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Design and Development of Material Handling Crane

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Abstract: - **In case of construction equipment there is a mainly requirement of material to be transfer from one place to another place or from one floor to another floor. This material may contain the grain particles, cubes, heavy cement bags, etc. This is very important to transfer the material at right place at right time for its good working environment.**

So there is a main requirement of the construction crane for the purpose of material handling from one place to another place.

This project will helpful for the specific requirement of such application of material handling in case of construction sites. Basically these construction sites requires more human interfere for proper completion of the construction work.

Keywords: Tower cum Jib crane, Steel structural design, FEM, Material sourcing, manufacturing procedure, testing procedure.

INTRODUCTION:

In the construction or heavy mechanical industry there is a need to transmit the material from one place to another place. There are so many varieties of cranes used in these industries. The commonly used cranes are overhead cranes, mobile cranes, rough terrain cranes, tower cranes, jib cranes. In case of construction work small cranes are normally used which carries approximately 100 kg can load. Also in this construction industry, the tower cranes are mostly used for high buildings applications. Sothere is a need of design of a crane, which considers the requirement of sponsorer.

Due to some limitations of conventional methods, it is impossible to improve workability. In order to successfully come up with these problems, material handling crane which is designed features plays vital role in day-today

industrial as well as civil work. To overcome the problem in existing methodology of working it was proposed to **Design and development a Material handling Crane** by which the workability improves.

In this paper the Design, Manufacturing and Execution of crane. And proposed requirements of the project,

- Material of weight 500 Kg to be carry.
- Maximum lifting height should be 132 feet.
- Material can place in between radius of 20feet
- Angular movement of 180 degrees of crane axis.
- Motor drive for hoist to lift the material.
- Minimum persons required to operate the crane.
- Crane should be mobile having less weight.
- Easily assembled on construction site (normally within 2.5 hours.

ORGANIZATION OF THE WORK

Chapter 1: Design

This chapter gives various Design considerations in structures, components and its applications of CAD / CAE in new product design.

1.1 Calculations of the maximum stresses induced in the members of the vertical structure of the crane.

A structural failure may be said to occur when a structure collapses due to rupture or excessive distortion of members. The main mode for structural failure of material would be by shear, tension, buckling, crushing, fatigue or brittle fracture.In elastic design, the allowable stresses are taken less than the structure of material by an appropriate factor called “Factor of Safety”.

a) For steel, a factor of safety of **1.67** is used in axial tension and compression and **1.5** in bending.
b) The usual value of load factor is taken **1.7** for beams.

The shear force at distance 6.3 meters from the free end is equal to the unbalanced vertical force i.e. F_x=-10KN and the bending moment at this section,
M = -10 KN x 6.3 m = -63 KN-m

Box type design is considered, 500 mm x 500 mm is used as a column, with a one end fixed and other is free, then by Euler’s formula the crippling load will be,

$$P = \frac{\pi^2 \times E \times I}{L^2} \qquad [1]$$

Considering Modulus of Elasticity E=200 GPa

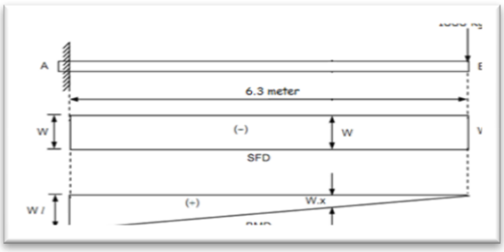

Fig. 1.1 SFD and BMD

So, calculating the Moment of Inertia for the selected column section will be,

I = $\frac{BD^3}{12}$ = $\frac{500 \times 500^3}{12}$ = 5.2 x$10^9 mm^4$

Safe Load = $\frac{\text{Buckling Load}}{F.O.S.}$ = 2.78x10^6 KN

Since, the column is fixed at one end and free at other end, the equivalent length of column is,

L= 2 x l (length) = 2 x 3 x10^3 mm= 6 x10^3 mm

Sr. No	**End Connections**	**Crippling Load**	**Relation between equivalent and actual length**
1	Both ends hinged	$\frac{\pi^2 EI}{L^2}$	L=1
2	One end fixed and the other free	$\frac{\pi^2 EI}{2L^2}$	L=2l
3	Both end fixed	$\frac{\pi^2 EI}{(L/2)^2}$	L=$\frac{l}{2}$
4	One end fixed and other hinged	$\frac{\pi^2 \times E \times I}{(L/\sqrt{2})^2}$	L=$\frac{1}{\sqrt{2}}$

