times 290}$$

= 75507.77 mm^3

Stress:

Stress produced on the beam is as under:

$$\sigma = \frac{Mmax}{Z_{xx}}$$

$$= \frac{805587}{75507.77}$$

= 10.67 N/mm^2.

C. Ansys

Case 1: Normal Load Condition

Normal working conditions for front part 230kg force is applied and at rear 770kg have applied as shown in Figs.7 and 8.

1. Maximum deflection for the normal conditions is: 4.882mm.

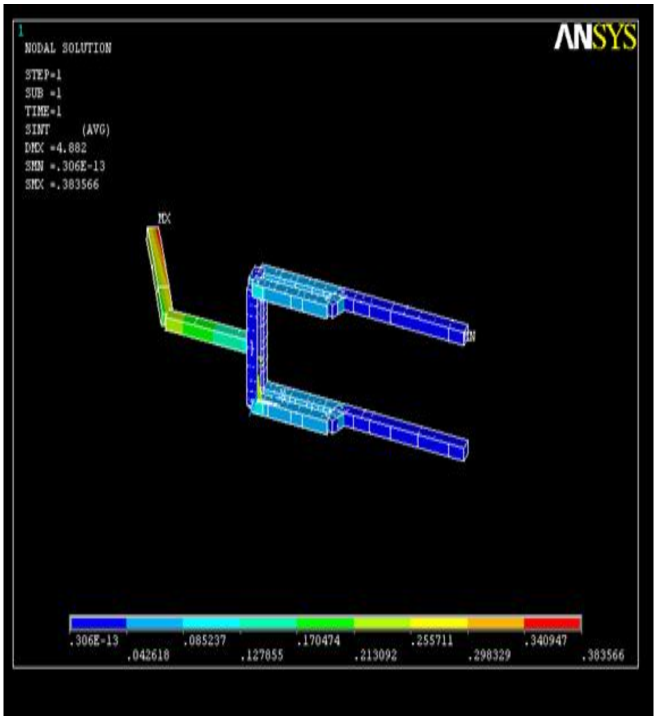

Fig.7. Deflection in concept model chassis in normal load condition.

2. Maximum stress for the normal condition is: 5.156N/mm^2

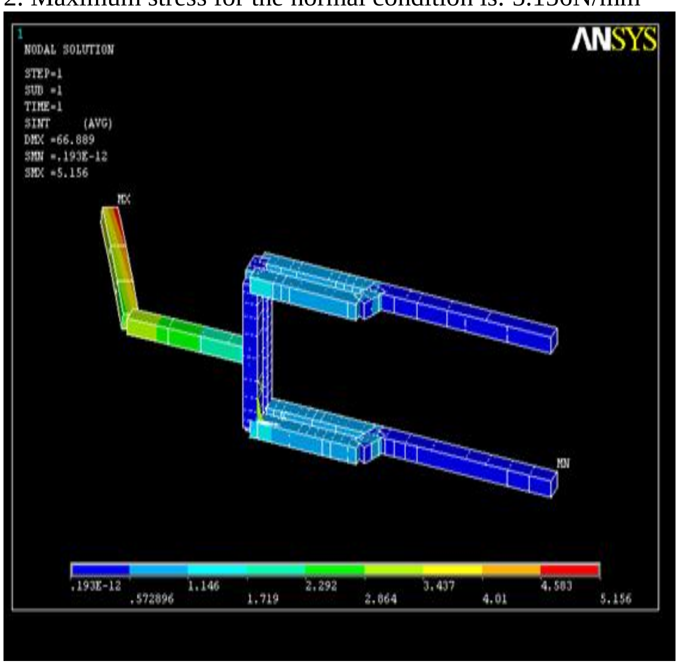

Fig. 8. Von misses stresses in concept model chassis in normal load condition.

Case 2: Over Load Condition

Over load condition (i.e., 50% extra load) for front part 345kg force is applied and at rear 1155kg have applied as shown in Figs.9 and 10.

1. Maximum deflection for the over load condition is: 7.322mm.

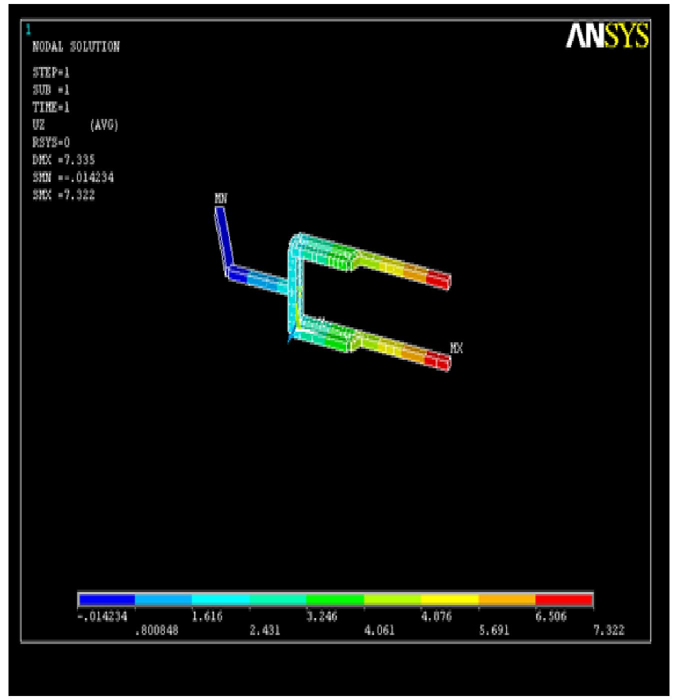

Fig. 9. Deflection in concept model chassis in over load condition.

