Structural Analysis of LCV Ladder Chassis Frame under Vertical Bending Condition

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Abstract:

The objective of the paper is to establish the effects of the common load body mounting methods used in commercial vehicles and the selection of the suitable method for the frame design. This paper also discusses the evaluation of possibilities of material reduction of the chassis frame. The frame used for analysis is that of an On-Test Commercial Vehicle from Ashok Leyland. There are several cross sections of frame used in the commercial vehicle space. This paper deals with C section frames only but the same procedure can be followed for other cross sections also. This research work concentrates on the effects of bending stresses on the frame alone. The 3-D modeling and finite element analysis is performed using CATIA and ANSYS respectively.

Keywords: Bending Moment, Clapeyron Method, Total Deformation, Safety Factor

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1. Introduction:

Automobile Frame is an important structural component over which all other components such as engine, transmission system , axles , cabin , load body etc., are mounted. There are several types of frames such as space frame, ladder frame, unibody, X-frame, perimeter frame etc., For Commercial Vehicles, ladder frame is most commonly used. Ladder Frame consists of longitudinal member and cross member. The longitudinal member acts as main stress member which bears the bending stress and also the load and longitudinal forces caused by acceleration and braking. The purpose of cross member is to support the long members and to provide torsional rigidity. Ladder frame is preferred since it is easy to design and build.

The commonly used load body mounting methods are i. using brackets ii. using runner and U bolts. In general practice, the use of the mountings is based on the Gross Vehicle Weight (GVW) of the vehicle. Runner and U bolts opted for commercial vehicles with higher GVW while brackets are used for their lesser counterparts.

2. Problem Statement:

Mounting the load body on the frame using a runner is advantageous, since the weights of the load body and the payload acts as Uniformly Distributed Load hence helping with uniform weight distribution. But, this adds to an additional cost since both a runner and U bolts have to be used. Whereas, using brackets to mount the load body is proved to be less effective in load distribution because the weights due to the load body and the payload acts as point loads. But, this method of mounting the load body is effective on the cost side. The two methods of load body mounting cannot be generalized. It has to be selected based on the frame design.

The frame is not subjected to uniform load intensity throughout it's span instead maximum loads act at specific local points on the frame. So, the frame section need not be uniform throughout the span. Instead, section can be reduced for a span with less load intensity.

This may lead to considerable material savings and cost reduction, without compromising on the frame’s structural integrity.

3. Objective:

To theoretically analyze the factor of safety of the frame at various load acting points for both the cases, considering the frame as 1-Dimensional Overhanging continuous beam . To perform computational analysis of the 3-D model of the frame to calculate the stress distribution. Based on the results, optimum mounting method is selected and the frame is analyzed for possibilities of material savings. The allowable factor of safety is taken as 3, considering the overload conditons.