Table No. 1.1 The equivalent lengths (L) for given end conditions [1]

Effective length of struts

The effective lengths according to IS: 800-1984 for various combinations of the end connections are

Effectively held in position at both ends and restrained against rotation at one end is given by,

0.80 L = 0.80 x 4

The total height is approximately

13 FT = 4 meters = 0.80x4
= **3.2 Meters.**

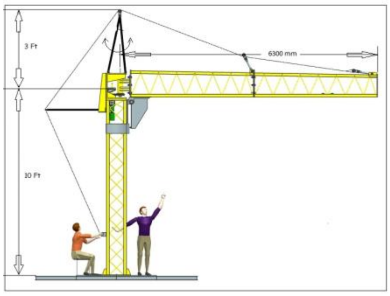

Fig. 1.2 Effective length

CHECKING THE BUCKLING OF BUILT-UP COLUMNS.

Forbuilt-up columns, we have to determine the safe load by Rankine's Formula having the column length of 3.2 meters.

Length, l = 3.2 meters

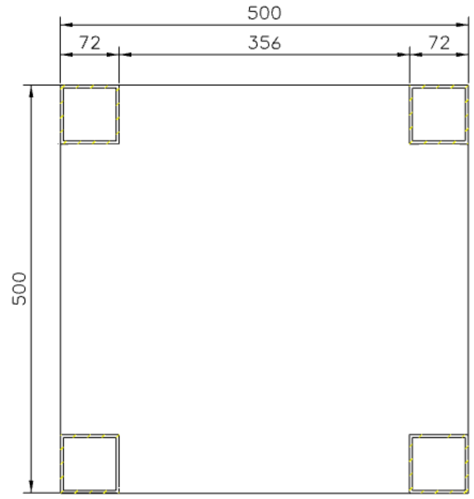

Fig 1.3 Buckling of built-up section

Factorof safety = 5

Area, a = 500 x 500 = 2.5 x 10^5 mm^2

Moment of Inertia, I= 1.56 x 10^{10}

Radius of gyration is given by,

= √ (1.56 x 10^{10} / 2.5 x 10^5)= 249.7 mm Say = 250 mm.

For built-up columns, we have to determine the safe load by Rankine's Formula having the column length of 3.2 meters.

Length, l = 3.2 meters

Factor of safety = 5

Area, a = 500 x 500 = 2.5 x 10^5 mm^2

Moment of Inertia, I= 1.56 x 10^{10}

Radius of gyration is given by,

= √ (1.56 x 10^{10} / 2.5 x 10^5)= 250 mm

Therefore the Crippling load on the column is calculated by following,

P = (6c x A) / (1 + a $(L/K)^2$)

[1] [6]

$P = (320 \times 2.5 \times 10^2) / (1 + (1/7500) \times ((3.2 \times 10^3) / 250)) =$

80×10^3 KN

Safe load on the column = $(80 \times 10^3 / 5) = 16 \times 10^3$ KN

Thus column is **safer** for Buckling.

DESIGN OF COLUMN BASES:

Required width of gusset plate (B) = (Depth of girder + 2 x Cover plate thickness + 2 x Gusset plate thickness + Width of an angle connecting base plate + Clearance.

B = 500 + 2 (16) +2 (16+100+14)

B = 792 mm and A = 114 mm

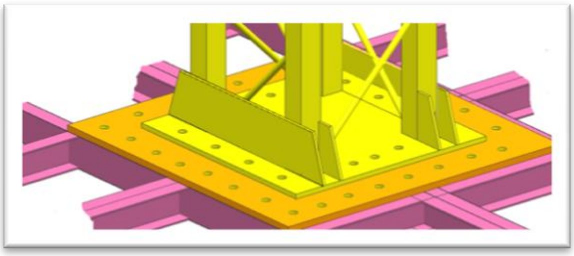

Fig 1.4 Column bases

Length of the gusset plate = $4.16 \times 10^3 / 792 = 5.25$ mm say 6mm
Area of a gusset plate provided = $6 \times 792 = 4752\ mm^2 > 4160\ mm^2$
Intensity of pressure between the plate and concrete = $25 \times 10^3 / 4.752 \times 10^3 = 5.26$ MPa < 6 MPa
The critical section for the bending moment is at the face of the angle.
Length of the critical section = (115-16) + 14= 113 mm
Considering unit width,Bending moment at critical section = $5.26 \times (113^2 /2) = 33582.5$ N mm