2. Maximum stress for the over load condition is: 0.573 N/mm^2

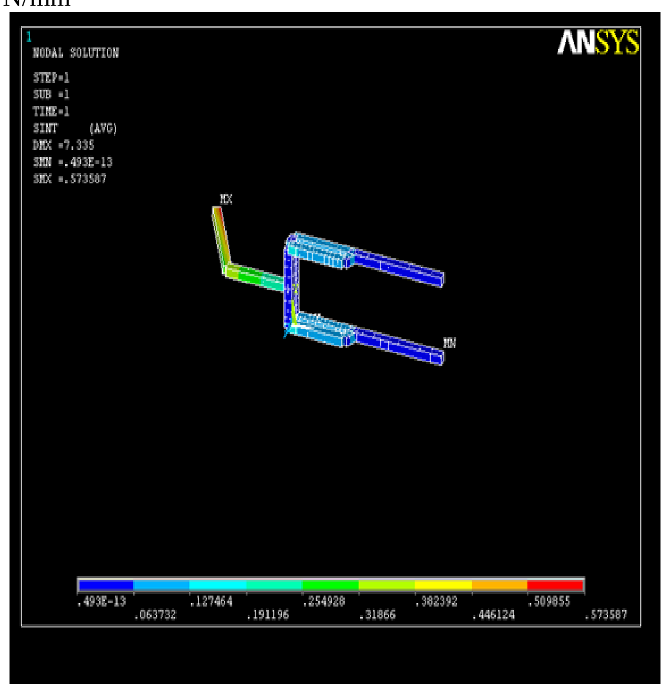

Fig. 10. Von misses stresses in concept model chassis in over load condition.

V. SELECTION OF MATERIAL

The added material is decided as CRS(cold roll steel), as the chassis material is also same. And the cross section as C-channel as shown in Fig.11.

Properties of the material:

Young's modulus: $E= 2.05*10^3$
Poisson's ratio: $v= 0.3$

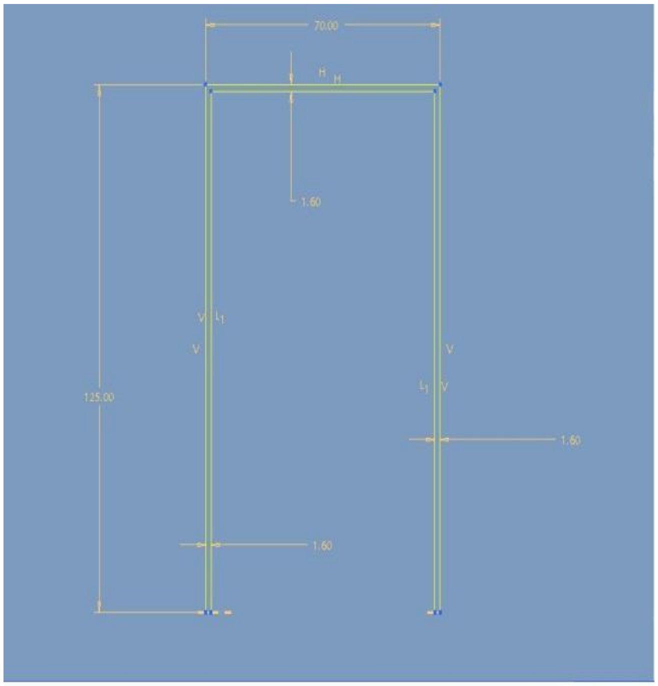

Fig.11. Cross section of added material in prototype.

Under normal loading conditions the vehicle has undergone a static deflection of 6.44mm vertically downwards and the stresses developed were $20N/mm^2$. Whereas with 50% overloading conditions the deflection and stress were 9.659mm and $27N/mm^2$ respectively. Since the material selected was CRS-D Grade of strength $450N/mm^2$, we can say that the body can withstand these stresses. Hence the vehicle is said to be safe under these conditions as shown in Fig.12.

Fig.12. Semi Integral Frame[5].

VI. ENGINEERING PROPERTIES OF CRS D-GRADE MATERIAL

Young's Modulus of Elasticity	200 x 103 MPa at 20 °C
Density	7.87 g/cm3at 20 °C
Coefficient of Thermal Expansion Low-Carbon/HSLA	12.4 µm/m/°C in 20 °C to 100 °C range I-F Steel: 12.9 µm/m/°C in 20 °C to 100 °C range
Thermal Conductivity Low-Carbon/HSLA:	89 W/m°C at 20 °C I-F Steel: 93 W/m°C at 20 °C
Specific Heat	481 J/kg/°C in 50 °C to 100 °C range
Electrical Resistivity	0.142 µΩm at 20 °C

VII. CONCLUSION

The concept model (or) prototype chassis is successfully designed and analyzed. The design is done by PRO_E software, analysis is done by using ANSYS. The design is developed after the study of the chassis design and analysis is performed on the chassis. Basic load calculations have been performed by using the concepts of strength of materials and these results have been compared with the results obtained through ANSYS. The FE results and theoretical results are in closed agreement, and the design stresses are within the limits of strength of material. Based on these results the passenger chassis is modified into the load carrier chassis which decreases the tooling cost and increases the productivity.

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