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DESIGN OF MOBILE TRUCK LOADER FOR VOLVO FH42R3LA

Naresh Nulu, Dr.K.Rambabu, P.S.B.Chowdary, P.S.Amarnadh

***Abstract*— The trucks are the backbones of transportation. 65% of the freight is being transported through trucks. Loading and unloading of truck requires man power and even with the man power loading weights above 100kg is a difficult task. Most widely used previous mobile cranes, Boom truck crane, Knuckle boom cranes involves rotary parts, The maintenance cost of these cranes is very high. Since there are rotary parts, If failure occurs, we have to use high cost bearings. In order to reduce this maintenance cost, a crane is designed avoiding rotary parts which involves design of an I-beam, end truck, four columns and two major supporting beams which were fitted to the chassis This crane is designed according to the British Standard and loads are simulated in ANSYS WORKBENCH 15.0 for all the elements and results are compared.**

***Index Terms*— Crane, Mobile Crane, Truck loader, Material handling equipment.**

I. INTRODUCTION

An area of 1000×1000 chosen. The center of gravity of the load to be lifted should be with in this area. where as the centroid of this area coincide with the centroid of the I-beam, on whose bottom flange the trolley and hoist mechanism lifts the load. It is assumed that the load will be lifted by the trolley and hoist mechanism when it is at the middle of the span.

Since there are no rotary elements. Using linear element structure is designed which can be attached to the chassis. carrying the load like an overhead crane.
Partial factors 1.6 for imposed loads and 1.4 for dead load. from BS_5950 .Weight to be lifted 500 Kg. weight of the selected cross-section is 31.1 Kg.

1. The load to be lifted is 500 Kg.
2. The mass of trolley hoist won't be more than 55Kg. Even if it is electrical trolley hoist.
3. The partial factors from BS 5950-1:2000 are 1.4 and 1.6 for dead load and imposed loads respectively
4. T he point load $= 555 \times 1.6 = 888\ Kg$
5. dead load or self weight $= 31.1\ \times 1.4 = 43.54\ Kg$
6. The out-plane load is taken assuming 1000×1000 area is 21.5625 % of the point load.$= 191.475\ Kg$
7. And the axial load is also 21.5625 % of the point load $= 191.475\ Kg$

The maximum allowable height of the object taken as 1.54516 m from the ground

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***Naresh Nulu**, Dept of Mechanical Engineering, Sir C.R.R College of Engineering,Eluru,W.G.D.T.Andhrapradesh,India. Mobile no: 7793932377.*
***Dr. K.Rambabu**, Dept of Mechanical Engineering,SirC.R.RCollegeofEngineering,Eluru,W.G.D.T.Andhrapradesh ,India. Mobile no: 9441695977*
***P.S.B.Choudary** Dept of Mechanical Engineering, Sir C.R.R College of Engineering,Eluru,W.G.D.T.Andhrapradesh,India.Mobile:944034268.**P.S. Amarnadh,**DeptofMechanical Engineering, SirC.R.R College of Engineering,Eluru,W.G.D.T.Andhrapradesh,India. Mobile no: 9985718678*

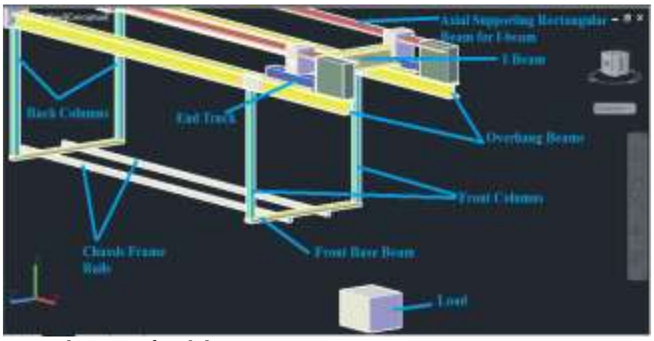
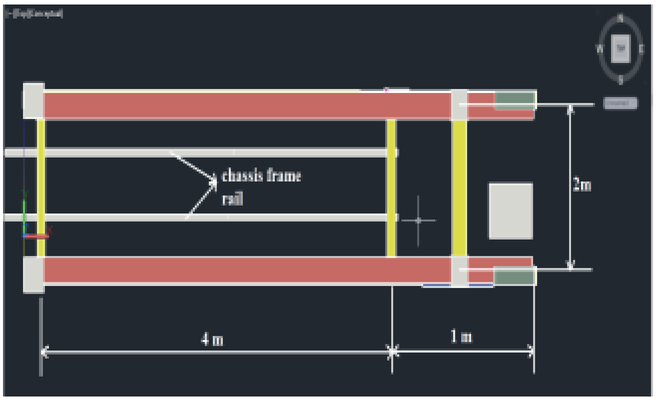
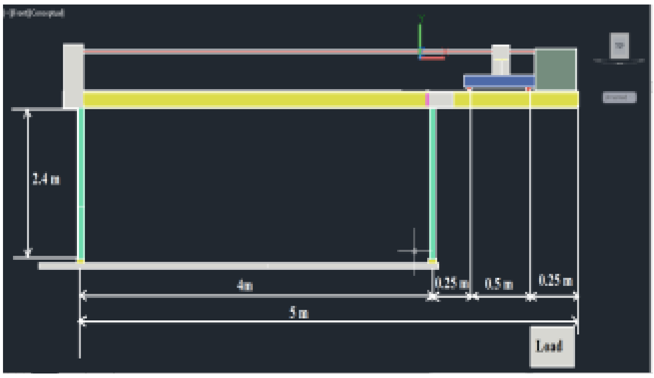


Fig 1. Elements of mobile crane



(a)



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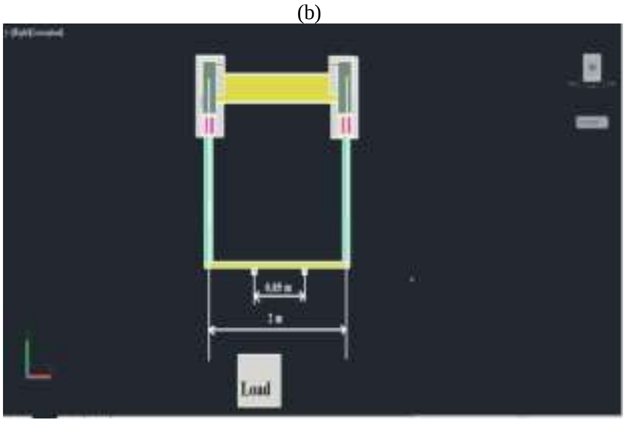

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Fig. 2. (a) Top view of the mobile crane (b) Side view of the mobile crane (c) Front view of the mobile crane

In the following sections following variables used.

