Design Optimization of Heavy Motor Vehicle Chassis using Response Surface Method

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Abstract: Chassis is an important part of an automobile which supports the body and different parts. In order to withstand maximum load, the chassis should be rigid enough to withstand twist, shock and vibration. In this research structural analysis of chassis is conducted using ANSYS FEA software to determine stresses and deformation under maximum loading condition. The CAD model of TATA 1612 chassis is prepared using Creo 2.0 software and analyzed. Taguchi design of experiments were performed using ANSYS optimization module and various responses are determined. With the help of response curves, optimal design parameters were obtained. Conclusions were drawn based on the results obtained so that optimal design parameters were used to build a chassis that has high strength to weight ratio.

Keywords: Chassis, Finite Element Analysis, Response Surface Method

I. INTRODUCTION

Commercial vehicles such as trucks, trailers and semi-trailers have chassis frames which are of the ladder type. These are so termed because of the configuration of their members. They generally consist of two side members arranged parallel to the longitudinal axis of the chassis and several cross members placed laterally between the side members. Thus, the axles, as well as the power plant, the driver's cab and platform or other superstructures, are easy to attach. Automobile industry has increasing demands for chassis frames for manufacturing of commercial vehicles meant for carrying heavy loads. The side members of ladder chassis frames are usually made from open channel or I-sections. An I-section is very efficient in providing bending stiffness but manufacturers prefer channel section side members because of cost and ease of construction. The cross members are often made from hollow rectangular, channel, top hat or I-sections. Hollow rectangular sections give efficient torsional and bending stiffness, but can lead to high overall frame torsional stiffness. The most flexible design of frame would have open section cross members - attached through end plates to the side member webs. Cross members can have variable cross section, i. e, shaped members to act as engine supports, cab mounts. There is a great variety of design of joints between cross members and side members, both as to joint configuration and the method of attachment of cross member to side member. The joints can greatly affect the torsional stiffness of the frame and cause high stress concentrations to develop. It is necessary that the desired torsional stiffness of a frame should not produce very high stresses in the joints which could cause them to fail. Fabrication of welded joints are hard and therefore costlier. Bolts and rivets in joints, although being the easiest methods of fixation, can cause stress concentration in the region of holes through which they pass.

II. LITERATURE REVIEW

Swami K.I.and Tuljapure S.B.(2014)[1] investigated ladder type truck chassis of Eicher 20 by ANSYS software having 2 side members of C section and 7 transverse members. The findings shows decrease in equivalent stress with increase in side member thickness. Aditya Singh (2014)[2] investigated TATA LP 912 chassis having different cross sections namely C,I, rectangular box. The results have shown that chassis made from rectangular cross section has lowest deformation compared to other 2 sections.

Sandip Godse and D.A.Patel(2013) [3] investigate TATA ACE chassis by ANSYS software and optimized stress using reinforcement technique. The stresses in base design was 37.04N/mm^2 which reduced to 22.97N/mm^2 after modification using reinforcement. Manpreet Singh Bajwa, Yatin Raturi and Amit Joshi (2013)[4] has also conducted structural analysis on TATA ACE chassis using ANSYS software having C shaped section and validated software results with analytical results. Madan Mohan Reddy and Lakshmi Kanta Reddy (2014) [5] has conducted Finite Element Analysis of container chassis to investigate failure due to bending by incorporation of stiffeners. Findings have shown considerable use of stiffeners has led to considerable reduction in equivalent stresses (37.11%) and stress intensity (36.23%)

Bhat KA, Untawale SP, Katore HV (2014) [6] has investigated tractor trolley chassis by changing “C” shaped cross section to “I” shape cross section and keeping the material same i.e. mild steel. This has led to considerable reduction in weight of chassis i.e. 31.79 Kg and incurred lower stresses as compared to previous cross section.

Ketan Gajanan Nalawade, Ashish Sabu and Baskar P (2014) [7] conducted structural analysis on chassis using E-glass composite by ANSYS software and found increase in stiffness along with 68% reduction in weight.

Abhishek Sharma, Pramod Kumar, Abdul Jabbar and Mohammad Mamoon Khan(2014)[8] have conducted structural analysis on heavy vehicle chassis using ANSYS 15.0 on TATA LPS 2515 EX model. The analysis is performed using three different alloys cast iron, AISI 4130 alloy steel and ASTM A710 and also worked with different cross sections. They found that out of the three alloys AISI 4130 has shown lower stress.

