DESIGN OF A FORMULA SAE CHASSIS ACCORDING TO LATERAL LOAD TRANSFER DISTRIBUTION

Satyam Tripathi[1], Aman Tiwary[2], Shivam Rai[3]

Abstract

This paper discusses the design of a Formula SAE racecar chassis for torsional stiffness. At first, the need of having a torsionally stiff chassis is discussed. Then an attempt is made to answer the question- how stiff is stiff enough?

To answer this question, a mathematical model of a flexible chassis is developed and compared to an infinitely stiff chassis based on roll stiffness distribution and lateral load transfer distribution. Two methods are developed to reach the target torsional stiffness value with minimum weight possible, one, by changing the cross sectional area of the tubes and second, by reallocation of tubes. In the end specific structural members are predicted which have a high effect on torsional stiffness of chassis.

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1. INTRODUCTION

This paper discusses the need of having a torsionally stiff chassis at first. Then we try to answer the long discussed question of how stiff a chassis should be. Stiffness can be, obviously, increased with increase in weight. But, if we have a chassis stiffness that is just stiff enough to do the ‘job’,a lot of weight saving can be done. This ‘job’is, essentially, transmitting lateral loads as predicted due to suspension roll stiffness. When a target has been set for chassis torsional stiffness, two methods are discussed to design it, the only constraint being weight. These methods are-

First, by changing the cross sectional area of tubes which changes their polar moment of inertia and thus their torsional stiffness.

Second, by reallocation of tubes, i.e, changing the position of tubes from areas which are already stiff, to areas which can be made stiffer.

Lastly we predict those members that have a large effect on the overall stiffness of the chassis. In the end, the chassis design is compared for weight, torsional stiffness and torsional stiffness to weight ratio.

2. NEED FOR TORSIONAL STIFFNESS

Apart from absorbing the loads coming from the road and other vibrating components such as the engine, an important function of the chassis is to control the amount of lateral load transfer. Thinking of the chassis as a large spring connecting the front and rear suspension: if thechassis is torsionally weak,attempts to control the lateral load transfer distribution will be confusing at best and impossible at worst.[1]

According to Deakin[2], for a racecar to handle properly, it must be possible to actually tune the handling balance.

Oversteer and understeer characteristics can be corrected by changing the amount of lateral load transfer distribution. The best way to change lateral load transfer distribution is by changing roll stiffness distribution. This is usually done with the help of anti-roll bars. But, if a chassis is weak, changes made in roll stiffness distribution will not be apparent and thus tuning the handling balance will be difficult. This happens because the chassis then acts as a spring instead of an infinitely rigid body. Thus, a chassis that is stiff enough to control the lateral load transfer distribution is required.

3. MATHEMATICAL MODEL FOR FLEXIBLE CHASSIS

According to Enrico[3], modeling chassis flexibility as a function of total load transfer that occurs at the front-

$$\Delta F_{zF} = \left(\frac{k_F d_{sF} m_{sF}}{k_F + \frac{k_R k_C}{k_R + k_C}} + \frac{\frac{k_F k_C}{k_F + k_C} d_{sR} m_{sR}}{\frac{k_F k_C}{k_F + k_C} + k_R} + z_F m_{sF} + h_{uF} m_{uF} \right) . \frac{a_y}{t_F}$$

ΔF_{zF}-partial lateral load transfer at front k_F-front roll stiffness
k_R-rear roll stiffness
k_C-chassis torsional stiffness
m_{sF},m_{sR}-sprung mass at front and rear m_{uF}-unsprung mass at front
z_F-front roll centre height
h_{uF}-height of centre of gravity of unsprung mass from ground a_y-lateral acceleration
t_F-track width (front)
$d_{sF}=h_{sF}-z_f$; $d_{sR}=h_{sR}-z_R$

Using these equations, graphs are plotted of front lateral load transfer vs front roll stiffness for chassis of stiffness of 900 Nm/° to 2700 Nm/° over a range of static weight distributions.

Graphs are also plotted for the same parameter but with infinitely stiff chassis. All other values of roll center height, cg height, etc ae kept constant and these values were taken according to the specifications of previous year's car.

4. OBSERVATIONS

In all graphs blue line represents infinitely rigid chassis and orange line represents flexible chassis.

- At 20-80 weight distribution, increasing chassis stiffness hardly has any effect in bridging the gap of lateral load transfer between rigid and flexible chassis.

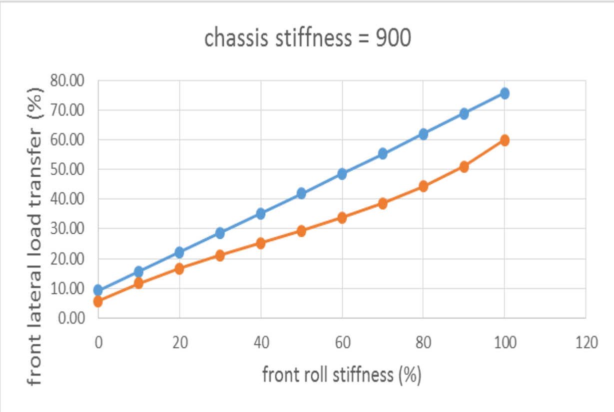
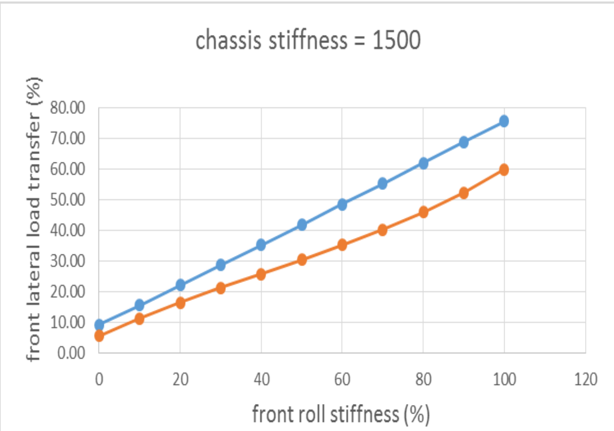


Fig: 1



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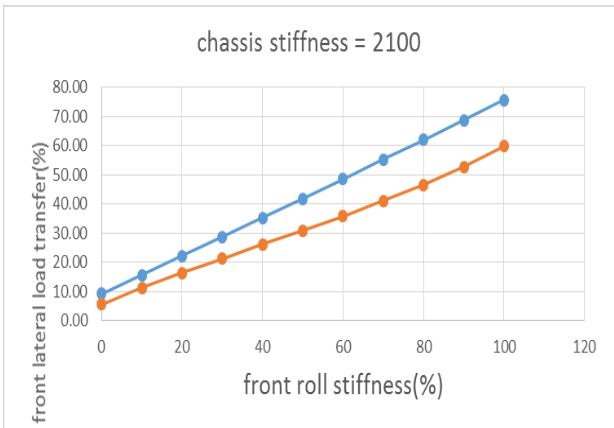

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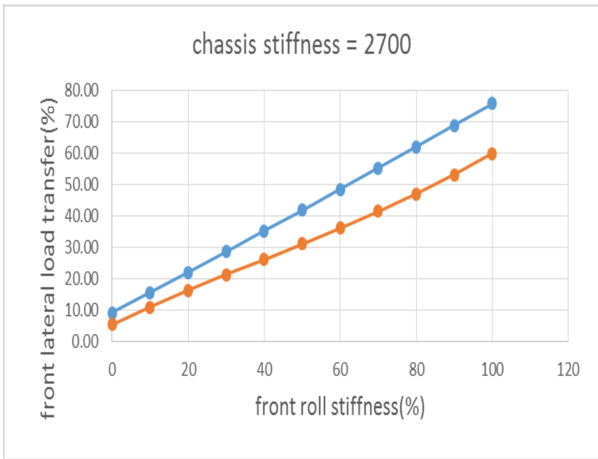
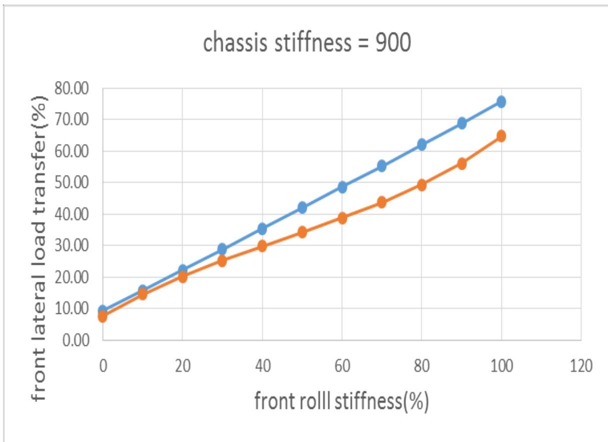


Fig: 4

- At 30-70 weight distribution, lateral load transfer in rigid and flexible are very close at around 10% front roll stiffness, but the front lateral load transfer is only about 15% of the total.