N_{Ed} = Axial compressive load
N_{Rd} = Axial compressive resistance
$M_{Y,Ed}$ = In-plane bending moment
$M_{Y,Rd}$ = In-plane bending moment resistance
$M_{Z,Ed}$ = Out-plane bending moment
$M_{Z,Rd}$ = Out-plane bending moment resistance
$M_{T,Ed}$ = Twisting moment (for closed cross-sections)
$M_{W,Ed}$ = Warping moment (for open cross-section)
$M_{W,Rd}$ = Warping moment resistance

Table 1. Loads on different elements of the crane

Type of Load / Name of the element	N_{Ed}	$M_{Y,Ed}$	$M_{Z,Ed}$	$M_{T,Ed}$ Or $M_{W,Ed}$
I-Beam	✓	✓	✓	✓
End Truck		✓		
Overhang Beam		✓		✓
Front Column	✓			
Back Column	✓			
Front Base Beam		✓		
Back Base Beam		✓		
Rectangular Beam For Axial Support		✓		

II. DESIGN CALCULATIONS

A. I-section Design :

I-section is chosen as the beam, Since We are using a trolley to carry the load, which moves along the length of the beam on the bottom flange. While lifting the weight, three types of loads act an instant on the beam, They are

.

1. In-plane bending load.
2. Out-plane bending load.
3. Axial compressive load.

The cross-section chosen for this is class 1 type cross-section and it can develop plastic moment resistance as mentioned in SCI_P362 document.

- The point load $= 555 \times 1.6 = 888\ Kg$
- Dead load or self weight $= 31.1 \times 1.4 = 43.54\ Kg$

1. *In-Plane Load :*

The in-plane bending load is taken as 500Kg equal to the weight of the load lifted and multiplied with the partial factors because, No matter what the position of load in the 1000×1000 area percentage of variation of bending load is very small. The vertical reaction on the end trucks and by the end truck trucks are.

Take R_1 and R_2 as the reactions.

$R_1 = 487.54\ kg$ and $R_2 = 487.54\ kg$

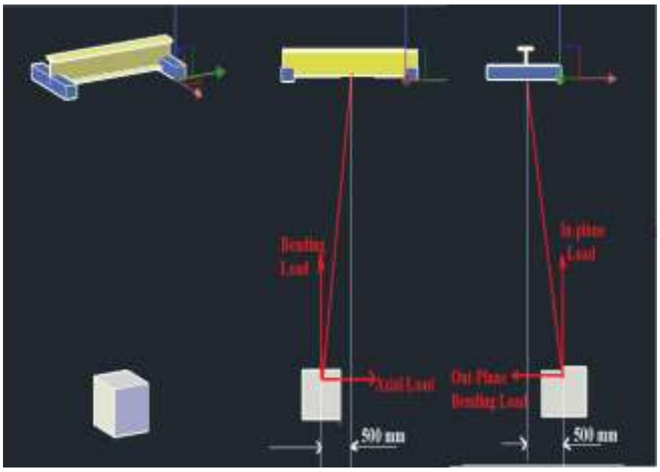

Fig. 3. Loads on I-beam

2. *Out-Plane Load:*

- The out-plane is taken assuming 1000×1000 area is 21.5625 % of the
- point load.$= 191.475\ Kg$
- Due to the point load in the middle reactions at both ends will be 939.2 N.
- The warping stress found following the detailed approach in "SCI_P385" document.

The warping stress for doubly symmetric I-section is given by $M_{W,Ed} = E.I_f.\ddot{\phi}\ (h - t_f)$ N-m.

Where I_f is the moment of inertia of the flange which approximately half of I_z

The value of $\ddot{\phi}$ double derivative of the rotation of beam for the applied torque, it is calculated using the formulas provided in Table C.1 case 5 in Appendix-C of SCI_P385 publication. And it's magnitude is 0.004045

3. *Axial Compressive Load :*

- The axial load is also 21.5625 % of the point load $= 191.475\ Kg$

The axial load causes the members to buckle or fail the members before the actual axial stress reaches the yield stress value. The load at which the buckling occur is less than the load corresponding to the yield stress. According to AISC the value of allowable axial stress is given by

$$\sigma_{Rd} = \frac{\left[1 - \frac{\left(\frac{Kl}{r}\right)^2}{2(C_c)^2}\right]}{\frac{5}{3} + \frac{3\left(\frac{Kl}{r}\right)}{8C_c}\quad\frac{\left(\frac{Kl}{r}\right)^3}{8C_c{}^3}} \times F_y \mathrm{N}/mm^2$$

It's found to be 133.274 MPa. The corresponding allowable axial load is 529097.78 N.

Table 2 shows only bending loads and bending resistances about Y and Z axis. The axial compressive load and warping moment and the axial compressive load resistance and warping resistance are be given in Table 3.

The ratio of the load and resistance should not be greater than 1. In order to resist the load with out fail.

Table 2. Loads and resistance of I-beam

Type of Load	$M_{Y,Ed}$	$M_{Z,Ed}$
Units	**N-m**	**N-m**
Value	4569.203	939.1848
Resistance	$M_{Y,Ed}$	$M_{Z,Ed}$
Units	**N-m**	**N-m**
Value	108075	25850
Ratio	0.04227	0.0364

Table 3 : Loads and resistance of I-section

Type of Load	$M_{W,Ed}$	N_{Ed}
Units	**N-m**	**N-m**
Value	230.996	1878.37
Resistance	$M_{W,Ed}$	N_{Ed}
Units	**N-m**	**N-m**
Value	12925	529097.78
Ratio	0.0178	0.00356

Now, Substituting the values

$$\frac{M_{Y,Ed}}{M_{Y,Rd}} + \frac{M_{Z,Ed}}{M_{Z,Rd}} + \frac{N_{Ed}}{N_{Rd}} + \frac{M_{W,Ed}}{M_{W,Rd}} \leq 1.0$$