III. PROPOSED WORK

The objective of this research is to optimize chassis design by varying widths of cross members (3 members) using response surface method of optimization. Selecting cross member width as optimization parameter and determining design points using design of experiments. Determining response surface, goodness of fit curve, sensitivity chart and linear curves to determine effect of input parameters on output variables.

IV. METHODOLOGY

The CAD model of chassis is done using ANSYS software in design modeller. The CAD model of ladder chassis is developed using C shape profile with dimensions C type (116mm x25mm x5 mm) and frame width 884mm. [9]
Front Overhang (a) = 740 mm and
Rear Overhang (c) = 1400 mm and
Wheel Base (b) = 6670 m

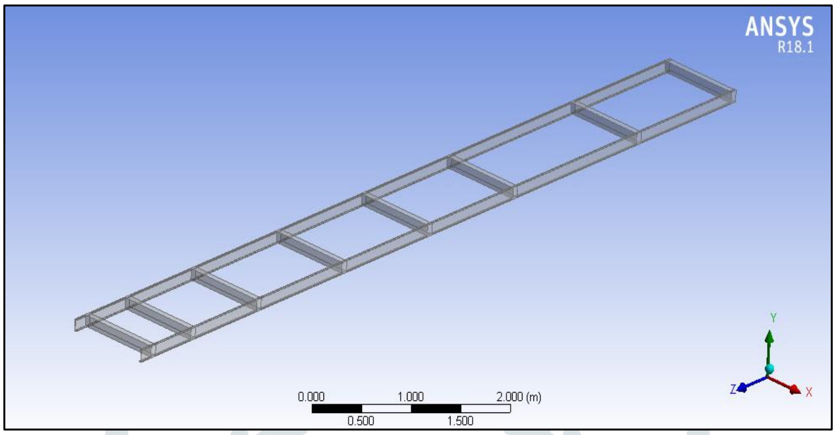

Figure 2: CAD model of Ladder Chassis

The CAD model of chassis is meshed using tetra elements as shown in figure 3 below. The model is meshed using adaptive size function, relevance order 100 and fine sizing. The transition is set to smooth, span angle center set to coarse.

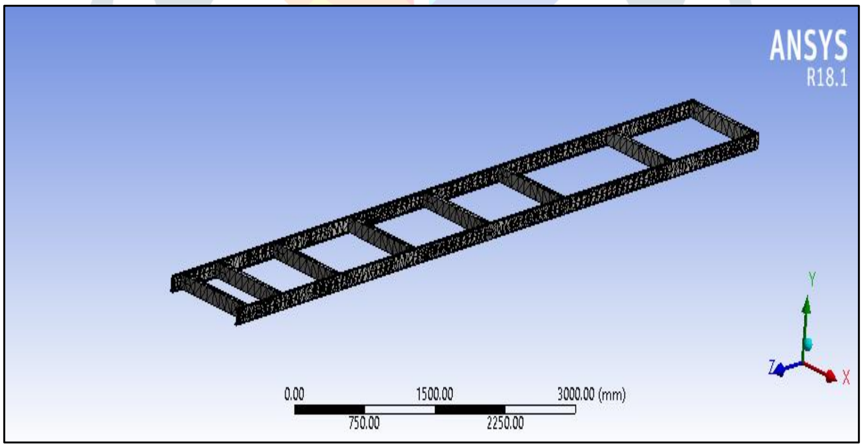

Figure 3: Meshed model of Ladder Chassis

Basic calculation for chassis frame Model No. = Tata 1612
Front Overhang (a) = 740 mm
Rear Overhang (c) = 1400 mm
Wheel Base (b) = 6670 mm
Load on Chassis = Capacity of the Chassis + Weight of body and engine
= (25000+600+400+200) *9.81 = 257022N
Uniformly Distributed Load is 128511/ 8810 =14.58 N/mm
Chassis as a simply supported beam with overhang Stress generated
M –max = 72022530.91N-mm
Moment of inertia around the x-x axis = 1266840 mm^4
Section of modulus about X-X axis = 21842.06897 mm^3
stress produced on the beam = 3297.422 N/mm^2