Plastic modulus required,
$Zp = M \times \gamma_{mo} / Fy = 33582.5 \times (1.1 / 250) = 147.8$ Say 148 mm^3
Where,
γ_{mo}= Partial safety factor = 1.1

Elastic modulus,
$Ze = 148 / 1/14 = 129.8$ say 130 mm^3
$130 = 1 \times (t^2 / 6)$
t= 27.9 mm say 28 mm.
Bending moment at critical section yy,
$= W (B-2a)^2 / 8 – W \times (a^2/2)5.26 (792 – (2 \times 114)^2 / 8- 5.26 \times 114^2 / 2 = 174968.64$ N.mm
Plastic Modulus required;$Zp = M \times \gamma_{mo}/ F_y = 174968.64 \times 1.1 / 250 = 769.8\ mm^3$ say 770 mm^3
Elastic Modulus;$Ze = 770 / 1.14 = 675.43 = 1x\ t^2$
$t^2 = 174968.64 \times 6 = 63.66$ mm say 64 mm.

The central portion has bending in two directions and also supported by web, hence thickness of plate is halved.Therefore, t = (64 / 2) = 32 mm
So provided thickness of the base plate is 32 mm.

Design of Bolts: [1] [5]

The column section and the cover plates attached with the flanges as one unit. Therefore the bolts connecting gusset plate and column section are in single shear.
б$_p$ = $P / A_{total} = P / (n \times A) = (25 \times 10^3) / (8x \left(\frac{\pi}{4}\right) \times (24^2)) = 7\ N/mm^2$

Actual moment load applied on the plate and bolt is 65 KN
m = 65×10^3 N m.
б$_c$ = Number of bolts= 24
ζ= Average shear stress
ζ_{max}= Max shear stress
$\zeta = (T \times r) / (A \times r^2)$
$\zeta = 1655.21\ N/mm^2$
$\zeta_{max} = (T \times r) / (A \times \varepsilon \times r^2)$
$\zeta = 11605$ N/ mm
Torsional load,
$Pt = (T) / (r / \varepsilon\ r^2)$
r = 300

Fig 1. 5 Design of column bases with bolts

Shearing force= $(T \times r) / (\varepsilon\ r^2)$=11 KN and direct load = 25 KN.
Resultant load = $\sqrt{(25^2 + 11^2)} = 28$ KN
Maximum shear stress = $(28 \times 10^3) / 245 = 114.28\ N / mm^2$
Combined stress on the plate = 122 N / mm^2
Therefore, for M20 bolt size the tensile stress area = 245 mm^2
For minimum shear strength of bolt grade 4.6 is 185 N/mm^2 which is 1.32 times **safe.**

1.2 Calculations of the maximum stresses induced in the members of the vertical structure of the crane.
Bending Stresses: By the simple theory of bending, Fb= (M/I) x y
Allowable bending stress

As per IS: 800-1984, the allowable bending stress in tension Fbt is based upon the guaranteed minimum yield stress F_y of the steel. Considering factor of safety for bending stress is 1.5 times the bending stress.
Therefore,
$F_{bt} = 0.66 \times F_y = 250$ MPa
Means Fbt = 165 MPa.
And Shear stress

Fa= VAy / Ib and Fs= 0.45 Fy
According to Standard table IS-800, data for Design of beams, coefficient of maximum deflection K=1/3.
Therefore,
$\Delta = (1/3)\ (WL^3 / EI)$
$W = 10KN = 10X10^3$ N, L = 6300mmE = $200x10^3$ N/mm^2