$$0.04227 + 0.0364 + 0.0178 + 0.00356 \leq 1.0$$

$$0.10003 \leq 1.0$$

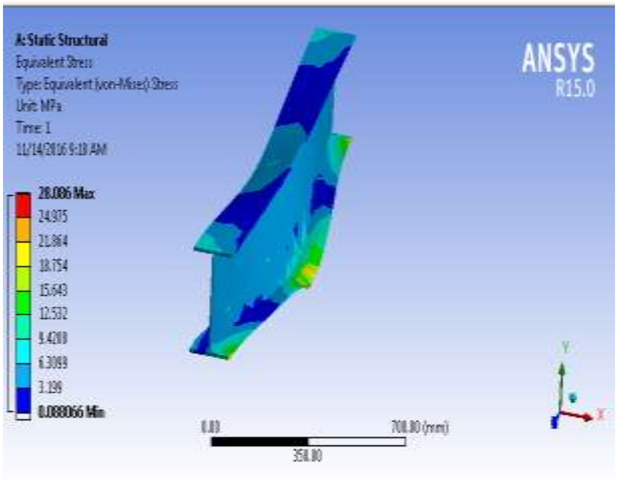

Fig.4 . : Stress results from simulation

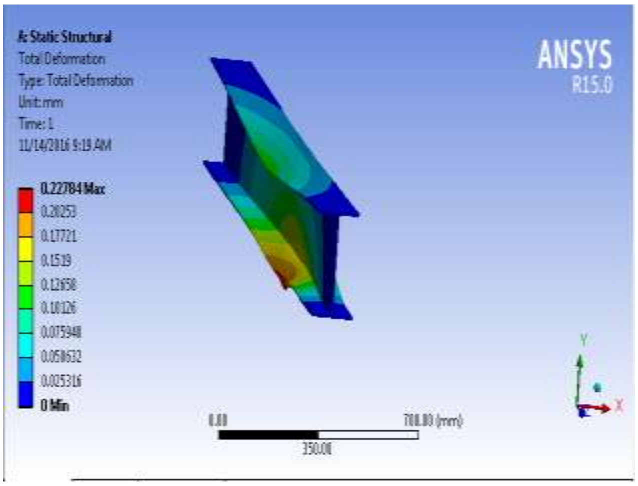

Fig.5 . : Deformation results from simulation

The chosen cross-section is 254 × 146 × 31. Chosen section properties can be found in Design data blue book (P363) document. Where 31 indicates the mass of the section per unit length which is meter in our case.

B. Additional design checkings :

There are additional checking to be done for the beams to know weather beam is actually developing the strength that should corresponding to it's strength and shape. They are share resistance, axial resistance and lateral buckling resistance. In theory of bending we neglect the shear forces in the beam, but in actual case there is limit for these forces, These forces should not exceed certain limits. Just like shear force, There are allowable values for axial compressive load and lateral torsional buckling also. These values should be checked weather they are in limits.

1. Verification of Shear Force :

If the shear force acting on the beam is more than 50 % of the shear resistance then, The bending resistance offered by the section will not be the same.

$$\frac{V_{Ed}}{V_{Pl,Rd}} \leq 1.0$$

$$V_{Pl,Rd} = \frac{A_v(F_y/\sqrt{3})}{\gamma M_0}$$

But due to the presence of torsion the shear resistance will decrease and it can be found as stated in the

Eurocode 3 : Design of steel structures.

The reduced shear resistance is given by

$$V_{Pl,r,Rd} = \sqrt{1 - \frac{\tau_{w,Ed}}{1.25(f_y/\sqrt{3})/\gamma_{M0}}}\, V_{Pl,Rd}$$

$$\tau_{w,Ed} = ES_{w1}\frac{\dddot{\phi}}{t_f}$$

The value of $\dddot{\phi}$ to determine the value of $\tau_{w,Ed}$ determined by following the detailed approach in SCI_P385 publication and it's value is 0.01128.

Value of S_{w1} is also given in the tables in the same document for the chosen section.

Table 4. Shear load and shear resistance

Load	a. V_{Ed}	
Units	N	
Value	4782.7674	
Resistance	$V_{Pl,Rd}$	$V_{Pl,r,Rd}$
Units	N	N
Value	202668.4197	201883.7125
`		0.02369 $\leq$ 1.0

2. Axial Compressive Load :

Table 5. Axial compressive load and compressive resistance

The axial load acting on the member should satisfy the following equations other wise the decreased bending resistance of the member must be calculated.

$N_{Ed} \leq 0.25\, N_{Pl,Rd}$ ....(a)

Where $N_{Pl,Rd}$ = Load which is causing the bending moment.

$$N_{Ed} \leq 0.5\frac{h_w t_w F_y}{\gamma M_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

Table 5. Axial load and Axial resistance

Load	2. N_{Ed}	
Units	N	
Value	1876.455 N	
Resistance	N_{Ed}	$0.5\frac{h_w t_w F_y}{\gamma M_0}$
Units	N	N
Value	1876.455.	345526.5
`	$N_{Ed} \leq 0.25\, N_{Pl,Rd}$	1876.455 $< 345 \times 10^3$

3. Verification of Lateral Torsional Buckling :

But, the beam is not supported laterally, the lateral torsional buckling must be verified.

$$M_{b,Rd} = \chi_{LT} W_y \frac{F_y}{\gamma M_1}$$

$\overline{\chi_{LT}} = \sqrt{\frac{W_{Pl} F_y}{M_{Cr}}}$, Which is a dimensionless parameter

The critical moment value can be found from the formula.

$$M_{Cr} = C_1 \frac{\pi^2 E I_Z}{L^2}\sqrt{\left\{\frac{I_w}{I_z} + \frac{L^2 G I_t}{\pi^2 E I_Z}\right\}} \text{ N-m}$$

$C_1 = 1.0$ is conservative.

The critical moment value is 295672.56 N-m. The critical moment can also be found from the LTBeam software.The value of $\overline{\chi_{LT}}$ is found to be 0.6045 .The corresponding reduction factor χ_{LT} = 0.9125 from

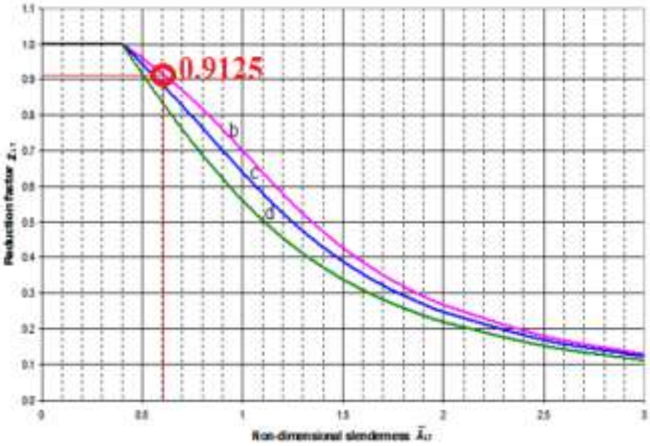

Fig .5. : Lateral torsional buckling reduction factor

Table 6. Critical bending moment and buckling resistance moment

Load	$M_{Y,Ed}$
Units	**N-m**
VALUE	4569.2037N-m
Resistance	$M_{b,Rd}$
Units	**N-m**
VALUE	98618.4375
LOAD/RESISTANCE	$\frac{M_{Ed}}{M_{b,Rd}} = \frac{4596.2037}{98618.4375} = 0.0463 < 1.0$

Table 7. Load and resistance of end truck in case 1

Load	$M_{Y,Ed}$
Units	**N-m**
Value	718.96352
Resistance	$M_{Y,Rd}$
Units	**N-m**
Value	8470
LOAD/RESISTANCE	$0.084883 < 1.0$

C. End truck design :

End truck carries the I-section (Which is carrying the load) along the length of the bed in-order to achieve the correct location of the load. There are two cases in which only in one case the stress in end truck becomes maximum.