Conditions for material savings,

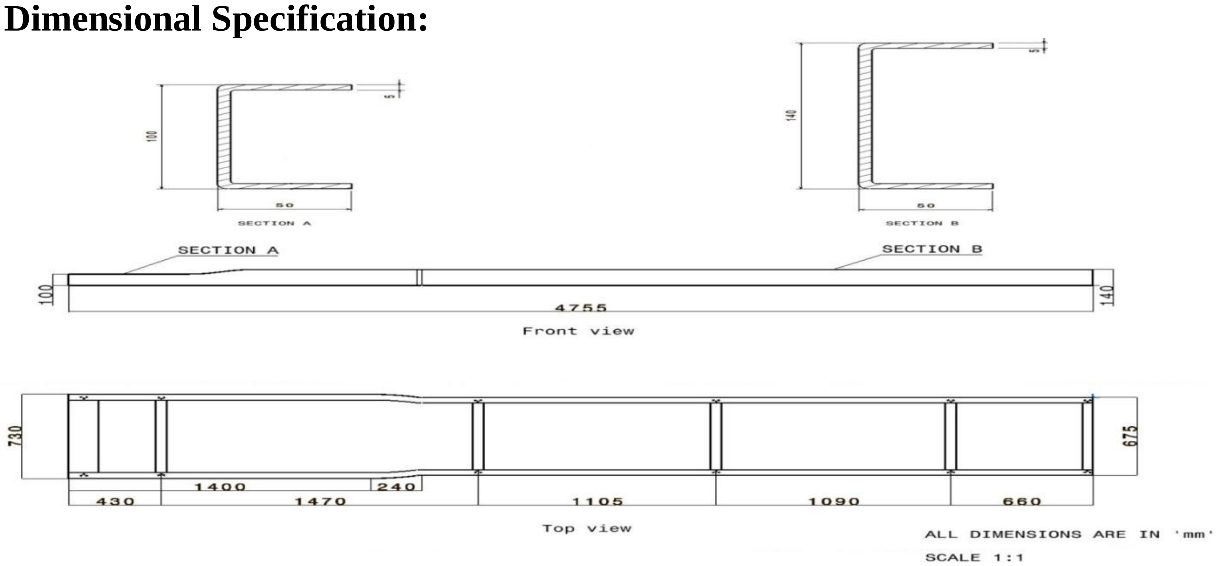
a. Consecutive load acting points with factor of safety twice of the allowable factor of safety (3) are listed.
b. The span of the listed load acting points have to be considerable.
c. Only one set of load acting points with maximum span has to be taken for consideration to avoid inconsistent frame profile.

4. Methodology:

The following methodology is opted to arrive at a solution for the problem stated,

a. Necessary data including major dimensions, sectional details, cross member position and load acting points are to be taken from the frame considered – Ashok Leyland On Test Vehicle. The frame is analysed for a payload of 3.5 tonne.
b. 1-D Line Diagram of the frame is to be drawn considering the frame as Overhanging Continuous beam.
c. Theoretical calculation of the bending moments and factor of safety at the load acting points is to be done using Clapeyron Three moment method.
d. Computational 1-D analysis is to be done using Ansys Mechanical APDL.
e. 3-D modeling of the frame is to be created using CATIA V5.
f. The 3-D model is to be analyzed using Ansys Workbench.
g. The results for both the cases is to be compared to select the optimum method for the frame.
h. Possibilities of enforcing material savings is to be analyzed and the frame is redesigned.
i. The redesigned frame is analyzed to ensure the factor of safety of the frame.

5. Dimensional Specification:

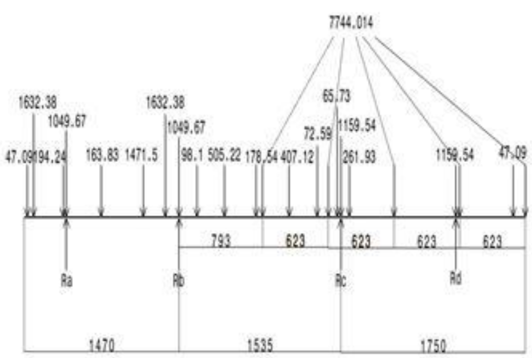


6. Load Specification:

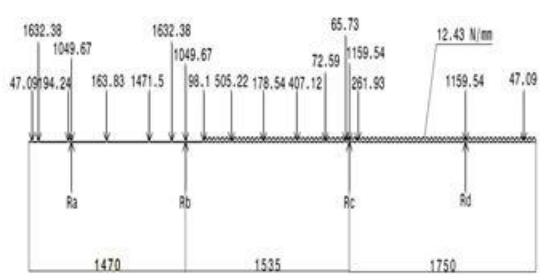
Components	Weight (in Kg)	Load (in N)	Distance from Front End(in mm)
Frame Front Edge	0	0	0
Bull Bar	4.8	47.088	30
Front CAB Mount	166.4	1632.384	90
Steering	19.8	194.238	368.7
Load at front spring FR	107	1049.67	400
Radiator	16.7	163.827	730
Engine	150	1471.5	1130
Rear CAB mount	166.4	1632.384	1340
Load at front spring RR	107	1049.67	1470
Air Filter	10	98.1	1640
Gear Box	51.5	505.215	1900
Battery	18.2	178.542	2200
Fuel Tank	41.5	407.115	2515
Exhaust	7.4	72.594	2780
Propeller Shaft	6.7	65.727	2968
Load at rear spring FR	118.2	1159.542	3005
Spare Wheel	26.7	261.927	3087
Load at rear spring RR	118.2	1159.542	4095
Rear Bumper	4.8	47.088	4640
Frame Rear Edge	0	0	4755
Load Body (UDL)	3947	12.430199 N/mm	3115 – Span Of UDL
Pay Load	3500	34335	