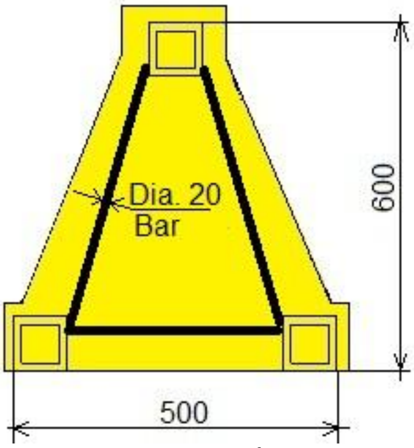

Fig 1.6 Moment of Inertia

I = 66.32 cm^4 = 66.32 mm^4
Load to be distributed considering 3 tubes,
10KN / 3 = 3.33 KN Say 3.5 x 10^3 N
The maximum deflection at the end point will be
$\Delta = (1/3)\ (WL^3 / EI) = 2199$mm

Calculating moment of Inertia:
$I_A = BD^3 / 12$
$I_A = 8.5x10^9$ mm^{4}and$I_B = BD^3 / 12$
$I_B = 18x10^9$ mm^4
Total Moment of Inertia,
$I_C = I_A\text{-}2I_B = 6.7 \times 10^9$ say 7×10^9

Therefore the maximum deflection at the end is given by;
$\Delta = (1/3)\ (WL^3 / EI) = (1/3)\ (10 \times 10^3 \times 6300^3) / (200 \times 10^3 \times 7 \times 10^9) = 0.622$ mm

The maximum deflection at the middle is given by;
$\Delta = (1/3)\ (WL^3 / EI) = (1/3)\ (10 \times 10^3 \times 3150^3) / (200 \times 10^3 \times 7 \times 10^9) = 0.07$ mm

Considering the deflection practically, we can define every aspect separately and then add it to deflection formula,
The square section having an area = 8.54 cm^2 = 854 mm^2
Considering horizontal section of ϕ20 mm bar having length 392 mm,

$I_{Bar} = BD^3 / 12 = 20 \times (392)^3 / 12 = 100 \times 10^6$ mm^4

Therefore the total moment of inertia;

$I_{sq.section}$ = 66.32 cm^4 = 66.32x 10^4 mm^{4}and I_{Bar} = 100 x 10^6 mm^4= 201.98 x 10^6= 202 x 10^6 mm^4

The applied load =10 KN= 10 x 10^3 N and E = 200 x 10^3 N/mm^2

The maximum deflection is given by;

$\Delta = (1/3)\ (WL^3 / EI) = 20.63$ mm say 21 mm. Thus Δ / L = 21 / 6300 = 1/300

As per IS: 800, the allowable deflection should not exceed than 2/325 of span for cantilever. Thus, **design** is safe for deflection.

1.3 Design considerations for drive section and calculations for thestresses and loadcarrying capacity of the main drive shaft of the crane. [1] [3] [5]

When a shaft is subjected to bending moment M_b and Torsional moment M_t, the bending stress 6_b and Torsional shear stress ζ given by,

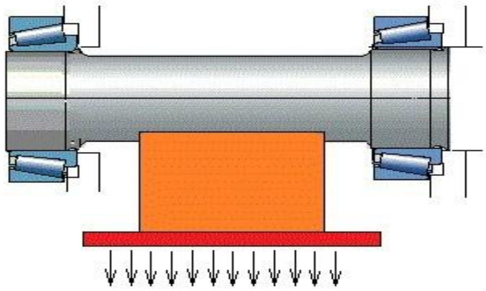
Fig 1.7 Design of drive shaft

M_t, the bending stress 6_b and Torsional shear stress ζ

$$6_b = (M_b \times y) / I = 32\ M_b / \pi d^3$$

$$\zeta = (M_t \times r) / y = 16\ M_t / \pi d^3$$

Material - En8 with Yield strength of 620 N/mm^2.
And M_t= 63x10^6 N mm
Shear stress can be taken as,
S_{st}= 0.577 x 620 N/mm^2= 357.74 say 358 N/mm^2

Considering shaft diameter 110 mm.
$\zeta = 16\ M_t / \pi d^3 = (16x63x10^6) / (\pi \times 110^3) = 241.04$ say 241N/mm^2

FOS = ζ / ζ_{max}= 358 /241= 1.48 say 1.5 times

Considering bending strength,
R_B x 660= (15 x 300) x 330= 2250 N and R_A = (15 x 300) - 2250= 2250 N