1. Case 1 : While I-section is lifting the load, the end trucks acts as support reactions and in addition to that, The torsional load acting on the I-section due to the out-plane load creates moment on the end truck. This moment will be responsible for the magnitude of support reactions of the end truck. While lifting the load. 4782.76 N will act on the beam with a moment in the middle of the span of end truck with a magnitude of 236.11 N-m.

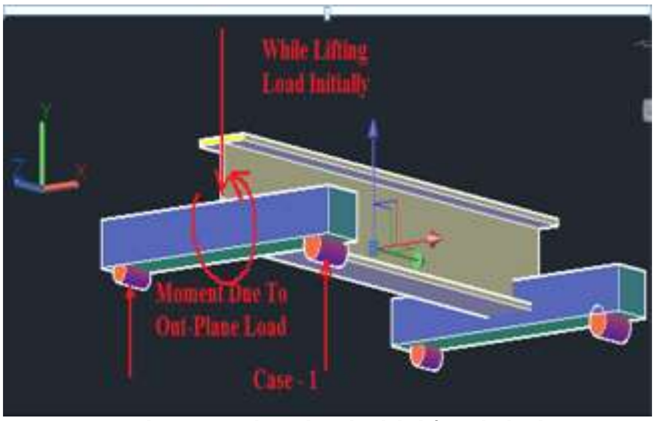

Fig. 6. : Loads acting on the end truck while lifting the load.

2. Case 2 : After load has been lifted, to place the load on the bed if the trolley reaches the extreme position then the load on the end truck will be different from the case 1. It do not involve any moment but the direct transverse load. The maximum reaction is to be given by the adjacent end truck for the extreme position of the trolley. When trolley at it's extreme position the adjacent end truck should give the maximum reaction and it's magnitude is 8275.716 N.

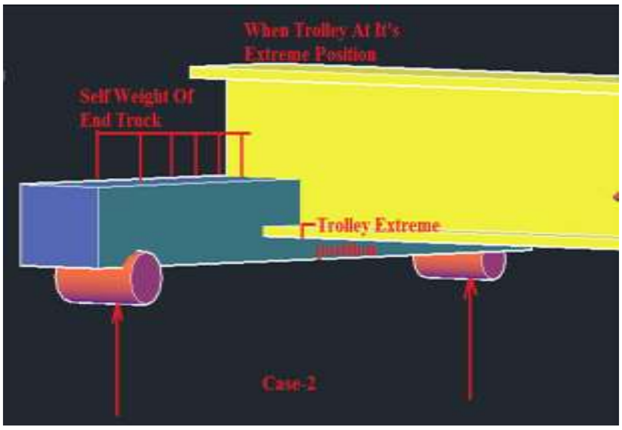

Fig. 7. :When trolley at it's extreme position

Table 8. Load and resistance of end truck in case 2

Load	$M_{Y,Ed}$
Units	**N-m**
Value	1043.652
Resistance	$M_{Y,Rd}$
Units	**N-m**
Value	8470
LOAD/RESISTANCE	$123275 < 1.0$

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D. Additional design checkings :

1. Since case-2 is the case in which the shear load is more. It is to be checked weather the shear force is with in the limits so that no change in bending resistance is required. If the shear force acting on the beam is more than 50 % of the shear resistance then, The bending resistance offered by the section will not be the same.

$$\frac{V_{Ed}}{V_{Pl,Rd}} \leq 1.0$$

$$V_{Pl,Rd} = \frac{A_v(F_y/\sqrt{3})}{\gamma M_0}$$

Table 9. Share load and shear resistance

Load	V_{Ed}
Units	**N**
Value	4186.859
Resistance	$V_{Pl,Rd}$
Units	**N**
Value	111139.9268
LOAD/RESISTANCE	0.037672 < 1.0

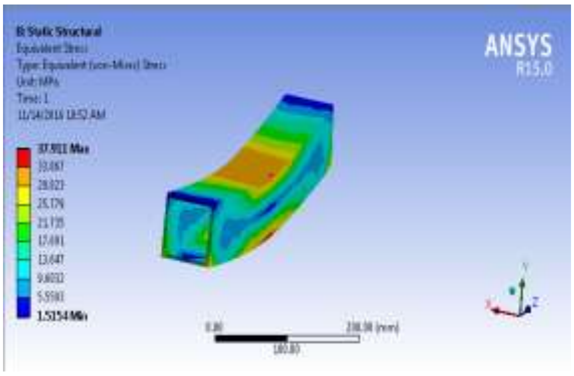

Fig. 8. : Stress results from simulation

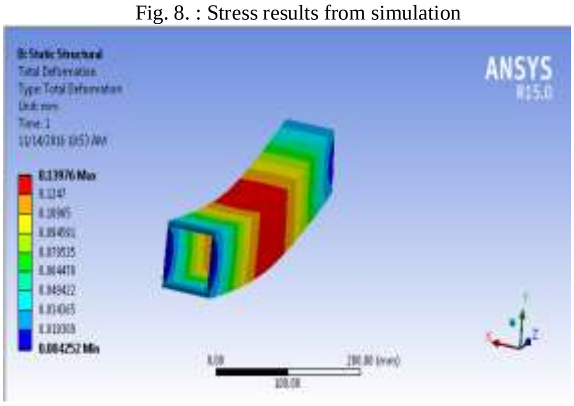

Fig. 9. : Deformation results from simulation

E. Overhang beam design :

It is the beam on which the end truck carries the i- beam carrying the load along the length. The beam should support the end truck in two possible case the bending moment becomes maximum.

1. Case 1 **:** In case 1, While lifting the load axial load is also present. This load will be resisted by the rectangular beam out-plane bending resistance. The necessary reaction is given by the torsional resistance by the overhang beam at the end. Since it is also an open section the warping should considered and is as follows. The supporting reaction from the back column in the upward direction with magnitude 278.7614 N. The reaction form the front column in the upward direction with magnitude 7064.367

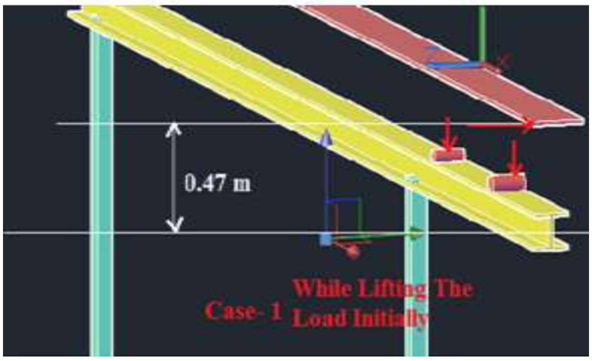

Fig. 10. : Different loads acting on overhang beam while lifting the load.