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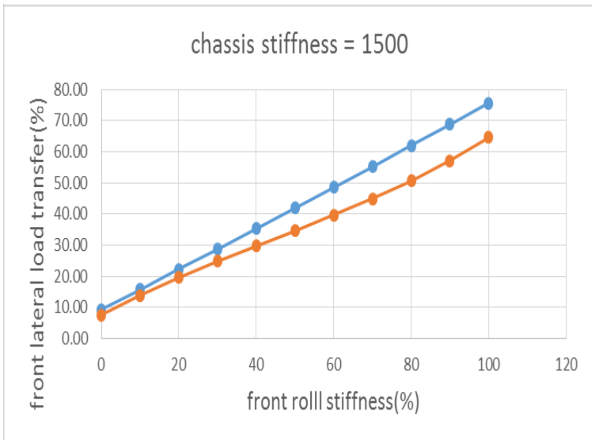

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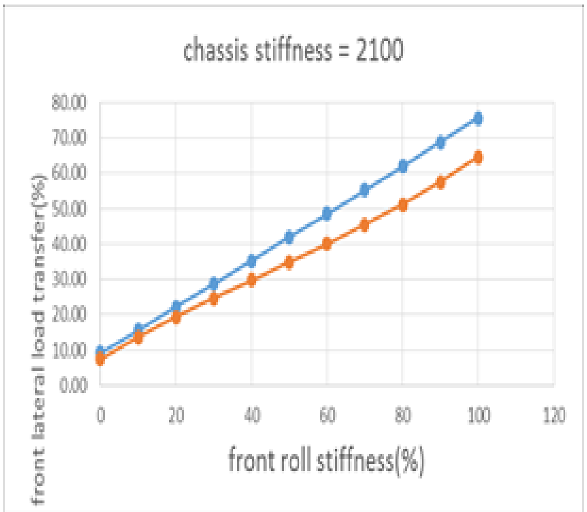

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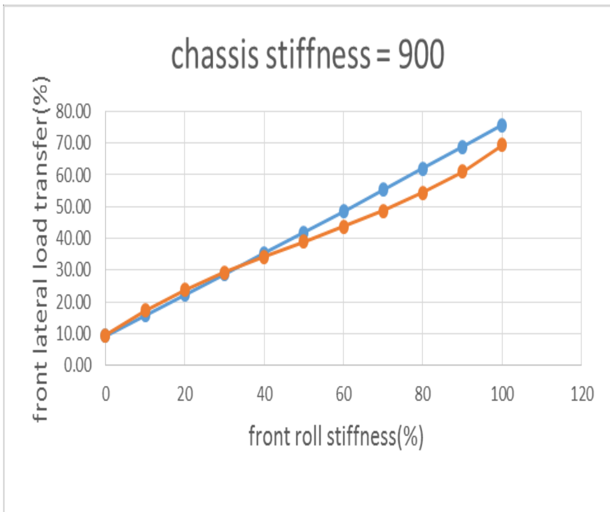

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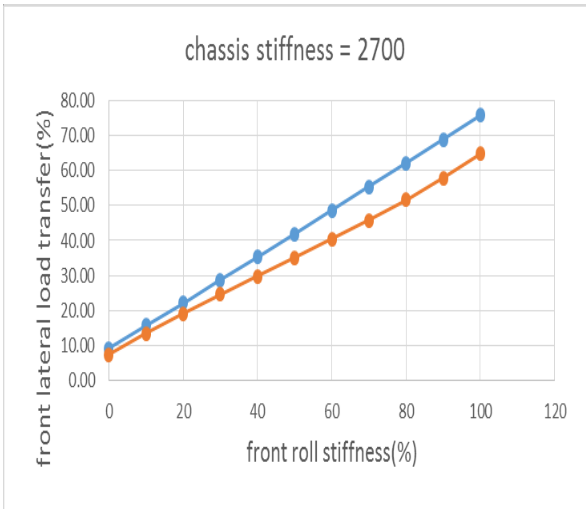

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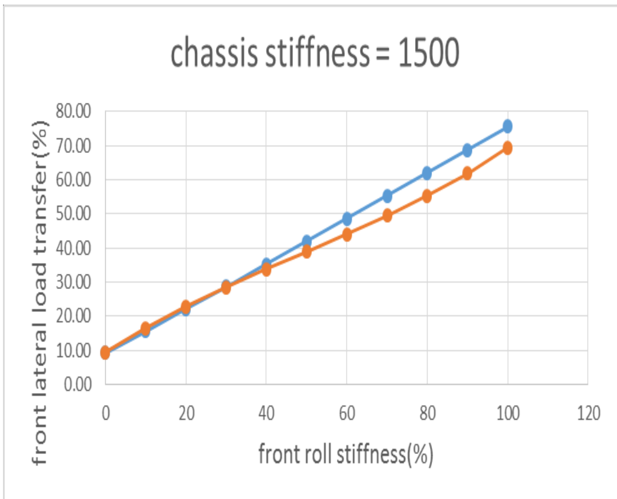
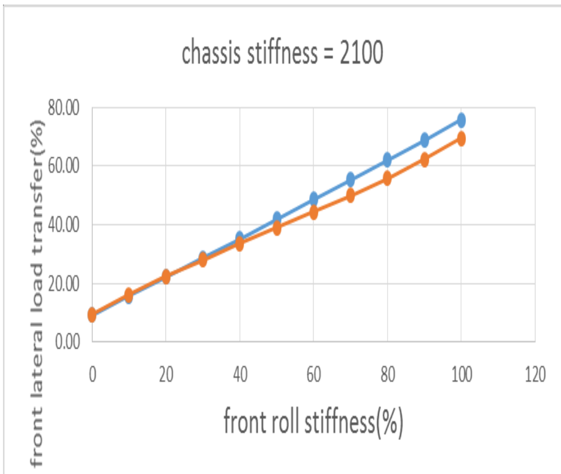


Fig: 10

- At 40-60 weight distribution, the graph of flexible chassis is very close to infinitely rigid chassis, and the gap between the two decreases as we increase the torsional stiffness of the chassis. But this is mainly true for low values of front roll stiffness.



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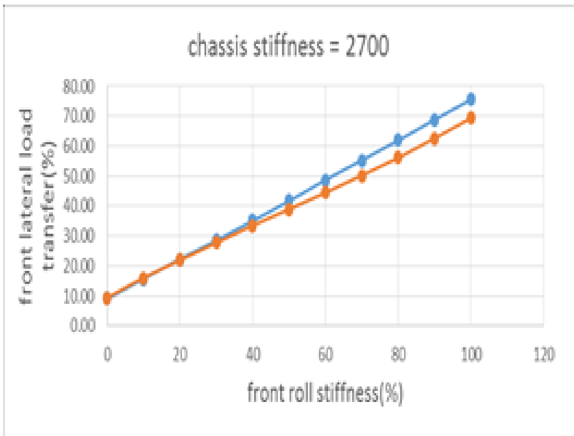
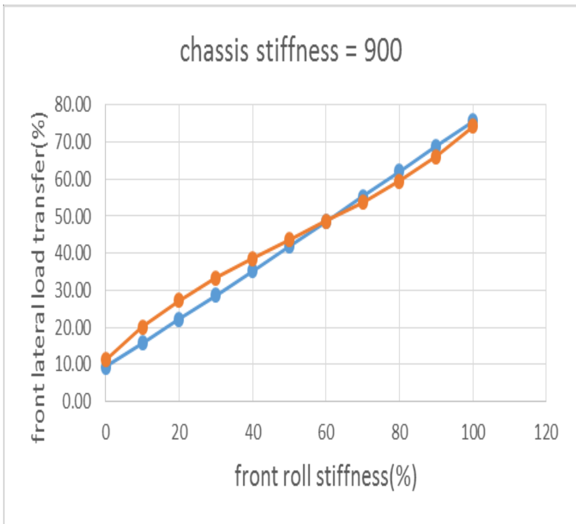


Fig: 12

- At 50-50 weight distribution, load transfers are very close even for low chassis stiffness. At 60% front roll stiffness the lateral load transfer is same for both rigid and flexible cases. Thus, at this value lateral load transfer distribution bcomes independent of chassis torsional stiffness.