Table 7.1

7. Line Diagram:



case 1. Point load



case 2. UDL

8. Theoretical Calculation

i) Case 1 – Point Load : 1. Based on Clapeyron Three moment method, the frame is divided into 3 spans of length 1470mm, 1535mm, 1750mm respectively.

2. The bending moments at each span are calculated as follows,

Components	Weight	Load	Distance from F.E	Moment abt the Point
Frame Front Edge	0	0	0	0
Bull bar	4.8	-47.088	30	0
Fr CAB Mount	166.4	-1632.384	90	-2825.28
Steering	19.8	-194.238	368.7	-470894.1264
Load at Frnt Spring FR	107	-1049.67	400	-529541.2494
Radiator	16.7	-163.827	730	-109086.3529
Engine	150	-1471.5	1130	335025.146
Rr CAB Mount	166.4	-1632.384	1340	259168.6829
Load at Frnt Spring RR	107	-1049.67	1470	0
Reaction A		4197.48575		
Reaction B		3043.27525		

Table 9.1 --Span A--

Components	Weight	Load	Distance from F.E	Moment abt the point
Load at Frnt Spring RR	107	-1049.67	1470	0
Air Filter	10	-98.1	1640	855176.787
Gear Box	51.5	-505.215	1900	2137588.22
Battery	18.2	-178.542	2200	3465729.23
Load Body 1	789.4	-7744.01	2263	3733390.7
Fuel Tank	41.5	-407.115	2515	2852545.03
Exhaust	7.4	-72.594	2780	1818373.44
Load Body 2	789.4	-7744.01	2886	1397009.83
Prop Shaft	6.7	-65.727	2968	436040.165
Load at Rear Spring FR	118.2	-1159.54	3005	0
Reaction B		6080.122		
Reaction C		12944.41		

Table 9.2 -- Span B--

Components	Weight	Load	Distance from F.E	Moment abt the point
Load at Rear Spring FR	118.2	-1159.54	3005	0
Spare Wheel	26.7	-261.927	3087	-46734.4
Load Body 3	789.4	-7744.01	3509	-397779
Load at Rear Spring RR	118.2	-1159.54	4095	-5423241
Load Body 4	789.4	-7744.01	4132	-4848441
Rear Bumper	4.8	-47.088	4640	-890562
Load Body 5	789.4	-7744.01	4755	0
Frame Rear Edge	0	0	4755	
Reaction C		589.6098		
Reaction D		25270.53		

Table 9.3 -- Span C--

3. From the individual spans, Moment at points A and D are taken,
   Ma = -529541.2494 N.mm Md = -5423241 N.mm
4. From the individual spans, the area moment of inertia of the BMD is found to be,
   A1X1 = 2.36117x10^11 A2X2 = 2.32409 x10^12
   A2'X2'= 2.63608 x10^12 A3X3 = 2.35714 x10^12
5. Clapeyron Equation,
   Ma x L1 + 2(L1+L2)Mb + Mc x L2 = 6(A1X1/L1) + 6(A2X2/L2)
   Mb x L2 + 2(L2+L3)Mc + Md x L3 = 6(A2'X2'/L2) + 6(A3X3/L3)
   Where, L1,L2,L3 are the lengths of the spans A , B and C respectively.
6. Solving the above equations, moments at B and C are found to be,
   Mb = -1272527.67 N.mm Mc = -1056551.47 N.mm
7. Calculation of Reaction forces,