Table 10. Loads and resistance of i-beam in case 1

Type of Load	$M_{Y,Ed}$	$M_{W,Ed}$
Units	**N-m**	**N-m**
Value	2903.13	2762.956
Resistance	$M_{Y,Ed}$	$M_{W,Ed}$
Units	**N-m**	**N-m**
Value	120450	31267.378
Ratio	0.02410	0.08836

2. Case 2 **:** When the trolley is at it's extreme position. The load will induce pure bending and the calculations are as follows.

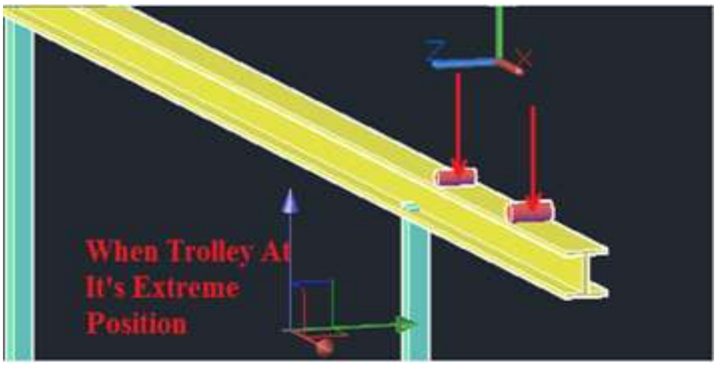

Fig. 11. : Different loads acting on overhang beam when trolley at it's extreme position.

3. The from the back column the reaction will be downwards on the overhang beam with magnitude 104.954 N. The reaction from the front column will be upwards with magnitude 10990.0327 N.

Table 11. Loads and resistance of i-beam in case 1

Load	$M_{Y,Ed}$
Units	**N-m**
Value	4437.995
Resistance	$M_{Y,Rd}$
Units	**N-m**
Value	120450
LOAD/RESISTANCE	0.03685 < 1

F. Additional design checkings :

1. If the shear force acting on the beam is more than 50 % of the shear resistance then, The bending resistance offered by the section will not be the same.

$$\frac{V_{Ed}}{V_{Pl,Rd}} \leq 1.0$$

$$V_{Pl,Rd} = \frac{A_v(F_y/\sqrt{3})}{\gamma M_0}$$

Due to the presence of the torsion the resistance offered by the element will not be plastic shear resistance. The reduced shear resistance is should be used to compare the actual shear load and reduced shear plastic resitance.
According to Eurocode 3 : Design of steel structures.
The reduced shear resistance is given by

$$V_{Pl,r,Rd} = \sqrt{1 - \frac{\tau_{w,Ed}}{1.25(f_y/\sqrt{3})/\gamma_{M0}}}\, V_{Pl,Rd}$$

Where $V_{Pl,r,Rd}$ = Reduced plastic shear resitance.

Table 12. Share load and shear resistance

Load	V_{Ed}	
Units	**N**	
Value	12894.16675	
Resistance	$V_{Pl,Rd}$	$V_{Pl,r,Rd}$
Units	**N**	**N**
Value	315792.9881	314959.2231
Ratio		0.0409 ≤ 1.0

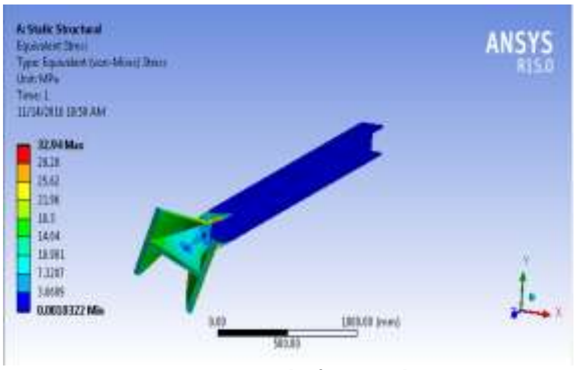

Fig. 12. :Stress results from simulation

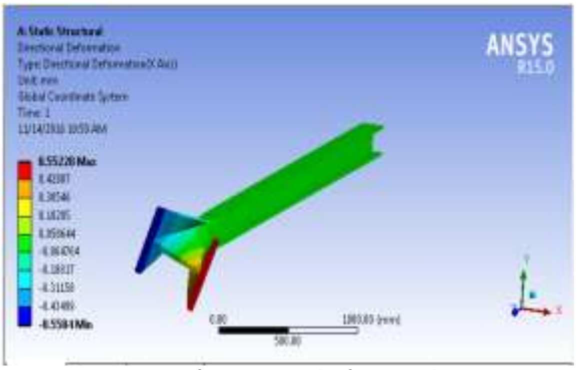

Fig. 12. : Deformation results from simulation

G. Front Column:

The load on the front column becomes maximum when the trolley reaches it's extreme position. The magnitude is 10990.032 N. If we consider only Euler's theory of column we can not involve the yield stress. So, by using modified Perry robert son formula we can involve yield stress. Which shows the relation between slenderness, column strength and imperfection. The column material is assumed to be hot finished and Table 6.2 in SCI_p362 document curve "a" is chosen and the corresponding imperfection factor is 0.21

$$(\sigma_{Cr} - \chi f_y)(f_y - \chi f_y) = \eta \chi \sigma_{Cr} f_y$$

χ = is the buckling reduction factor.
$\eta = \alpha(\lambda - \lambda_0)$, Where α is the imperfection factor.
λ = dimensionless slenderness ratio.
$\lambda_0 = 0.2$

No reduction of yield strength is needed up to 20 % of slenderness.

The following equation must be verified

$$\frac{N_{Ed}}{N_{Rd}} \leq 1.0$$

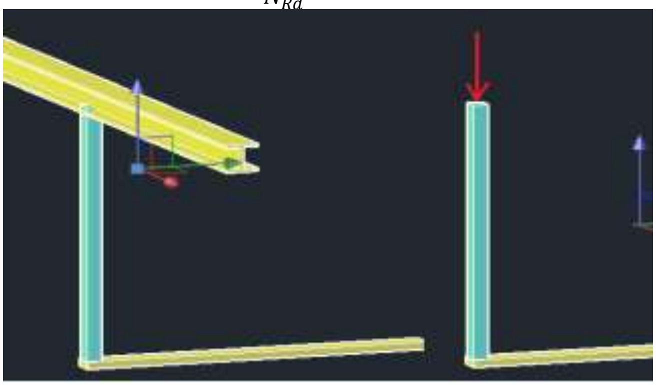
Fig .13. : Loads on front column

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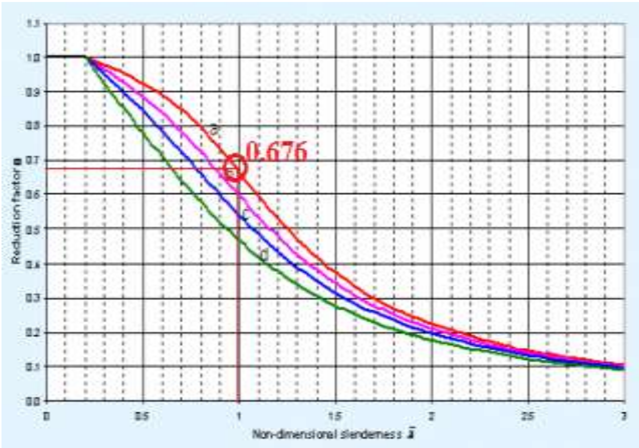