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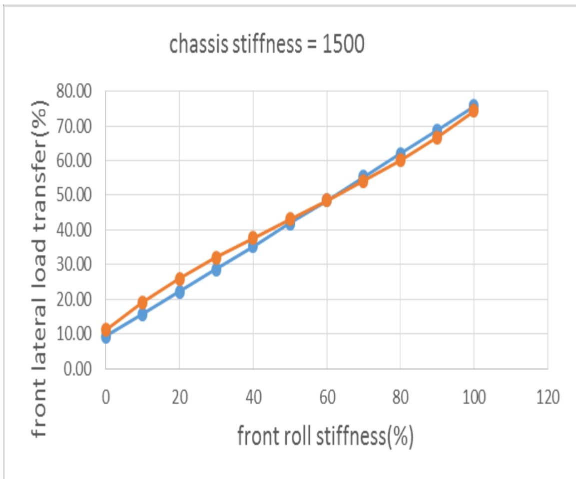

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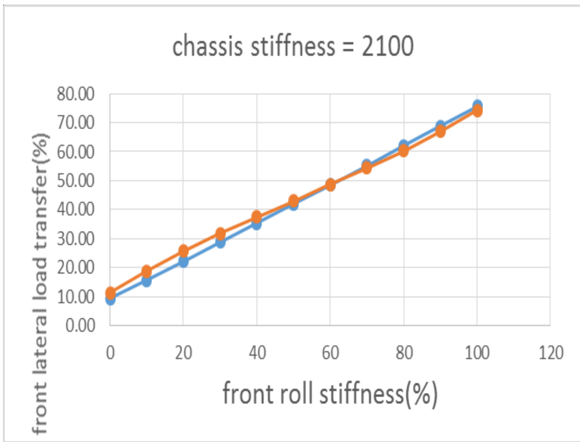

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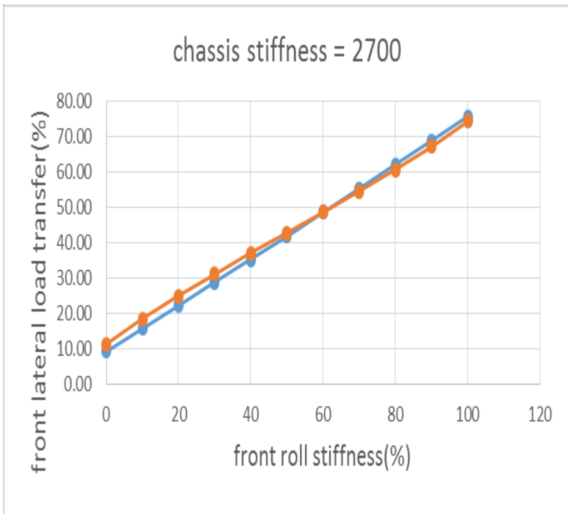
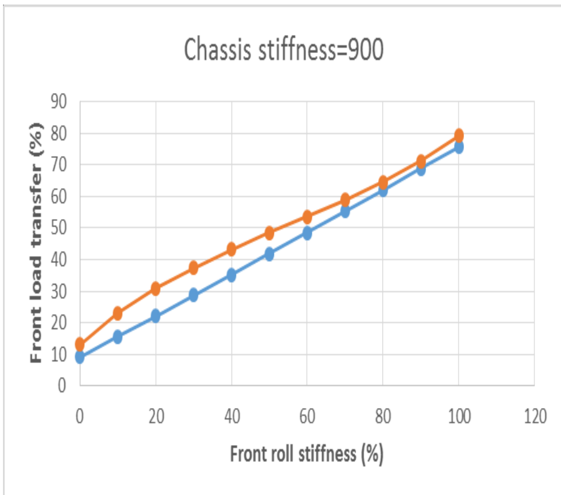


Fig: 16

- At 60-40 weight distribution, at around 90% front roll stiffness the lateral load transfer in both cases are close. From 0% to 50% front roll stiffness, the gap between the two curves is larger. On increasing chassis stiffness, this gap decreases.



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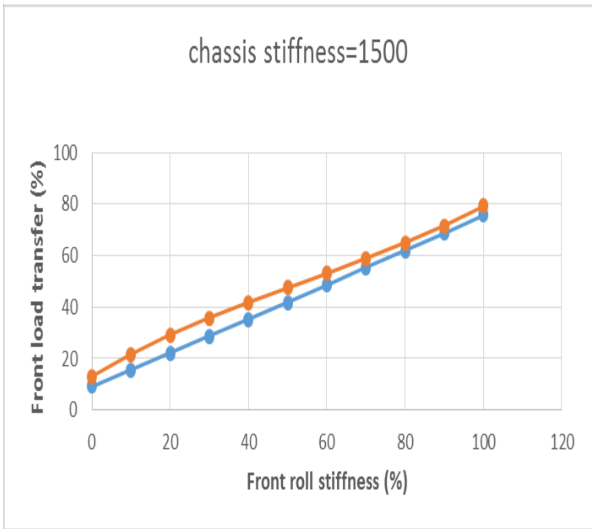

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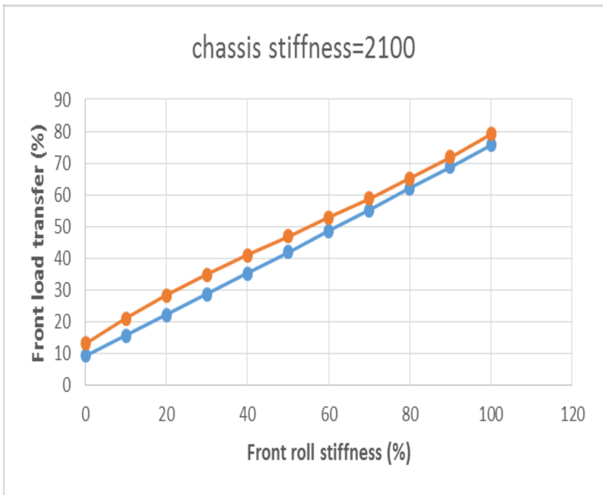

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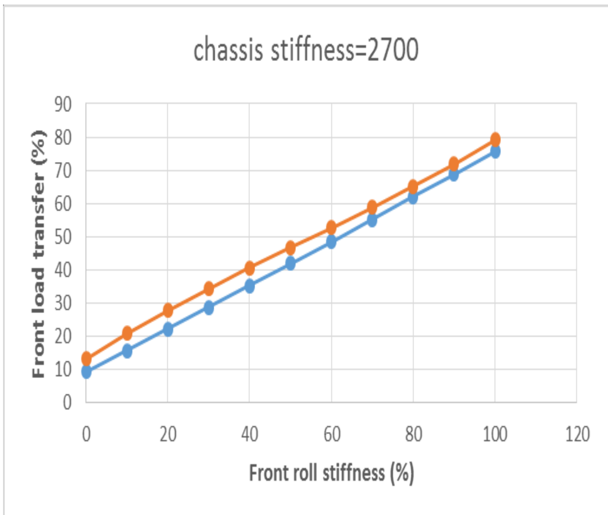
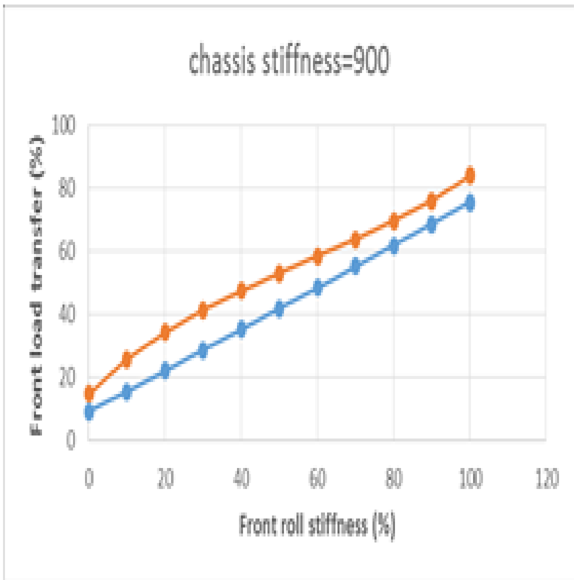


Fig: 20

- At 70-30 weight distribution, the two curves are close to parallel lines as we go on increasing chassis torsional stiffness.