i. Span A ,moment about B,
   Ra = 3008.208 N

ii. Span C ,moment about C,
   Rd = 26239.845 N

iii. Span ABC, moment about C,
   Rb = 9403.706 N

iv. Summation of Vertical forces,
   Rc = 11264.46 N

8. Resultant Bending moment of the beam,

Components	Weight	Load	Distance from F.E	Resultant Bending Moment (in N.mm)
Frame Front Edge	0	0	0	0
Bull bar	4.8	-47.088	30	0
Fr CAB Mount	166.4	-1632.38	90	-2825.28
Steering	19.8	-194.238	368.7	-470894.1264
Load at Frnt Spring FR	107	-1049.67	400	-529541.2494
Radiator	16.7	-163.827	730	-1354996.649
Engine	150	-1471.5	1130	-533147.9372
Rr CAB Mount	166.4	-1632.38	1340	-858752.8215
Load at Frnt Spring RR	107	-1049.67	1470	-1272527.67
Air Filter	10	-98.1	1640	-393431.695
Gear Box	51.5	-505.215	1900	925562.0313
Battery	18.2	-178.542	2200	2295913.369
Load Body 1	789.4	-7744.01	2263	2572439.004
Fuel Tank	41.5	-407.115	2515	1727050.016
Exhaust	7.4	-72.594	2780	730164.2168
Load Body 2	789.4	-7744.01	2886	323714.9329
Prop Shaft	6.7	-65.727	2968	-625717.246
Load at Rear Spring FR	118.2	-1159.54	3005	-1056551.47
Spare Wheel	26.7	-261.927	3087	-1182769.599
Load Body 3	789.4	-7744.01	3509	-1942864.383
Load at Rear Spring RR	118.2	-1159.54	4095	-5423240.718
Load Body 4	789.4	-7744.01	4132	-4848441.426
Rear Bumper	4.8	-47.088	4640	-890561.61
Load Body 5	789.4	-7744.01	4755	0

Table 9.4

9. Calculation of FOS,
Material Chosen : E36 Steel
Yield Stress : 355 MPa

Components	Resultant Bending Moment (in N.mm)	h	b	T	Moment Of Inertia (in mm^4)	y in mm	Working Stress (in N/mm^2)	Yield Stress (in N/mm^2)	Design Stress (in N/mm^2)	FOS
Frame Front Edge	0	100	50	5	1432917	50	0	355	284	Infinity
Bull bar	0	100	50	5	1432917	50	0	355	284	Infinity
Fr CAB Mount	-2825.28	100	50	5	1432917	50	0.098585	355	284	2880.765
Steering	-470894.1264	100	50	5	1432917	50	16.43132	355	284	17.28407
Load at Frnt Spring FR	-529541.2494	100	50	5	1432917	50	18.47774	355	284	15.36984
Radiator	-1354996.649	100	50	5	1432917	50	47.28107	355	284	6.006632
Engine	-533147.9372	140	50	5	3194583	70	11.68239	355	284	24.3101
Rr CAB Mount	-858752.8215	140	50	5	3194583	70	18.81707	355	284	15.09268
Load at Frnt Spring RR	-1272527.67	140	50	5	3194583	70	27.88374	355	284	10.18515
Air Filter	-393431.695	140	50	5	3194583	70	8.620911	355	284	32.94315
Gear Box	925562.0313	140	50	5	3194583	70	20.281	355	284	14.00325
Battery	2295913.369	140	50	5	3194583	70	50.30826	355	284	5.645196
Load Body 1	2572439.004	140	50	5	3194583	70	56.36752	355	284	5.038363
Fuel Tank	1727050.016	140	50	5	3194583	70	37.84328	355	284	7.504636
Exhaust	730164.2168	140	50	5	3194583	70	15.99942	355	284	17.75064
Load Body 2	323714.9329	140	50	5	3194583	70	7.093271	355	284	40.03795
Prop Shaft	-625717.246	140	50	5	3194583	70	13.71077	355	284	20.71364
Load at Rear Spring FR	-1056551.47	140	50	5	3194583	70	23.15125	355	284	12.26716
Spare Wheel	-1182769.599	140	50	5	3194583	70	25.91695	355	284	10.95808
Load Body 3	-1942864.383	140	50	5	3194583	70	42.57222	355	284	6.671017
Load at Rear Spring RR	-5423240.718	140	50	5	3194583	70	118.8345	355	284	2.389877
Load Body 4	-4848441.426	140	50	5	3194583	70	106.2395	355	284	2.673206
Rear Bumper	-890561.61	140	50	5	3194583	70	19.51407	355	284	14.5536
Load Body 5	0	140	50	5	3194583	70	0	355	284	Infinity
Frame Rear Edge	0									