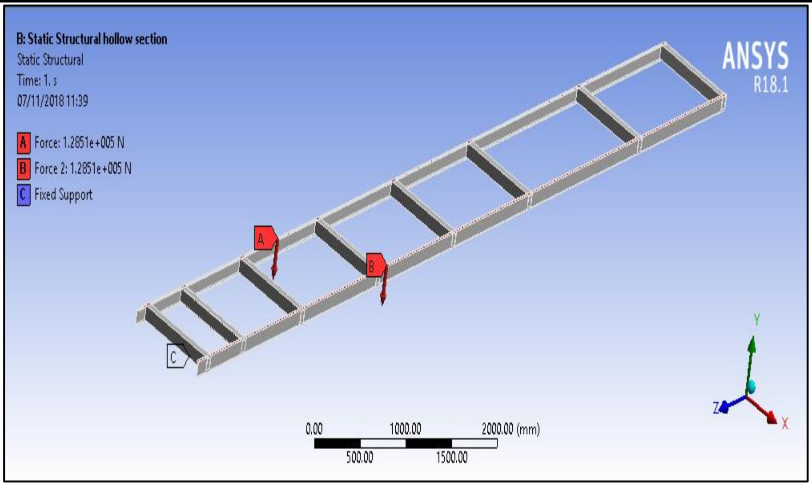

Figure 4: Loads and Boundary Conditions

Figure 4 above shows loads and boundary conditions applied on chassis. Two loads in downward direction are applied and fixed supports are provided at front cross member and rear cross member.

V. DESIGN OF EXPERIMENTS

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. ANSYS optimization is selected is central composite design scheme. After design points are generated using Design of Experiments, the output i.e. responses are determined from Central Composite Design scheme. These output parameters are shear stress and strain energy. The response surface graph is plotted showing variation of output variable (shear stress and strain energy) w.r.t input variable. The goodness of fit curve shows difference between observed values and values expected under the model in question. The sensitivity analysis graph is plotted showing the percentage influence of input parameter on desired response i.e. equivalent stress and deformation.

Name	P5 - cross_member1 (mm)	P6 - cross_member2 (mm)	P7 - cross_member3 (mm)
1 DP 32	65	65	65
2	58.5	65	65
3	71.5	65	65
4	65	58.5	65
5	65	71.5	65
6	65	65	58.5
7	65	65	71.5
8	59.715	59.715	59.715
9	70.285	59.715	59.715
10	59.715	70.285	59.715
11	70.285	70.285	59.715
12	59.715	59.715	70.285
13	70.285	59.715	70.285
14	59.715	70.285	70.285
15	70.285	70.285	70.285

Figure 5: Design Points generated from design of experiments

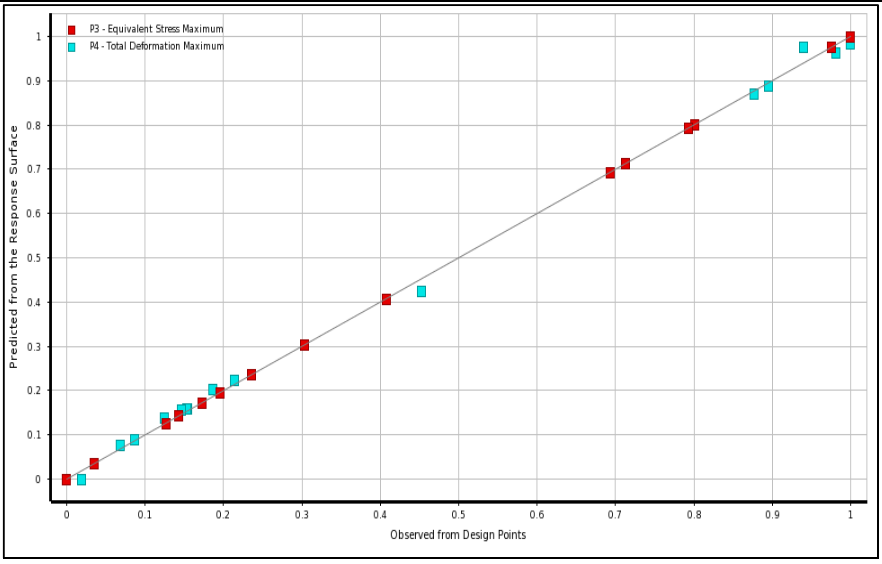

Figure 6: Goodness of Fit Curve

The goodness of fit curve is generated as shown in figure 6 above. Goodness of fit curve shows deviation of observed values from expected values. In this case except for certain design points both equivalent stress and total deformation doesn't show much deviation from expected values as shown by red color box for equivalent stress and blue color boxes for total deformation.