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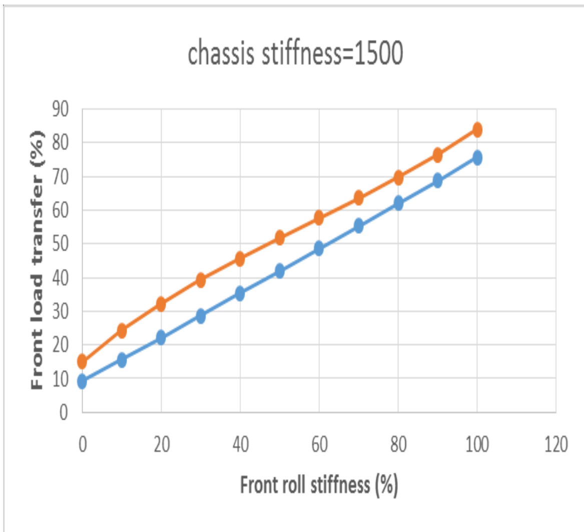

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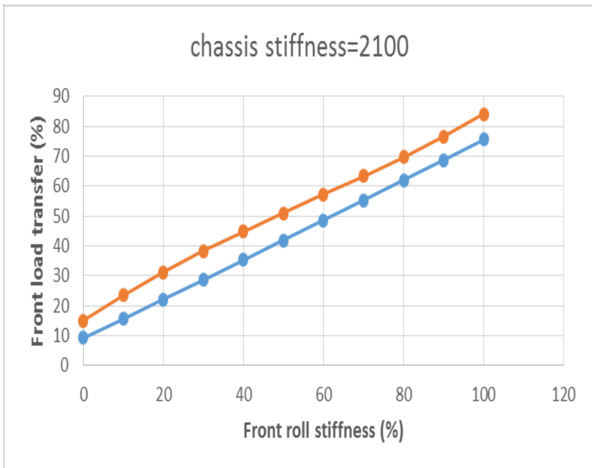

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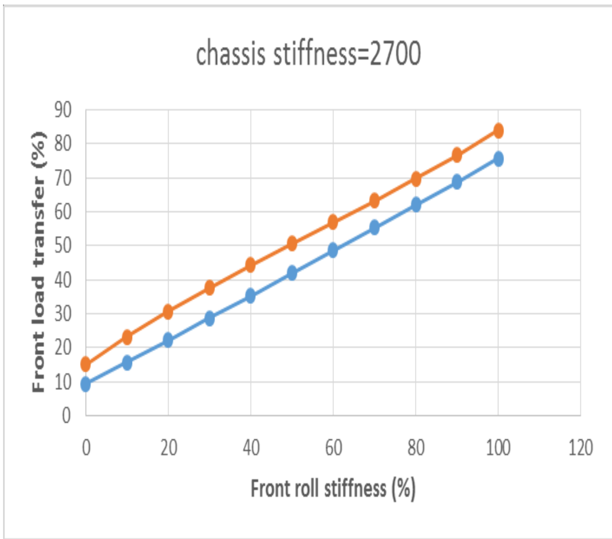
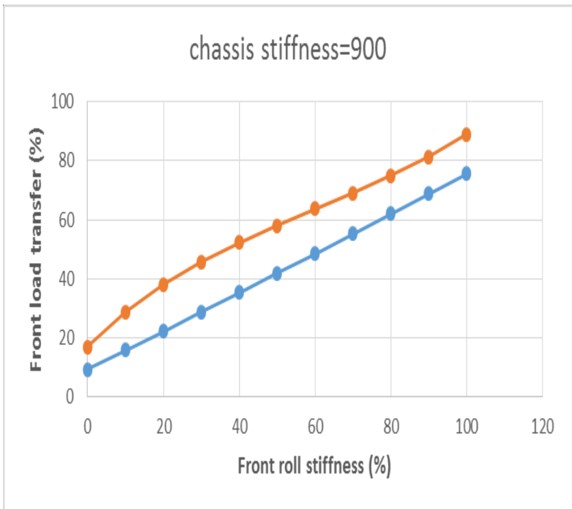


Fig: 24

- At 80-20 weight distribution, the gap is quite large and the lines are almost parallel.



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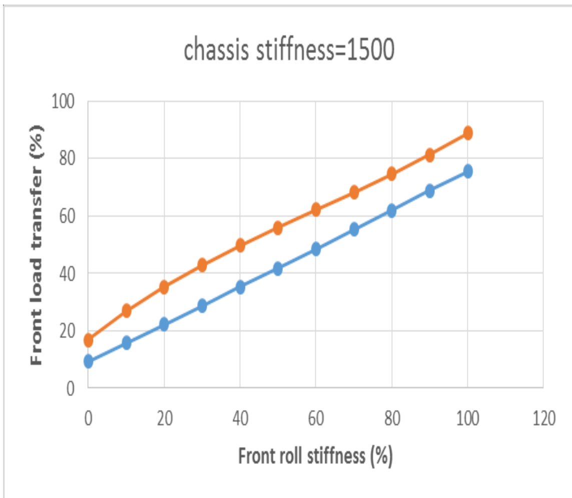

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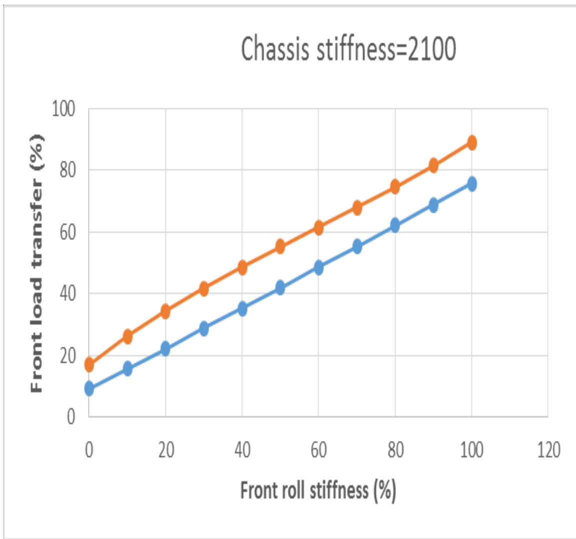

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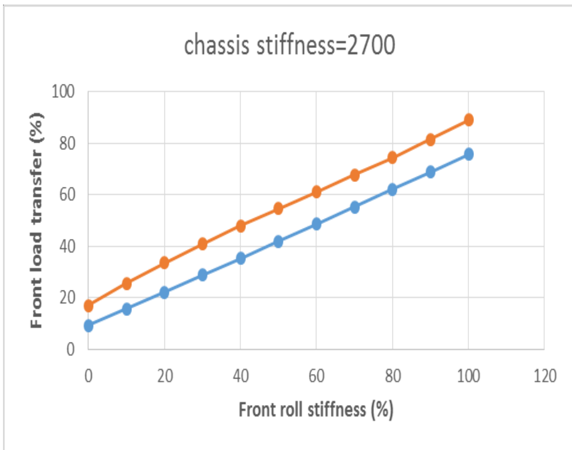
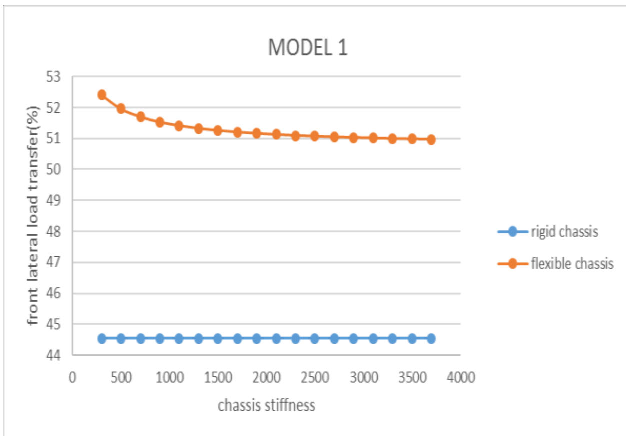


Fig: 28

5. TARGET TORSIONAL STIFFNESS

5 configurations of varying front and rear tracks,wheelbase, roll centre heights, roll stiffness distribution etc were decided on the basis of vehicle handling.