Table 9.5

10. Inference,

FOS at certain points is found to be lesser than allowable FOS .

$FOS_C < 3$.

ii. Case 2. UDL:

Similarly , the FOS of the frame under UDL is found to be,

Components	Resultant Bending Moment (in N.mm)	h	b	T	Moment Of Inertia (in mm^4)	y(in m m)	Working Stress (in N/mm^2)	Yield Stress (in N/mm^2)	Design Stress (in N/mm^2)	FOS
Frame Front Edge	0	100	50	5	1432917	50	0	355	284	infinity
Bull Bar	-0.94749	100	50	5	1432917	50	3.31E-05	355	284	8590029
Fr CAB Mount	-2826.3	100	50	5	1432917	50	0.098621	355	284	2879.725
Steering	-470890	100	50	5	1432917	50	16.43117	355	284	17.28422
Load at frnt spr FR	-529540	100	50	5	1432917	50	18.4777	355	284	15.36988
Radiator	-650520	100	50	5	1432917	50	22.69916	355	284	12.51148
Engine	-862700	140	50	5	3194583	70	18.90356	355	284	15.02362
Rr CAB mount	-1283100	140	50	5	3194583	70	28.1154	355	284	10.10122
Load at frnt spr RR	-1755600	140	50	5	3194583	70	38.46887	355	284	7.382593
Air Filter	-377990	140	50	5	3194583	70	8.282551	355	284	34.28895
Gear Box	1283300	140	50	5	3194583	70	28.11979	355	284	10.09965
Battery	2004400	140	50	5	3194583	70	43.92059	355	284	6.466215
Fuel Tank	1501400	140	50	5	3194583	70	32.89881	355	284	8.63253
Exhaust	15056	140	50	5	3194583	70	0.329908	355	284	860.8449
Propeller Shaft	-1582300	140	50	5	3194583	70	34.6715	355	284	8.191165
Load at rear spr FR	-1950900	140	50	5	3194583	70	42.7483	355	284	6.643539
Spare Wheel	-1476100	140	50	5	3194583	70	32.34444	355	284	8.78049
Load at rear spr RR	-2732900	140	50	5	3194583	70	59.88355	355	284	4.742538
Rear Bumper	-82193	140	50	5	3194583	70	1.80102	355	284	157.6884
Frame Rear Edge	0	140	50	5	3194583	70	0	355	284	infinity

Table 9.6

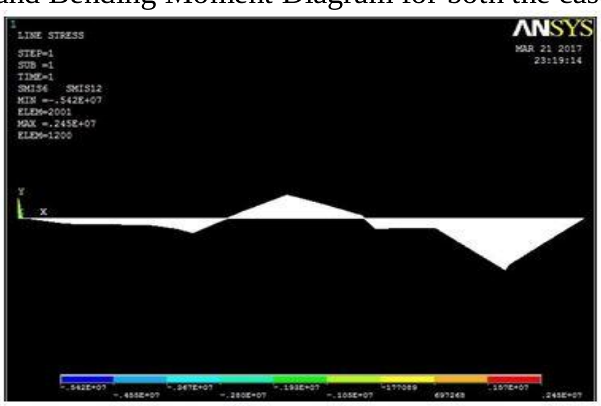
Inference :

FOS of the frame under UDL is found to be greater than allowable FOS .