The shear force diagram above and values tabulated below.
F_A= +R_A= 2250 andF_C= 2250 N and F_D = 2250-(15x300)= -2250 N and F_B= -2250 N

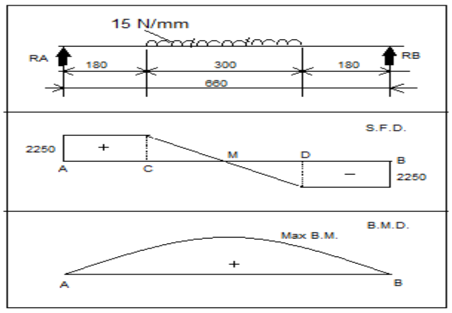

Fig. 1.8 SFD and BMD

On calculating M_A= 0 M_C= 337500, M_D= -337500

M_C= wl^2 / 8 M_C= 168750 N-mm

We have yield strength, S_{yt}= 620 N/mm^2.

If we consider that the shaft is having keyway, then
ζ_{max}= (16/ πd^3) x $\sqrt{\{(K_b \times M_b)^2 + (K_t \times M_t)^2\}}$

We know that,
S_{st}= 0.3x S_{yt} = 186 N/mm^2 and S_{ut}= 0.18x S_{yt} = 111.6 N/mm^2

According to standard, the following constants taken in to consideration.

K_b=1.5 and K_t= 1
ζ_{max}= (16/ πd^3) x $\sqrt{\{(K_b \times M_b)^2 + (K_t \times M_t)^2\}}$= 241.06 say 241 N/mm^2

Factor of safety = 241 / 114= 2.11 means design for shaft in tension and shear is safe.

1.4 Procedure for selection of Wire rope for safe working of crane. [1] [5]

Assuming number of wire ropes 'n'. The force acting on each wire rope compares weight of the material to be raised, the weight of the wire rope and the force due to the acceleration of the material and the wire rope.
The weight of the material raised by each wire rope, (10 x 1000/n) N (1)
From table mass of 100 m wire rope is 34.6 Kg, since the weight is,
= 34.6 x 9.81 x 40 / 100=135.77 N (2)
The mass of the material raised by each wire rope is (10000 / (n x9.81)) and that of each wire rope is, (34.6 x 40) / 100. Therefore, due to each acceleration is,
= [((10000/(nx9.81))+(34.6x40)/(100)]x1=[((1019.36)/n)+13.84]N(3)

From below table, the breaking strength of the wire rope is 44 KN.
Assuming the FOS to be 10.

(44000/10) = (10000 / n) + 135.77 + (1019.36 / n) + 13.84= 2.59 say 3

Nominal Diameter (mm)	**Approximate Mass (kg/100 m)**	**Minimum breaking load to tensile designation of wires of (KN)**		
		1230	**1420**	**1570**
6	12.5	13.6	15.7	17.4
7	17.0	18.5	21	24
8	22.1	24	28	31
9	28.0	31	35	39
10	34.6	38	44	48
11	41.9	46	53	58
12	49.8	54	63	69

Table 1.2 Breaking load and mass for 6x9 (12/6/1) Construction wire ropes as per IS

So two wire ropes of ϕ10 mm taken in to account. On an availability of material or wire rope selected is ½" or ϕ12 mm. considering, the diameter is selected is much safer side. Considering the maximum tension in the wire rope is 30 KN.

The mechanical properties of wire ropes considering IS-800: 2266-1981, Steel wire ropes general engineering purpose specifications, the nominal diameter (dr) of the wire rope indicate the diameter of the smallest circle enclosing the wire rope. The designation of the wires, such as 1570 or 1770 indicates the minimum ultimate tensile strength (in N/mm^2) of the individual wires used for making of the rope.

According the table for 6x19 (12/6x1) construction wire ropes for nominal diameter 81 KN for 1570 N/mm^2. This proves much safer for working.

1.5 Procedure to find out knuckle pin joint for wire rope. [5]

The total load carrying at the end of the mast is subjected to maximum stresses induced at the joining part of the rope and horizontal mast. This load is carried by means of the knuckle pin.
Considering the factor of safety to total load of 5 KN.