For each configuration a graph of front lateral load transfer % was plotted with increasing chassis torsional stiffness.



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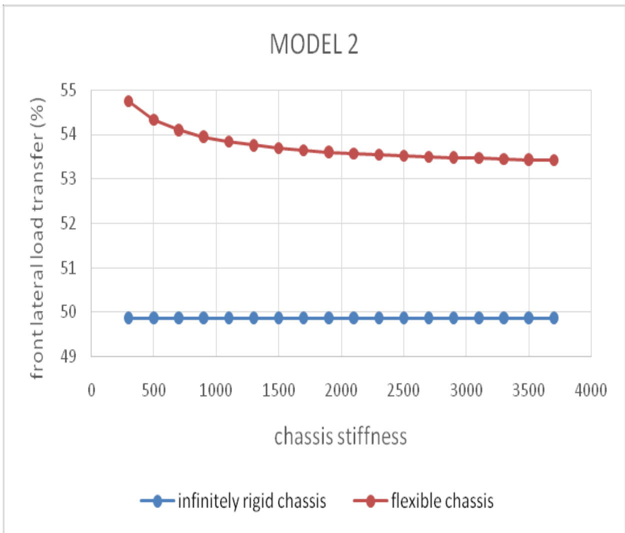

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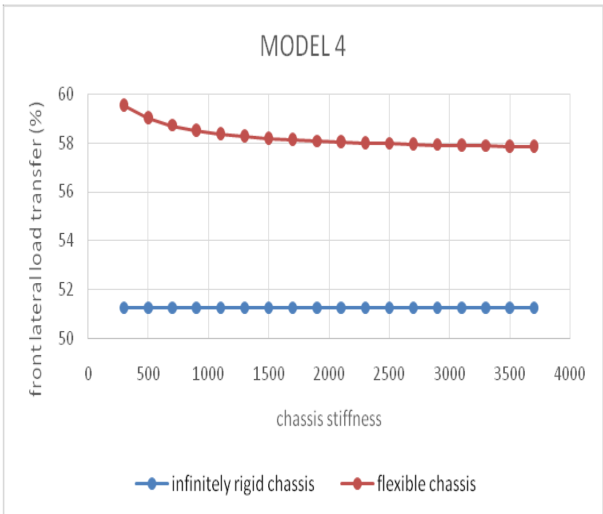
Fig: 31



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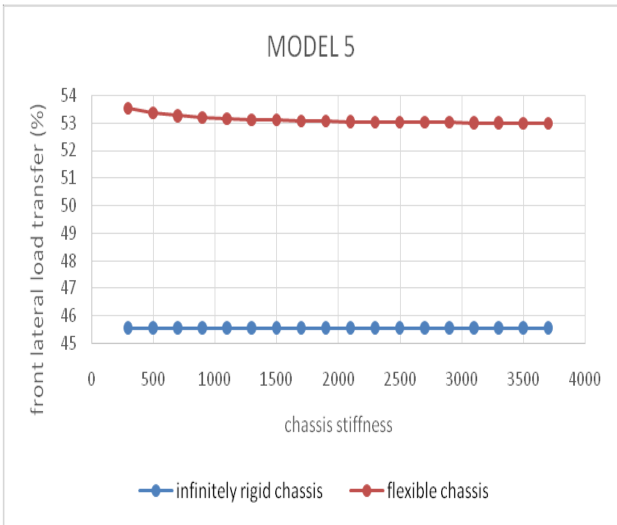


Fig: 33

Model 2 gave the closest results with the infinite case. It was also noted that after 1500 Nm/° there was no significant change in lateral load transfer,i.e, increasing torsional stiffness beyond this point did not bridge the gap of infinite and flexible cases significantly.

Thus, target value of torsional stiffness was chosen to be 1500 Nm/° and model 2 was selected for vehicle dynamics.

6. DESIGN FOR TORSIONAL STIFFNESS

Our previous year's chassis had a torsional stiffness of 1940 Nm/° and a weight of 37 Kgs. The target for the year 2017 has been set to 1500 Nm/° with the minimum possible weight. Before starting the design, a study was made on the previous year's design by two methods:-

1. Increasing one by one, the outside diameter , thickness ,and both outside diameter and thickness of major frame members by a factor of K=1.05 and noting the effects on torsional stiffness, weight and torsional stiffness to weight ratio.
2. By reallocation of various tubes within the frame. [All simulations were done in ANSYS mechanical APDL]

The above study gave the following results:

1. Variation of outer diameter and thickness

Table: 1

Member	Configuration	% increase in	% increase in	TS:Wt
Main hoop,		2.79	0.65	43.02
	TH x 1.05	0.56	0.43	42.19
	(OD+TH) x1.05	3.45	1.59	42.89
Side impact sructure	OD x 1.05	4.65	0.66	43.80
	TH x 1.05	1.41	0.52	42.51
	(OD+TH) x1.05	6.19	1.21	44.21

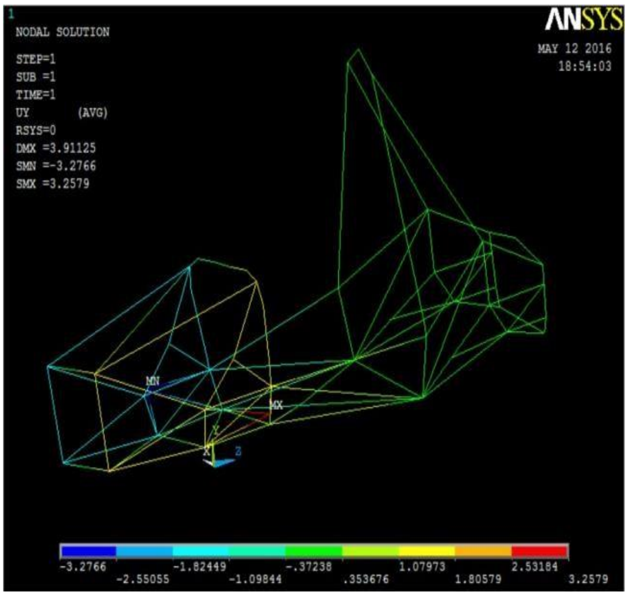
Front bulkhead support structure	OD x 1.05	1.12	0.69	42.31
	TH x 1.05	0.56	0.57	42.13
	(OD+TH) x1.05	1.43	1.30	42.19
Front bulkhead	OD x 1.05	0.11	0.22	42.08
	TH x 1.05	0	0.17	42.66
	(OD+TH) x1.05	0.14	0.41	42.02
Front hoop bracing	OD x 1.05	-.027	0.28	42
	TH x 1.05	-0.27	0.22	42.03
	(OD+TH) x1.05	-0.27	0.53	41.09
Main hoop bracing	OD x 1.05	0.08	0.24	42.06
	TH x 1.05	0	0.19	42.65
	(OD+TH) x1.05	0.14	0.45	42
Main hoop bracing supports	OD x 1.05	0.78	0.28	4.35
	TH x 1.05	0.22	0.23	42.13
	(OD+TH) x1.05	1.03	0.52	42.35

2. Reallocation of tubes

a) Straight front hoop bracing vs cross vs straight with triangulation

Table: 2

i) Cross		
% increase in TS	% increase in weight	TS:weight
0	0	0
ii) Straight		
% increase in TS	% increase in weight	TS:weight
1.76	1.3	39.64
iii) Straight with triangulation		
% increase in TS	% increase in weight	TS:weight
2.85	1.5	40.85