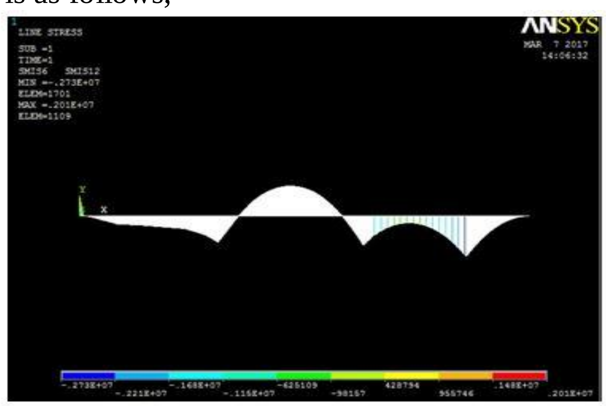
$FOS_C > 3.$

9. Computional 1-D analysis:

The computational analysis of the 1-Dimensional beam is done using Ansys Mechanical APDL and Bending Moment Diagram for both the cases is as follows,



case 1. Point Load



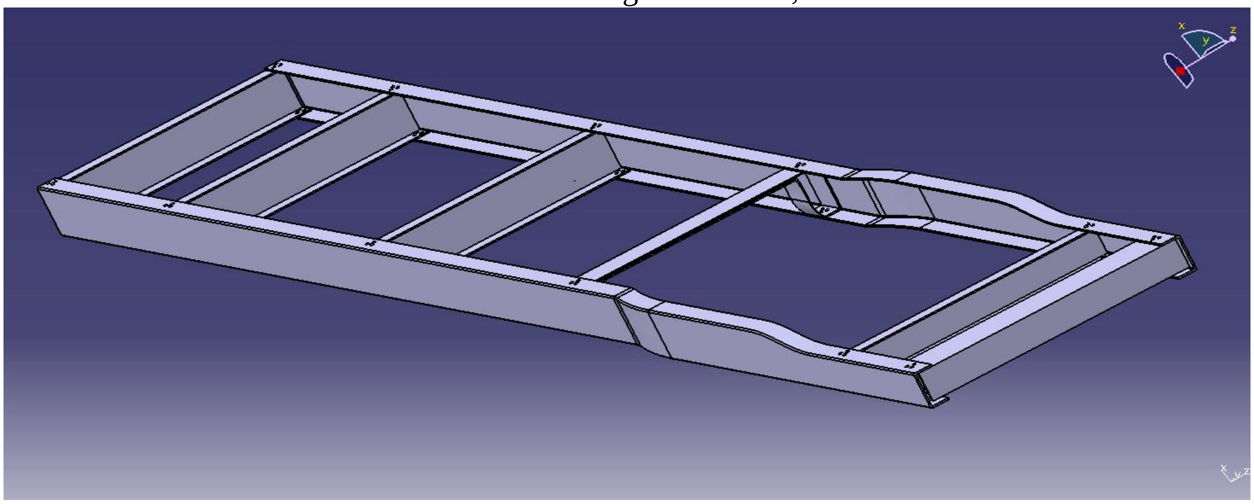
case 2. UDL

Inference:

It is evident from the BMD of both the cases that the stress distribution is better in case 2. (udl). It can also be found that the computational analysis is in accordance with the theoretical values.