Fig 1.9 Design of Knuckle pin

The torque (T) transmitted by pulley,
T = 30 x 5= 1.5 x 10^5 N mm
D = Minimum shaft diameter
Torque, T = 1.5 x 10^5 N mm
ζ = 45 MPa
D = to be find out
T= (π/16) x ζ x D^3

$D^3 = (1.5 \times 10^5 \times 16) / (\pi \times 45) = 26$ mm.

On an availability of the standard Knuckle pin at market, we have bought 30 mm knuckle pin on safer side.

1.6 FEA analysis of Crane with the help of NX 8 NASTRAN

Simple mathematical model can be solved analytically, but more complex model requires use of numerical methods. FEA is one of the numerical methods used to solve complex mathematical problem. The entire solution domain must be discredited into simply shaped sub domain called as elements. NX 8 NASTRAN software is used for the analysis of the Material Handling Crane, which is based on the FEA method.

STEPS IN FINITE ELEMENT ANALYSIS

1. *3D modeling of Material Handling Crane.*
The parts have been created with parametric modeling in 3Dusing NX-8 software

The created 3D model is saved in part.prt file format, as this file format is suitable during importing this model for meshing in NX NASTRAN software.

Fig 1.10 3D model

2. *Meshing of the 3D model of Drive section.*

In simple term meshing means connecting elements with each other. Elements are the building blocks of the finite element analysis.Meshing is carried out by using NX NASTRANsoftware which is largely used for

Fig 1.11Meshed model

meshing. Model is meshed by using SOLID 45 element and with 10 element size.
Total 41231 nodes and 410232 elements were created after meshing.

3. *Material properties:*After completion of meshing material properties are assigned to meshed model. These properties are listed below.
Material used-Steel En 8
Young's Modulus-2.1x 10^5 N/mm^2
Poisons Ratio -0.26

4. *Applying constraints:* After modeling of the parts the proper constraining of the part is carried out.

5. *Structural loading on the component:* Structural loading means applying proper stresses on the drive section parts.

6. *Solving of the FEA model:* In this case Post Solver of NX NASTRAN solves the matrices internally. In this case, the solver solves mathematical model and gives the required results

7. *Results and its physicalinterpretation*

After applying material properties and boundary conditions, problem was solved by the NASTRAN solver. NASTRAN solver formulates the governing structural stress strain equations for each and every element those formulated governing equation are solved for deformation.

SUMMARIZED PRINCIPAL STRESS DATA USING FEA:

The following images shows the various results for the vertical section, horizontal boom, drive section box, drive shaft, pulley bracket, etc.