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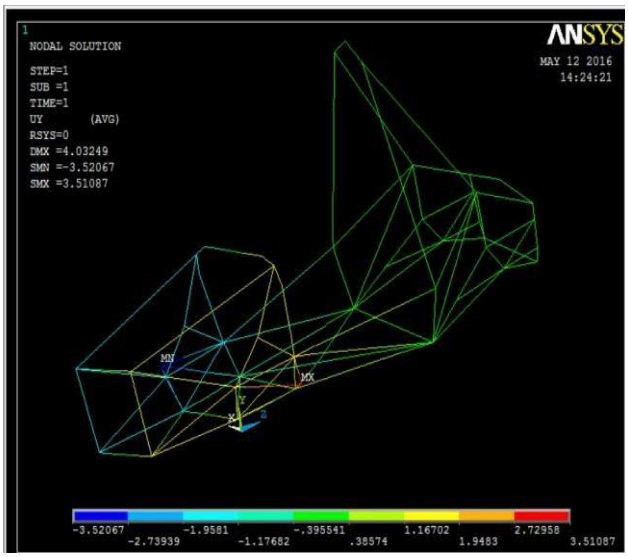

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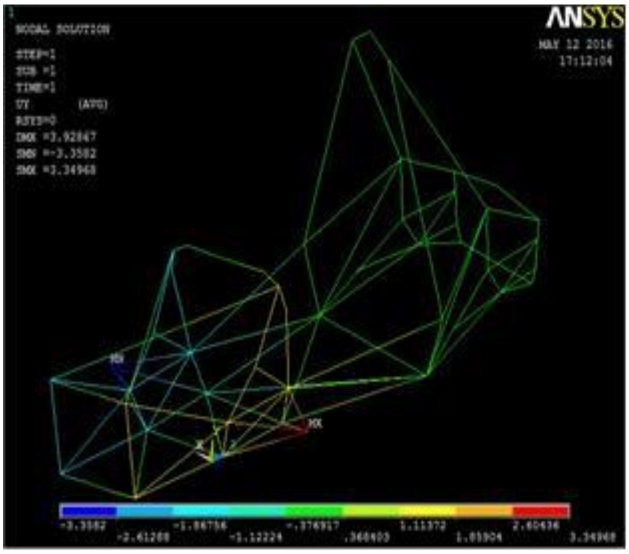

Fig: 37

b) Removing structural member joining front lower wishbone fore left and right

Table: 3

% increase in TS	% increase in weight	TS:weight
-2.44	-0.83	41.45

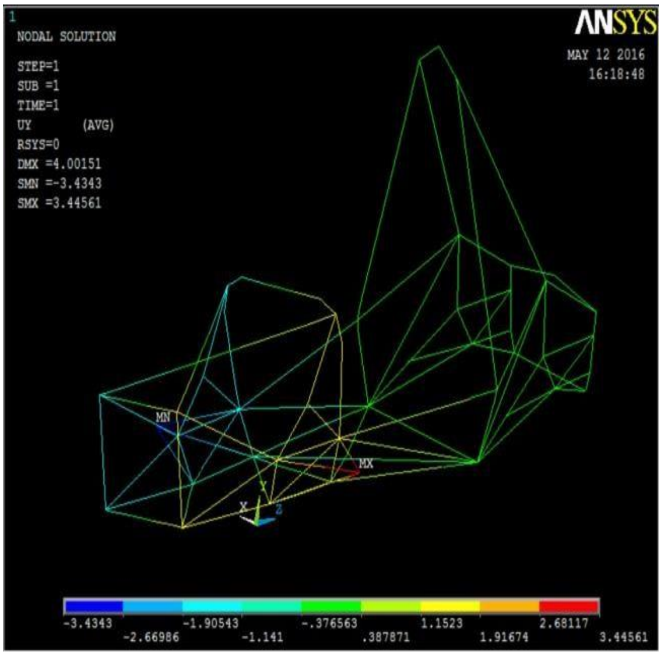

Fig: 38

c) Removing structural member joining the above member and front bulkhead lower member