Fig .14. : Flexural buckling reduction factor

Table 13. Front column design load and resistance

Parameter	$\bar{\lambda}$	χ	N_{Ed}	N_{Rd}
Units	---	----	N	N
Magnitude	0.9896	0.676	10990.032	98155.2

$$\frac{N_{Ed}}{N_{Rd}} = \frac{10990.0327}{98155.2} = 0.11196$$

Parameter	$\bar{\lambda}$	χ	N_{Ed}	N_{Rd}
Units	---	----	N	N
Magnitude	0.9302	0.718	9315.478	85693.2

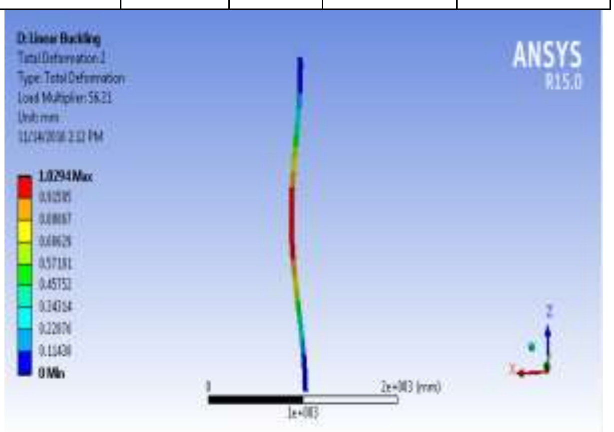

Fig .15.: First buckling mode shape

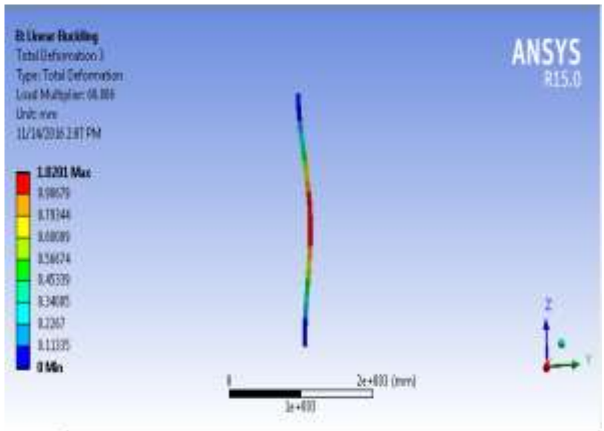

Fig .16.: Second buckling mode shape

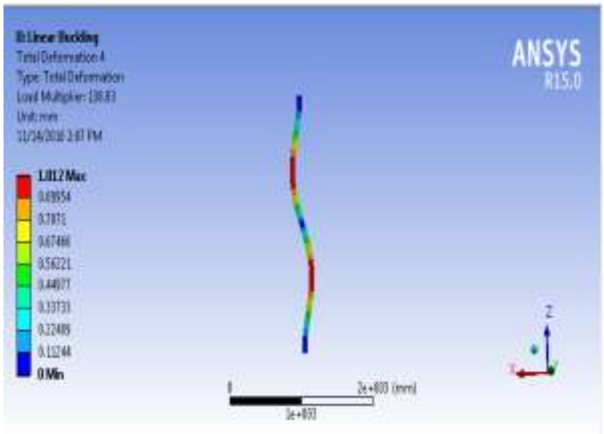

Fig .17.: Third buckling mode shape

F. Back Column :

Taking entire load carrying by the end truck and weight of the end truck as the load acting on the back column. It's magnitude is 9135 N. The column material is assumed to be hot finished and Table 6.2 in SCI_P362 document curve "a" is chosen and the corresponding imperfection factor is 0.21