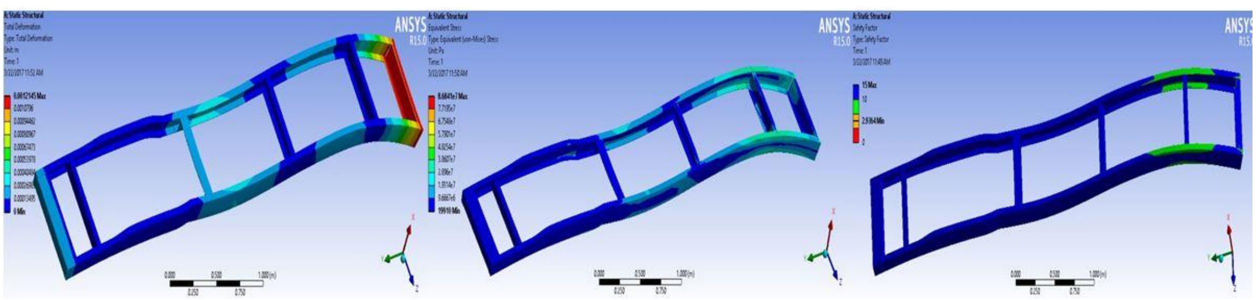
10. Computational 3-D analysis:

The 3-D model of the chassis frame created using CATIA V5,

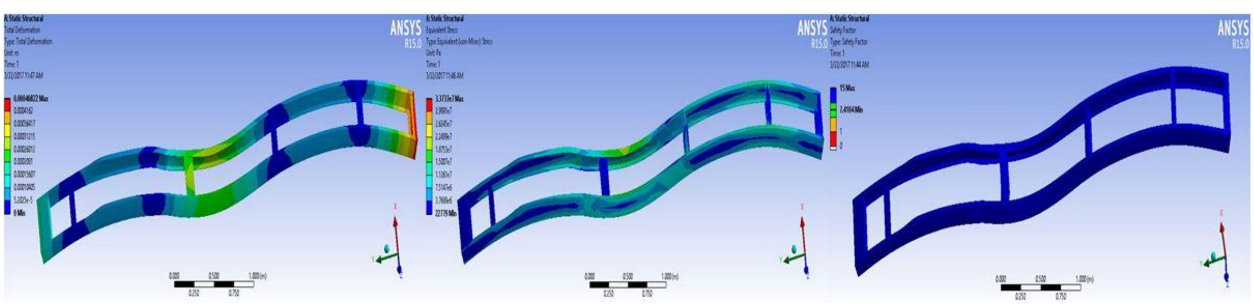


The 3-D model is put to static structural analysis and the following solutions are obtained.

i. Total Deformation
ii. Equivalent Stress
iii. Safety Factor



case 1. Point Load



case 2. UDL

Inference:

Case	Maximum Deformation (mm)	Equivalent Stress (N/mm2)		Safety Factor
		Min	Max	
Point Load	1.215	9.667	86.84	2.936
UDL	0.468	3.769	33.737	7.41

The above result comparison shows that the case 2 proves to be preferable since the maximum deformation and equivalent stress under udl is lesser compared to that of the point load condition.

11. Selection of Load body mounting method:

It is evident from the theoretical and computational analysis that mounting the load body using runner and U bolts proves to be better in every step of analysis. So, case 2 is selected.

12. Material Reduction:

By evaluating the FOS values of case 2 listed in Table 9.6 it is found that the FOS at each load acting point is twice that of the allowable FOS except for the point where Load at rear spring RR acts. The section is reduced to 100x50x5 and the FOS is to be verified.