Table: 4

% increase in TS	% increase in weight	TS:weight
-4.76	-1.09	40.57

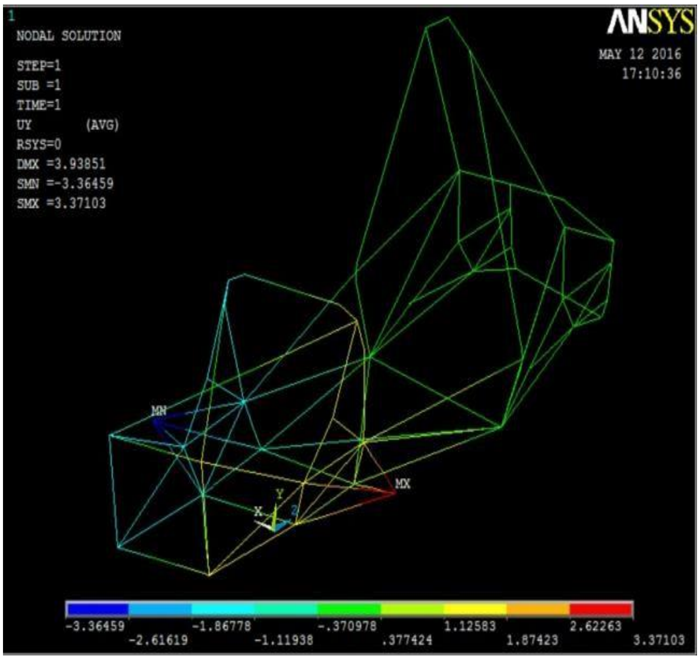

Fig: 39

d) Removing cockpit floor cross member

Table: 5

% increase in TS	% increase in weight	TS:weight
-2.7	-2.46	42.03

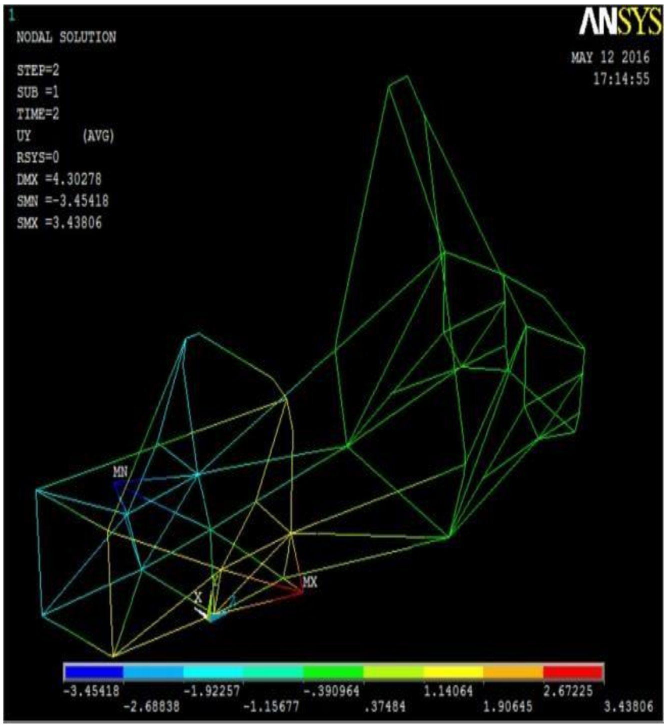

Fig: 40

e) Front suspension bay triangulation removed

Table: 6

% increase in TS	% increase in weight	TS:weight
-1.9	-1.44	41.93

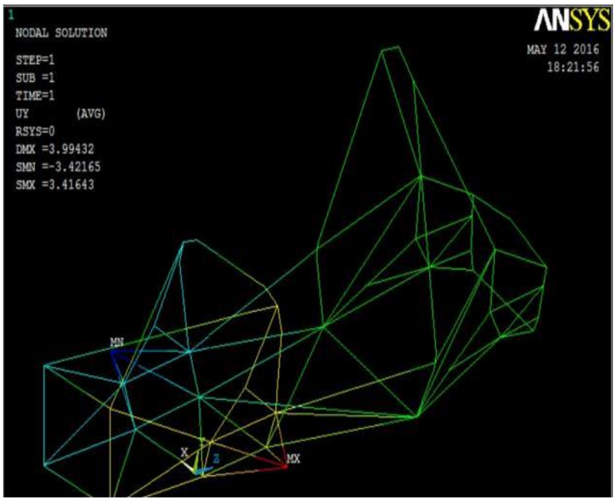

Fig: 41

f) Front suspension bay triangulation reversed

Table: 7

% increase in TS	% increase in weight	TS:weight
0.55	0.02	42.36

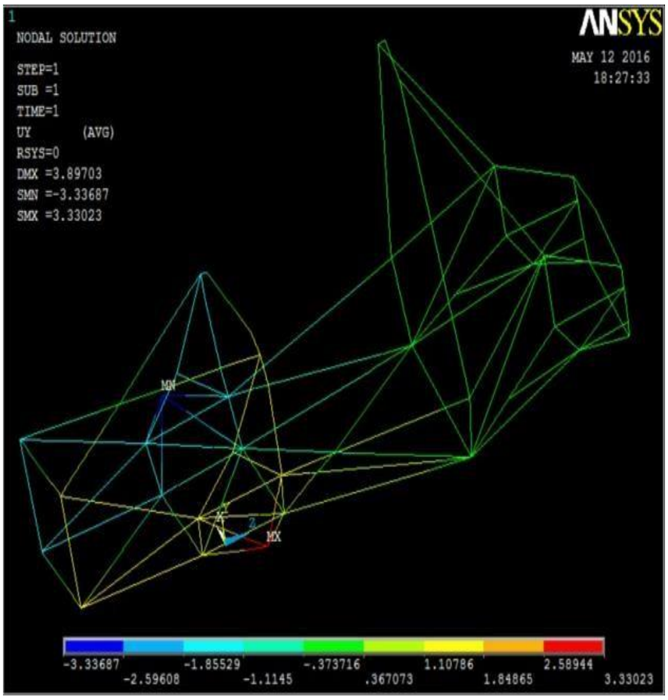

Fig: 42

g) Rear suspension bay triangulation removed

Table: 8

%increase in TS	% increase in weight	TS:weight
0	-0.94	42.54

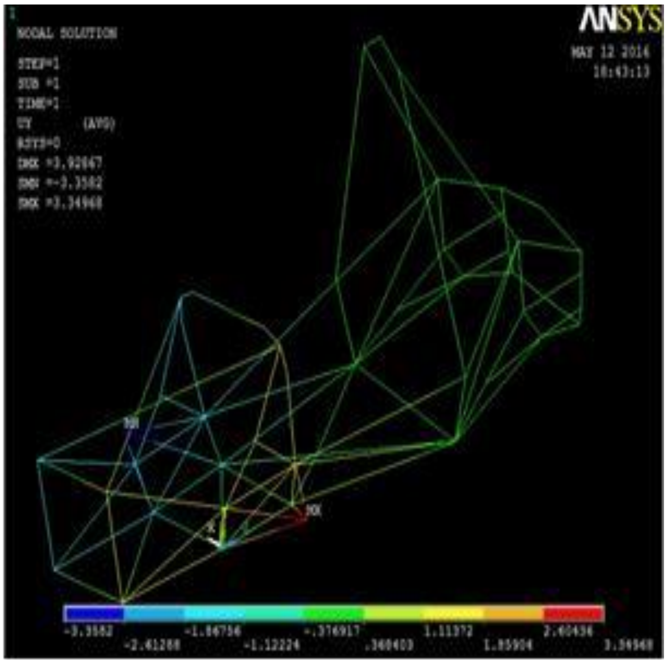

Fig: 43

h) Rear suspension bay triangulation reversed

Table: 9

%increase in TS	% increase in weight	TS:weight
0	-0.94	42.54

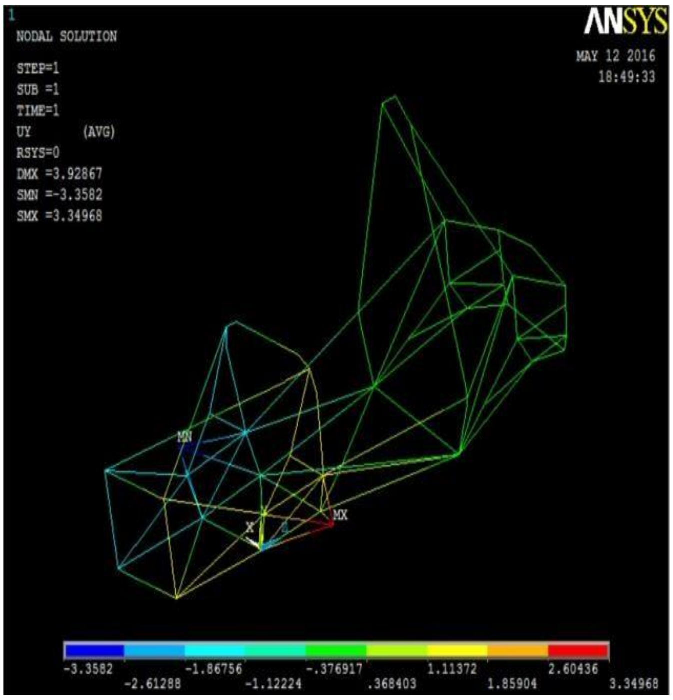

Fig: 44

i) Main hoop bracing forward

Table: 10

%increase in TS	% increase in weight	TS:weight
151.74	1.98	104.01

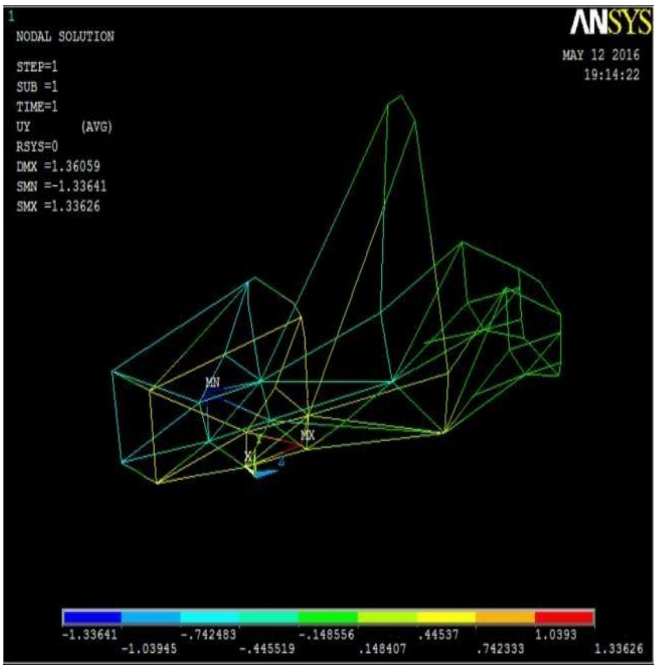

Fig: 45

j) Addition of Cockpit Bracing

Table: 11

%increase in TS	% increase in weight	TS:weight
146.57	3.93	96.32

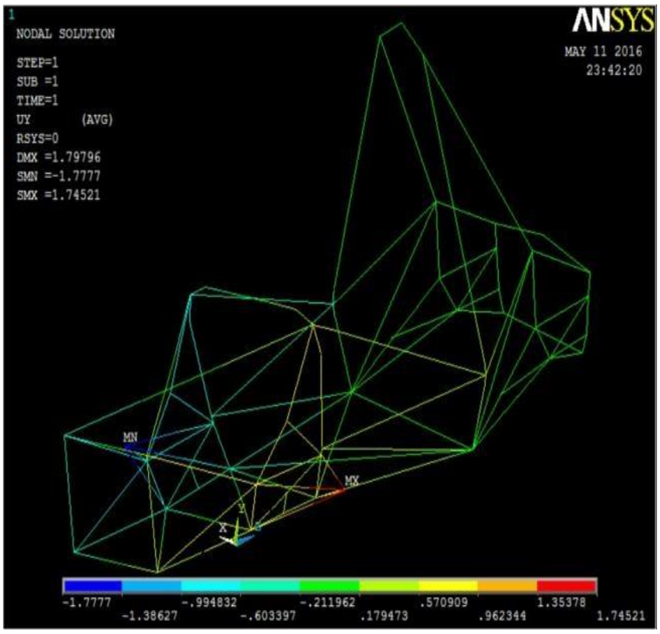

Fig: 46

7. CONCLUSION

In general, increasing outer diameter gave better results than increasing thickness or increasing both outer diameter and thickness.