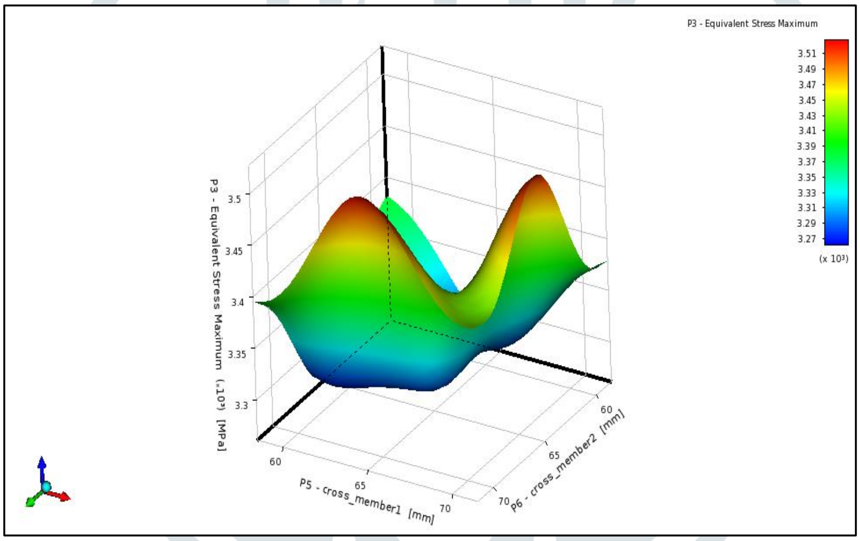

Figure 7: Response Surface Plot by optimizing cross member 1 and 2

The response surface plotted above shows great degree of non-uniformity in equivalent stress values. The maximum equivalent stress is shown by dark red color with magnitude of 3510MPa for cross member 1 dimension more than 70mm and cross member 2 dimensions between 62.5mm to 67.5mm. The minimum value of equivalent stress is observed to be 3270MPa for all other points.

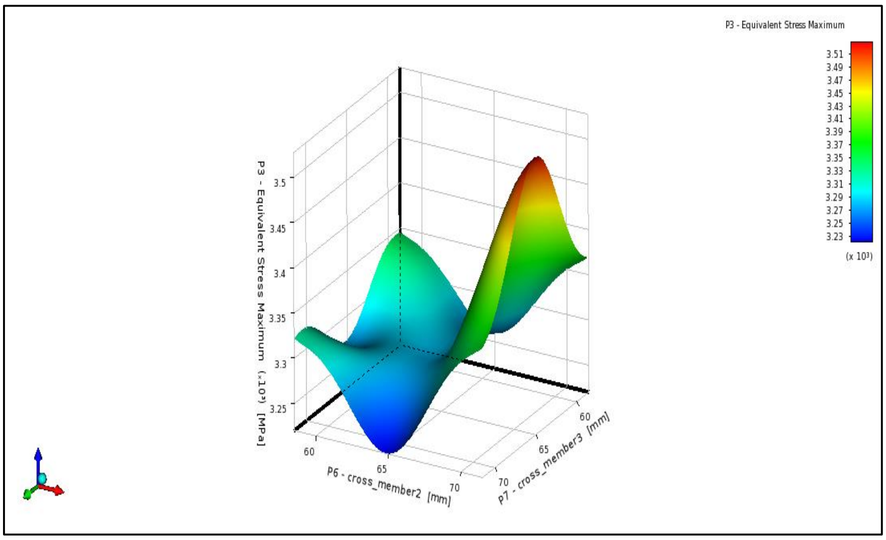

Figure 8: Response Surface Plot by optimizing cross member 2 and 3

The response surface generated by optimizing cross member 2 and cross member 3 is shown in figure 5.8 above. The graph shows single bump of red contour with maximum value of equivalent stress to be 3510 MPa and minimum value of equivalent stress observed is 3230MPa for cross member 2 dimensions more than 70 and cross member 3 dimensions near 65mm.