Components	Resultant Bending Moment (in N.mm)	h	b	t	Moment Of Inertia (in mm^4)	y(in mm)	Working Stress (in N/mm^2)	Yield Stress (in N/mm^2)	Design Stress (in N/mm^2)	FOS
Frame Front Edge	0	100	50	5	1432917	50	0	355	284	infinity
Bull Bar	-0.94749	100	50	5	1432917	50	3.31E-05	355	284	8590029
Fr CAB Mount	-2826.3	100	50	5	1432917	50	0.098621	355	284	2879.725
Steering	-470890	100	50	5	1432917	50	16.43117	355	284	17.28422
Load at frnt spr FR	-529540	100	50	5	1432917	50	18.4777	355	284	15.36988
Radiator	-650520	100	50	5	1432917	50	22.69916	355	284	12.51148
Engine	-862700	100	50	5	1432917	50	30.10294	355	284	9.434295
Rr CAB mount	-1283100	100	50	5	1432917	50	44.77232	355	284	6.343205
Load at frnt spr RR	-1755600	100	50	5	1432917	50	61.25967	355	284	4.636003
Air Filter	-377990	100	50	5	1432917	50	13.18953	355	284	21.53223
Gear Box	1283300	100	50	5	1432917	50	44.7793	355	284	6.342217
Battery	2004400	100	50	5	1432917	50	69.94126	355	284	4.06055
Fuel Tank	1501400	100	50	5	1432917	50	52.38965	355	284	5.420918
Exhaust	15056	100	50	5	1432917	50	0.525362	355	284	540.5796
Propeller Shaft	-1582300	100	50	5	1432917	50	55.21256	355	284	5.143757
Load at rear spr FR	-1950900	100	50	5	1432917	50	68.07444	355	284	4.171904
Spare Wheel	-1476100	100	50	5	1432917	50	51.40215	355	284	5.525061
Load at rear spr RR	-2732900	100	50	5	1432917	50	95.36144	355	284	2.978143
Rear Bumper	-82193	100	50	5	1432917	50	2.868031	355	284	99.02263
Frame Rear Edge	0	100	50	5	1432917	50	0	355	284	infinity

The Factor of Safety is found to be greater than the allowable FOS even after reducing the section to 100x50x5. The exception of the Load acting at rear spring RR is justified to be safe, since it has the added support of the Cross Member at the point.

Calculation of percentage of material savings:

i. Volume of Long Member with original section = Cross sectional area X Length

Volume of Long member = Volume of Span 1 with cross section 100x50x5 + Volume of Span 2 with cross section 140x50x5

Cross sectional area of Span 1 = 100x5 + 2(45x5) = 950 mm2

Volume 1 = 950 X 930 = 883500 mm3

Cross sectional are of Span 2 = 140x5 + 2(45X5) = 1150 mm2

Volume 2 = 1150 X 3825 = 4398750 mm3

Total Original Volume = 883500 + 4398750 = 5282250 mm3

ii. Volume of Long Member with updated section = Cross sectional area X Length

Cross sectional area = 100x5 + 2(45x5) = 950 mm2

Volume after material reduction = 950 x 4755 = 4517250 mm3

Volume of material reduction = 5282250 – 4517250 = 765000 mm3

% of material savings = (765000/5282250) x 100 = 14.48%

13. Conclusion:

The research work follows the analysis of the ladder chassis frame of Ashok Leyland's On Test Vehicle using Theoretical and Computational methods. It is observed that mounting the load body with the frame using runner and U-bolts facilitates better stress distribution leading to better factor of safety of 7.41 compared to 2.936 provided by the bracket mounting method. The two cases are analyzed under identical self-weight and payload conditions. The better factor of safety of the runner mounting method is backed with lesser deformation and Von Mises Stress values of 0.468 mm and 3.769 N/mm2 (min) and 33.737 N/mm2 (max) respectively, compared to that of the bracket mounting method which produces maximum deformation and Von Mises Stress values of 1.215 mm and 9.667 N/mm2 (min) and 86.84 N/mm2 (max) respectively. The degree of stress distribution of the runner mounting has given rise to optimizing the frame section leading to 14.48% of material saving.

14. Acknowledgement:

We are obliged to express our immense gratitude to Mr. B.Mohan, Manager , Department of Product Development , Ashok Leyland Technologies for his thoughtful guidance and intellectual support. We are also bound to thank Ashok Leyland Technologies for permitting us to use their facility and equipments.

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