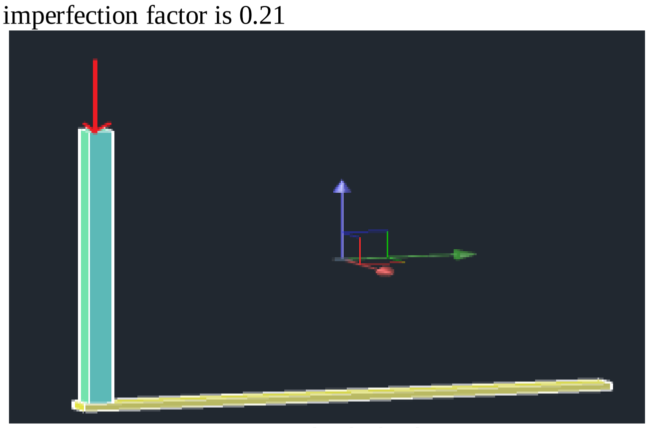
Fig .18. : Load on back column

Table 13. Back column design load and resistance

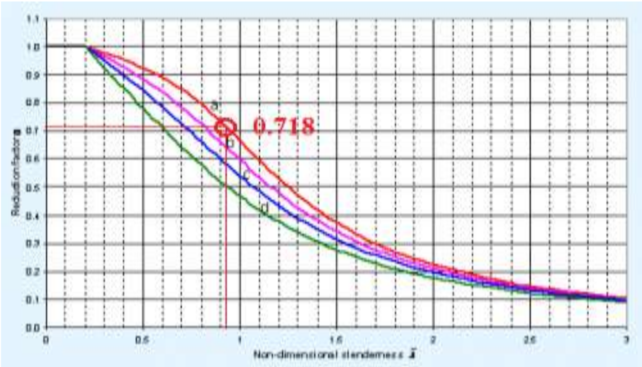

Fig .19.: Flexural buckling reduction factor

Table 14. Front column design load and resistance

$$\frac{N_{Ed}}{N_{Rd}} = \frac{9315.4787}{85693.2} = 0.1087$$

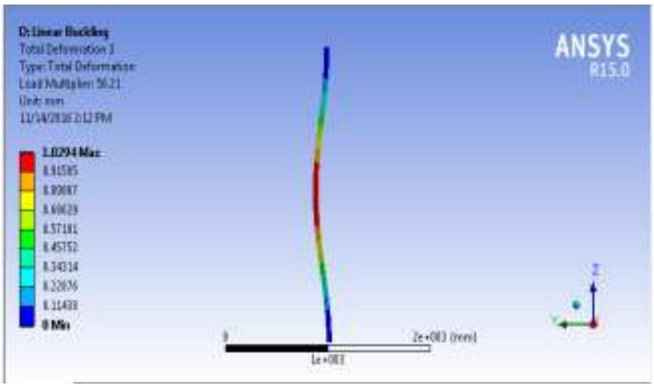

Fig .20.: First buckling mode shape

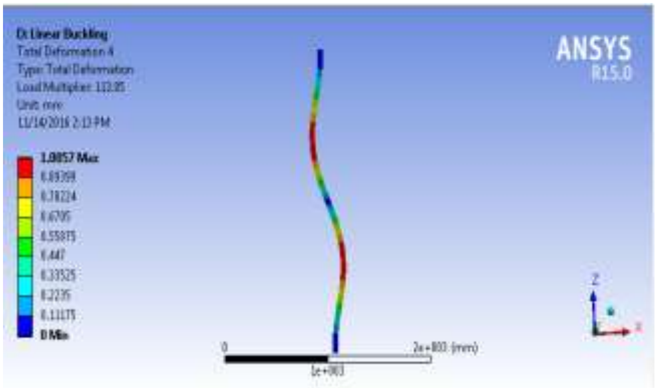

Fig .21.: Second buckling mode shape

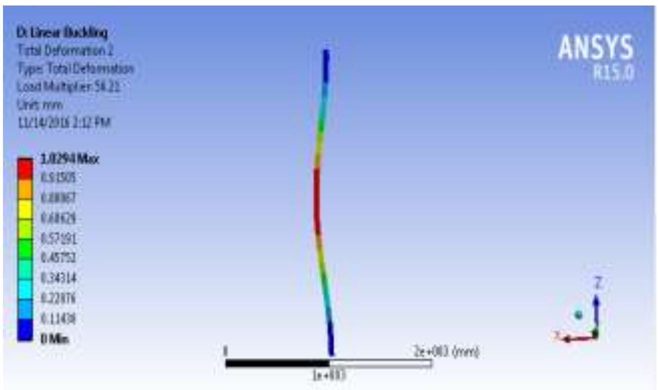

Fig .22.: Third buckling mode shape

G. Front Major Beam :

This beam is attached to the chassis of the truck and give the necessary support to the column on it. Since the loads on the front column are more than the back column the front beam dimensions are more than the back beam. The distance between the frame rail web sections is 850 mm.

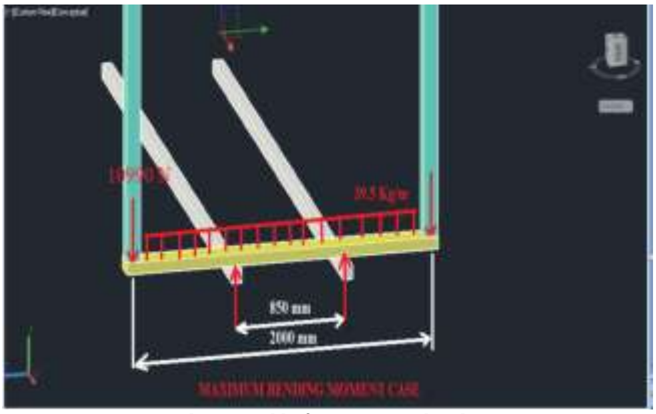

Fig .23.: Load responsible for maximum bending moment

The following equation must be satisfied.

$$\frac{M_{Ed}}{M_{Rd}} \leq 1.0$$

Table 14. Front base beam design load and resistance

Load	$M_{Y,Ed}$
Units	**N-m**
Value	6251.54651
Resistance	$M_{Y,Rd}$
Units	**N-m**
Value	55275
LOAD/RESISTANCE	0.1131 < 1

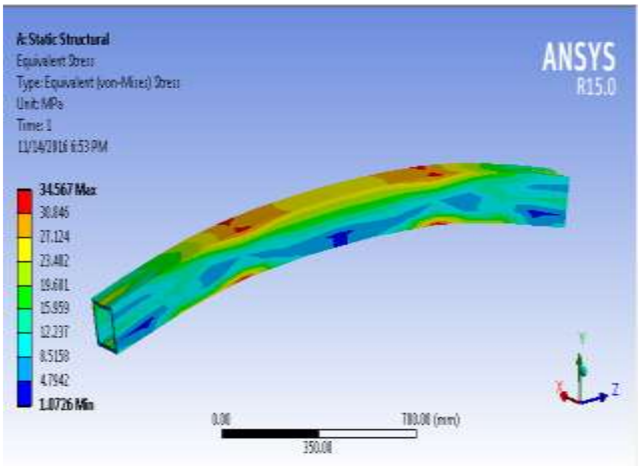

Fig .24. : Stress results from simulation

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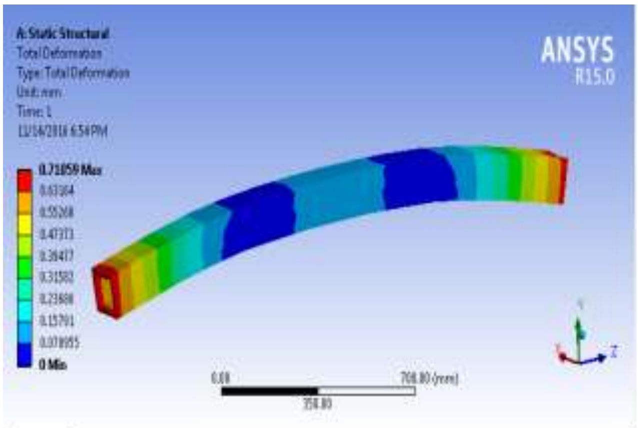

Fig .25. : Deformation results from simulation

H. Back Major Beam :

This beam supports the back columns. when the trolley above the columns the maximum bending moment will occur in the beam.

$$\frac{M_{Ed}}{M_{Rd}} \leq 1.0$$

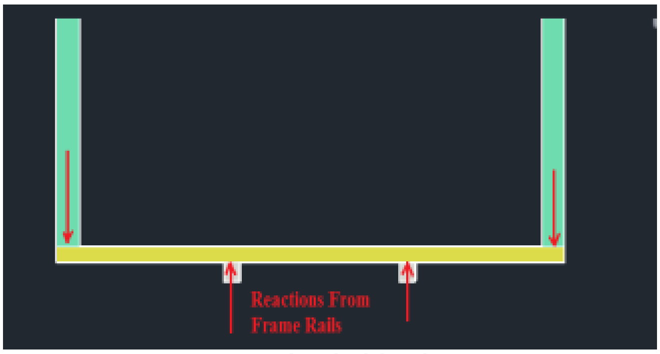

Fig .26.: Loads on back base beam

The maximum bending in the beam is given by

$$M_{Ed} = M_{max} = 9315.4787 \times 0.575 + 39.5 \times 9.81 \times 0.575 \times 0.2875$$
$$= 5356.4002 \text{ N-m}$$

The design moment resistance is given by.

$$M_{Rd} = W_{Pl,y} \times F_y \text{ N-m}$$
$$= 201 \times 275 = 55275 \text{ N-m}$$