Stiffening the cockpit has the largest effect on stiffness of the whole chassis. This is because front part of the chassis is generally stiff enough as a lot of rules govern its design. Rear part is stiff in this analysis as the rear hard points are fixed in all degrees of freedom. Had we applied a torque at the rear and constrained the front, the result could have been different. But, this was not done because engine can act as a structural member, which is even stiffer than the chassis. Thus the front and rear parts are very stiff. Cockpit, on the other hand, is open from top. It becomes the weakest part of the chassis with the least amount of triangulation. Thus, increasing the cross- section of main hoop, front hoop and side impact structure has a large effect on the overall stiffness of the chassis.

Attaching the main hoop bracings forward of the main hoop has a huge effect on the overall stiffness. This is in accordance with the above point of stiffening the cockpit. Also, this is against the general trend of fossae chassis which have main hoop bracing rearward of main hoop.

Members joining upper part of front hoop to the point of attachment of upper side impact member and main hoop also has a large effect on the overall stiffness. Again, this is in accordance with the second point. We have called this member cockpit bracing.

Removal or reversal of suspension bay triangulation member has little or no effect on overall stiffness.

Other members like front bulkhead, front bulkhead support, main hoop bracing, and main hoop bracing supports have little effect on overall stiffness.

8. FINAL DESIGN

According to the above analysis a chassis is to be designed keeping in mind the FSAE rules. The target torsional stiffness was 1500 Nm/° according to vehicle dynamics configuration 2.

The first cad MODEL is shown in the figure. It has a torsional stiffness of 583.94 Nm/° and a weight of 21.6 kg. This is very light but it does not meet our stiffness target.

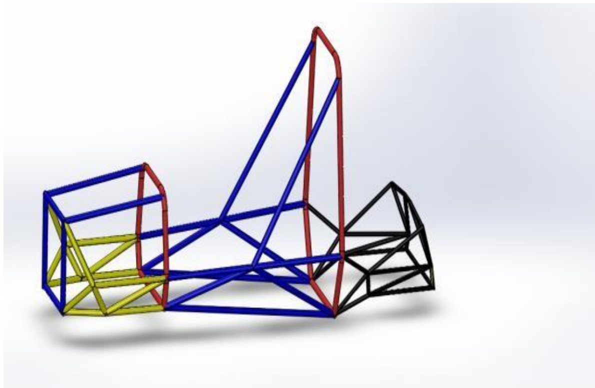

Fig: 47

In he second iteration, fore upper wishbone node was connected near the top of front hoop. It had a little increase on stiffness to 595.85 Nm/°.

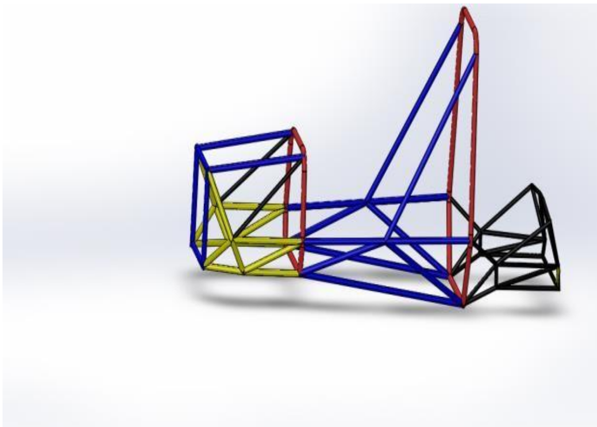

Fig: 48

Third iteration involved the addition of cockpit bracing. This had a huge effect. Stiffness increased to 1346.2 Nm/°, and total weight 22.6 kg.

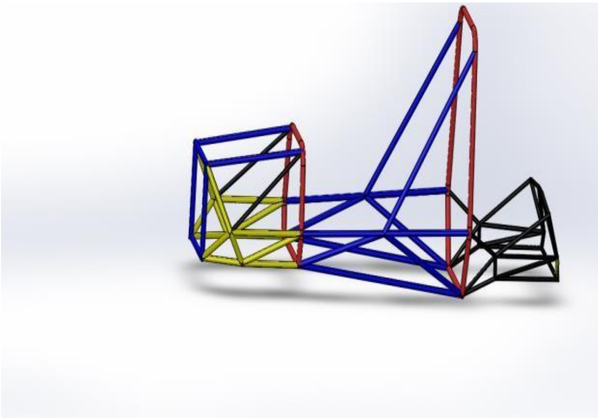

Fig: 49

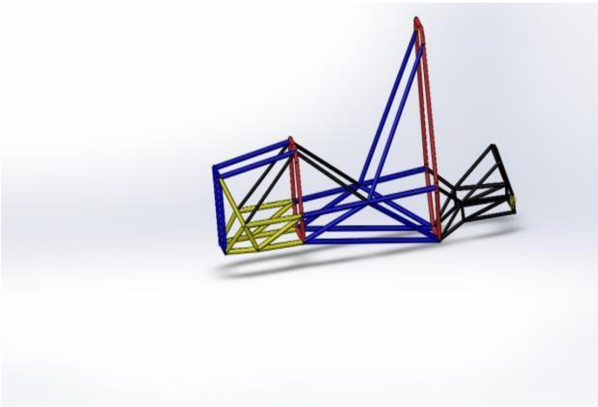

Fig: 50

Iteration 4 involved addition of X-members in the floor of cockpit. Stiffness reached a value of 1419.28 Nm/°.

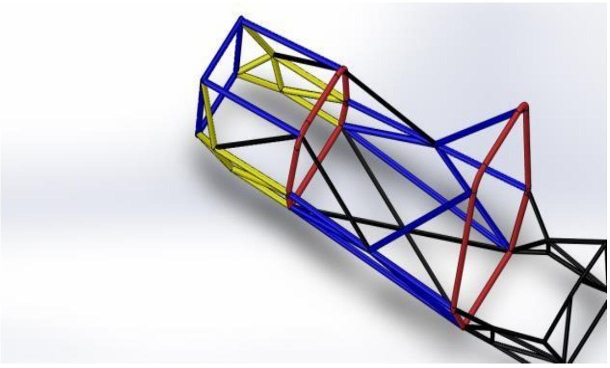

Fig: 51

Iteration 5 involved addition of triangulation of front hoop bracing. Stiffness further increased to 1586.88 Nm/°. Thus, the goal of 1500 Nm/° was reached. Actual stiffness (experimental) is always less than the FEA value. Hub to hub stiffness would also take into consideration the compliances at various suspension components like bolts and bearings. This would further decrease the stiffness. But all this can be overlooked in this analysis as the engine stiffness is not considered. Engine is very stiff compared to the chassis and would increase chassis stiffness by 300 to 400 Nm/°.

The following table compares all the above iterations in terms of torsional stiffness (TS), weight and torsional stiffness to weight ratio (TS: weight).

Table: 12

Frame	TS	weight	TS:weight
Initial	583.94	21.6	27.02
Iteration 2	595.85	22.08	26.98
Iteration 3	1346.2	22.6	59.55
Iteration 4	1419.28	23.62	60.08
Iteration 5	1586.88	23.91	66.35

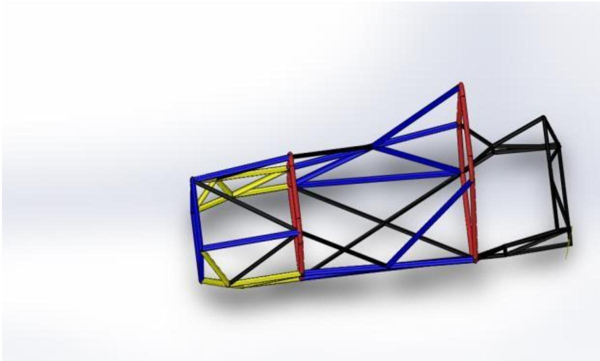

Fig: 52

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[1] Willliam F. Milliken and Douglas L. Milliken, “RACE CAR VEHICLE DYNAMICS”, Society of Automotive Engineers Inc.,

[2] Andrew Deakin, David Crolla, Juan Pablo Ramirez and Ray Hanley, “ The Effect of Chassis Stiffness on Race Car Handling Balance”

[3] Enrico Sampò, “Modelling chassis flexibility in vehicle dynamics simulation”