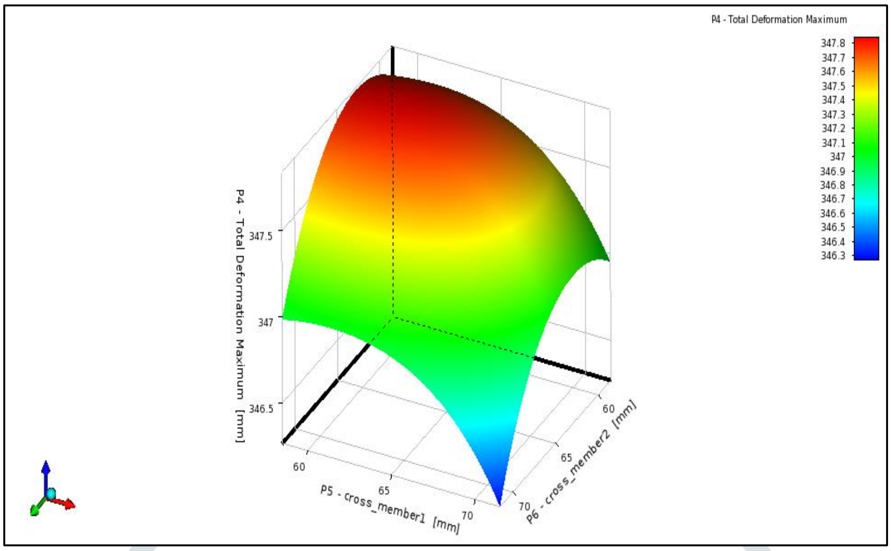

Figure 9: Response Surface Plot for deformation by optimizing cross member 1 & 2

The response surface plot for deformation is shown in figure 5.12 above. The input parameters for optimization are cross member 1 width and cross member 2 width. The plot shows higher values of deformation of magnitude of 347.8mm for cross member 1 width less than 65mm and for cross member 2 width also less than 65mm. The minimum values of deformation is observed to be 346.3mm for width greater than 70mm for both 1 & 2.

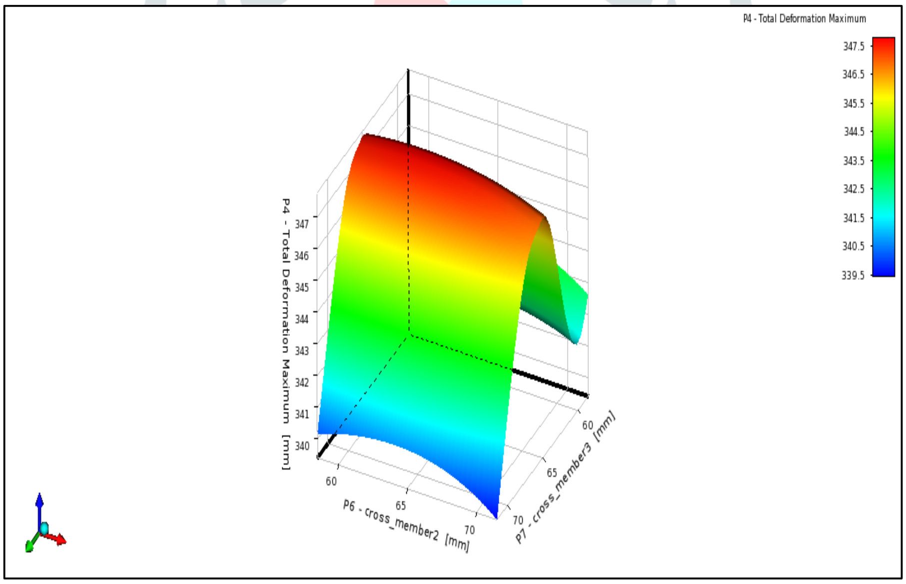

Figure 10: Response Surface Plot for deformation by optimizing cross member 2 & 3

The response surface plot for deformation is shown in figure 5.13 above. The input parameters for optimization are cross member 2 width and cross member 3 width. The plot shows higher values of deformation of magnitude of 347.8mm for cross member 3 width ranging from 62.5mm to 67.5mm. The single bump is observed in the plot shown by dark red color. Minimum deformation observed is 339.5mm.