The ratio of design bending moment and bending resistance should be less than 1.

$$\frac{M_{Ed}}{M_{Rd}} = \frac{5356.4002}{55275} = 0.095 < 1.0$$

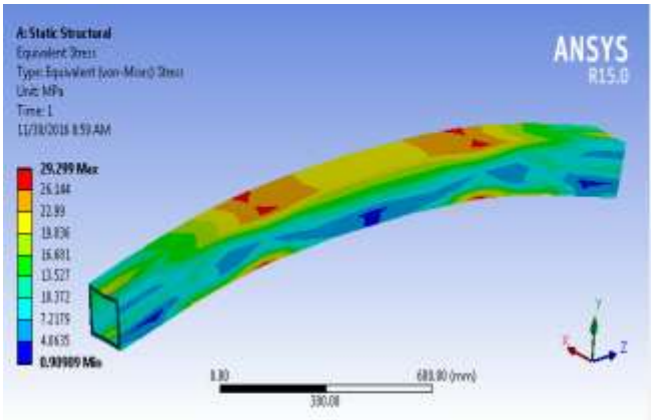

Fig. 27. :Stress results from simulation

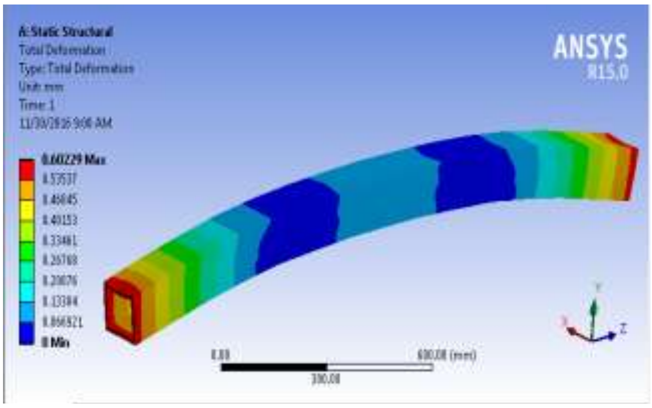

Fig .28. : Deformation results from simulation

I. Axial Load Supporting Beam:

This beam supports the i-beam on which the trolley travels in the axial direction. While supporting 1691 N-m. The maximum bending moment occurs in the beam will be 1691 × 4.5 = 7609.5 N-m. or $M_{Ed} = 7609.5\ N - m$. For this, We have to take a factor of safety 8.

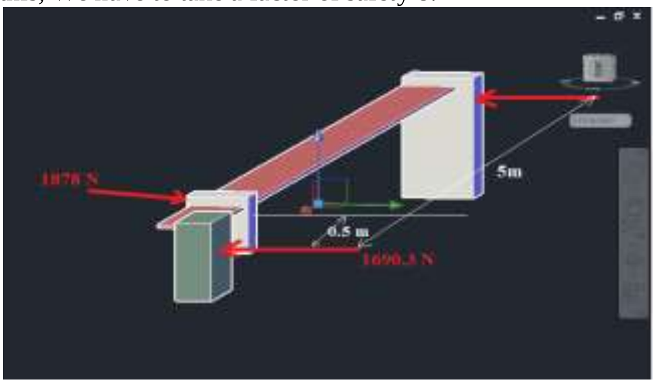

Fig .29. : Loads on axial supporting beam

Lets us assume a ratio 0.14285

$$\frac{M_{Ed}}{M_{Rd}} \leq 0.14285$$

Then the M_{Rd} will become.

$$\frac{803.225}{0.14285} \leq M_{Rd}$$

Now, The design resistance should not be less than the following value.

$$M_{Rd} = \frac{td^2}{4} \times 275 \geq 5623 \text{ N-m}$$

If we equate them $td^2 = 0.81789 \times 10^{-4}\ M^3$

Taking appropriate value of one value will give another value. Taking the value of d = 0.1 m we get the value of t=0.00818m.

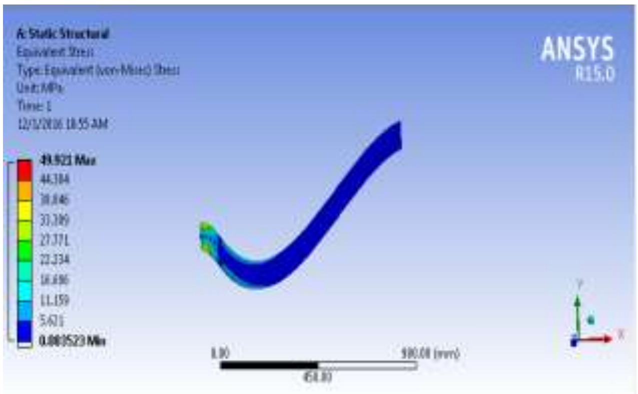

Fig. 30. :Stress results from simulation

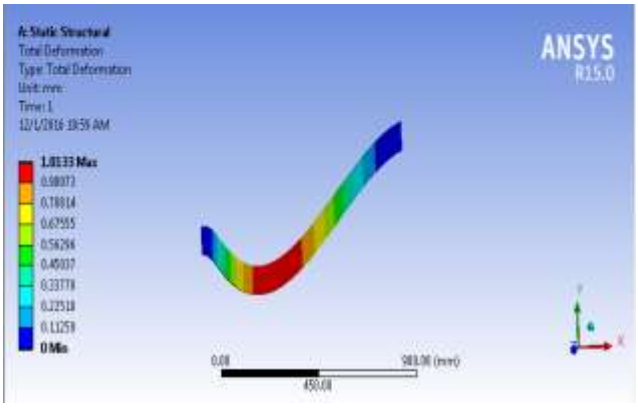

Fig .31. : Deformation results from simulation

Table 15. Comparison of analytical and simulation results

NAME OF THE ELEMENT	SIMULATION RESULTS	THEORETICAL	% OF ERROR
I-Section	28.086	27.582	1.827
End truck	37.911	33.88	11.89
Overhang beam	32.94	30.926	6.5
Front column	10.791	10.271	5.06
Back column	6.9938	5.822	20.12
Front base beam	34.567	31.1025	11.14
Back base beam	29.29	26.125	12.11
Axial supporting beam	49.921	39.2875	27.06

III. Conclusion

The mobile crane for Indian truck is one of the best way to lift heavy weights up to 500Kg and due to the simple structure the maintenance cost is low. The structure weights just more than 600 Kg but the cost of fuel expenses are less than that will be used for the man power to load and unload up to certain limit. Trouble shooting is also very easy compared to other cranes.

The knuckle boom crane consumes electricity. Where as in the designed mobile crane using the manual trolley to lift the load can save electricity. Operation of crane is safe.

Slightly increasing the dimensions of the elements and supporting the front base beam (base beam behind the vehicle) with two columns with the columns above and below base beam coinciding, weight more than 500kg can be lifted.
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