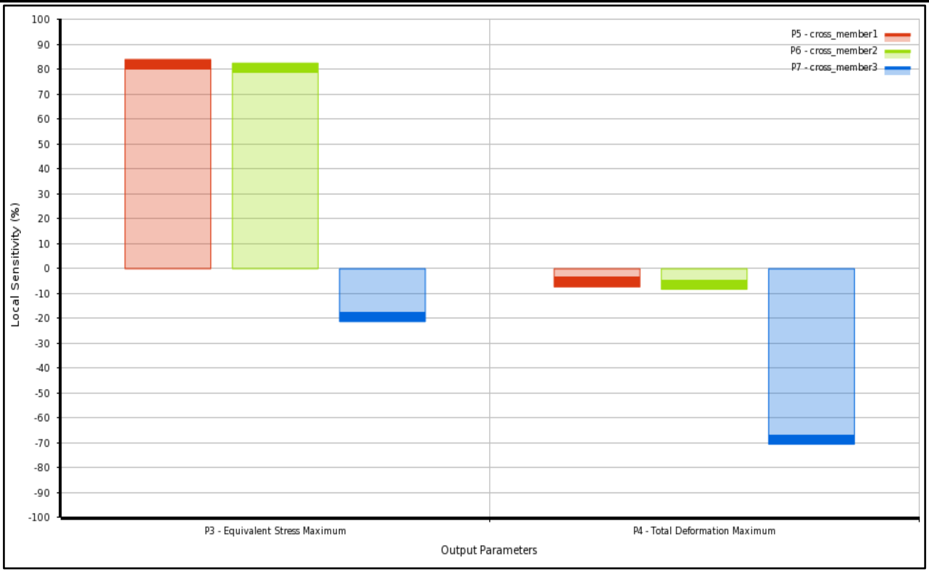

Figure 11: Sensitivity Analysis plot

The sensitivity graph showing sensitivities of different input parameters (cross member 1,2 & 3 width). As its evident from sensitivity plots above cross member 1 & 2 shows positive sensitivity for equivalent stress i.e. increasing width of cross member 1 & 2 increases equivalent stress while cross member 3 shows negative sensitivity i.e. increasing width of cross member 3 decreases equivalent stress. Sensitivity percentage of cross member 1 is 84.019%, sensitivity percentage of cross member 2 is 82.582% and sensitivity percentage of cross member 3 is -21.23% for equivalent stress. The sensitivities for deformation is negative for displacement of all the there input parameters width of cross member 1,2 & 3. The sensitivity percentage is -7.26%, -8.26% and -70.48% for cross member 1,2 & 3.

Table 5.1: Maximum and minimum values of equivalent stress and deformation

	A	B	C
1	Name	Calculated Minimum	Calculated Maximum
2	P3 - Equivalent Stress Maximum (MPa)	3220.3	3527.7
3	P4 - Total Deformation Maximum (mm)	338.08	347.89
4	P8 - Solid Mass (kg)	200.46	228.82

The maximum and minimum values of deformation and equivalent stress are obtained from response surface method of optimization and is shown in table 5.1 above. The maximum value of equivalent stress obtained from all set of design points is 3527.7MPa and minimum value of equivalent stress is 3220.3MPa. Similarly, the maximum values of deformation for all set of design points is 338.08mm and minimum value of deformation is 347.89mm. The maximum mass obtained from optimization is 228.82Kg and minimum mass is 200.46Kg.

VI. CONCLUSION

The FEA analysis of chassis frame is conducted using ANSYS software and results are analytically verified. The lateral members (1st three members) of chassis frame are optimized using design of experiments and response surface methodology. The response surface plots are generated for deformation and equivalent stresses. From response surface plots the range of magnitude of parameters (cross member widths) can be determined for maximum and minimum values of equivalent stress and deformation. The details are as follows:

- The equivalent stress plot as shown above shows the maximum value of 3280.5MPa near the front portion and rear portion at the vicinity of joints. While the remaining portion of chassis has almost same value of stress and higher at mid portion

- The maximum deformation is seen on the mid portion of chassis with value of 347.45mm and minimum deformation is seen on the ends of chassis near to supports.

- For design of experiments 1st three cross member widths have been taken for analysis and sensitivity analysis shows that cross member 3 width has maximum negative sensitivity in deformation of chassis i.e. increasing the width of cross member 3 will reduce deformation of chassis and vice versa.

- In equivalent stress case, the cross member 1 width shows maximum positive sensitivity i.e. increasing cross member 1 width increases equivalent stress and vice versa.

- The response surface plot of deformation shows higher values of deformation of magnitude of 347.8mm for cross member 1 width less than 65mm and for cross member 2 width also less than 65mm. The minimum values of deformation is observed to be 346.3mm for width greater than 70mm for both 1 & 2.

- The response surface plot of deformation (cross member 2 and cross member 3) shows higher values of deformation of magnitude of 347.8mm for cross member 3 width ranging from 62.5mm to 67.5mm.

- The response surface plot of equivalent stress (cross member 2 and cross member 3) maximum value of equivalent stress to be 3510 MPa and minimum value of equivalent stress observed is 3230MPa for cross member 2 dimensions more than 70 and cross member 3 dimensions near 65mm.

- From response surface plot of equivalent stress shows maximum magnitude of 3510MPa for cross member 1 dimension more than 70mm and cross member 2 dimensions between 62.5mm to 67.5mm. The minimum value of equivalent stress is observed to be 3270MPa for all other points.

- From DOE it is found that mass of chassis can be minimized to 200.46Kg at certain design points.

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