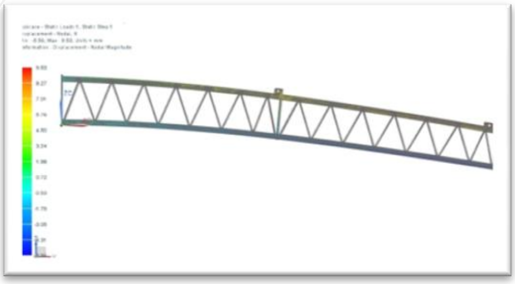

Fig 1.12 Deflection of horizontal boom

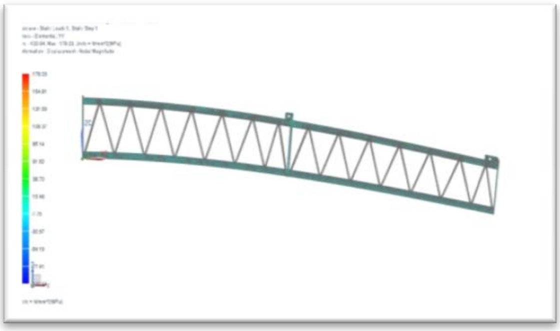

Fig 1.13 Von mises stress at horizontal boom

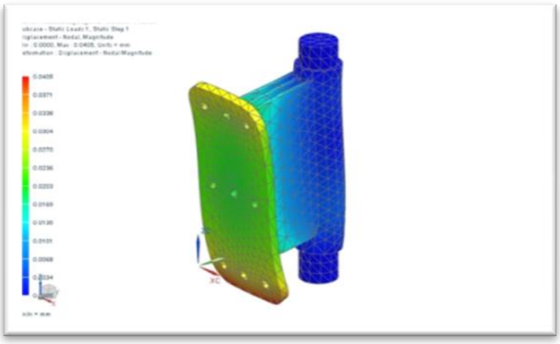

Fig 1.14 Displacement at drive shaft

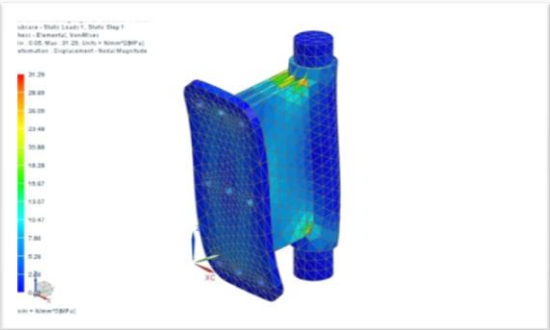

Fig 1.15 Von-mises stresses at drive shaft

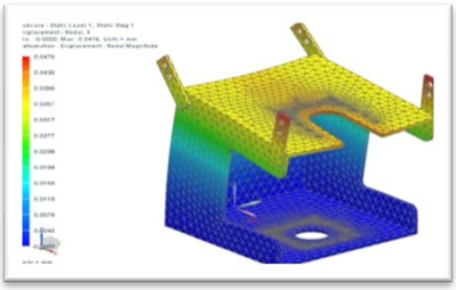

Fig 1.16 Displacement at drive Box

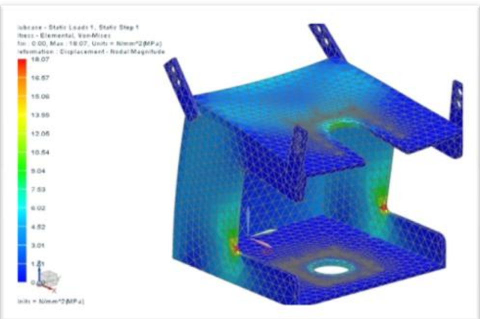

Fig 1.17 Von-mises stresses at drive Box

Chapter 2: Manufacturing

According to the design considerations the manufacturing of the Material Handling Crane was carried out at "Maharatna Steel Industries, Sakharale". Before the manufacturing of the crane, following things considered;

1) Availability of the space
2) Working machineries.
3) Manufacturing knowledge
4) Handling equipment's
5) Their clients.
6) Manpower
7) Technical knowledge
8) Transportation

MANUFACTURING PROCESS

Manufacturing of a crane was divided in to following parts;

1. Fabrication of vertical structure
2. Fabrication of horizontal boom structure
3. Fabrication and manufacturing of drive section.
4. Fabrication of supplementary parts like temporary base, rope support bracket, support plate.

The following photos elaborate the fabrication of a steel structure, manufacturing of the shaft, bearing plates, drive box setion.

Fig. 2.1 Manufacturing of Drive Box

Fig. 2.3 Manufacturing of Vertical Section

Fig 2.4 manufacturing of Horizontal Section

Chapter 3: Assembly and Testing

3.1 Assembly of the crane structure

The total assembly of the crane structure is carried out after manufacturing and fabrication of all components. The heavy structure is assembled at free space at Maharatna Steel industries. Followingprocedure is carried out during the assembly of the Crane structure.

Fig. 3.2 Complete assembly of crane

3.2 Inspection and Testing

After assembly of the crane structure the testing procedure is carried out. The inspection report is generated with reference to IS: 807 and IS: 3177 for cranes.
For testing purpose, the small weights weighing 20 Kg each has been taken. Load is gradually increased while testing of the crane.

Fig. 3.3 Testing of Crane

CHAPTER 3: CONCLUSION

In this dissertation work an attempt has been made for **Design and Development of Material Handling Crane.** Various design considerations made by previous design parameters and analyzed these models for better results.

The advent of innovative crane design has bought with the provision and tendency for being used as items of lifting and material handling equipment. This situation will present a whole new set of health and safety hazards to crane owners, operators.

. Following mentioned are some of the conclusion made on the Design and Development of Material Handling crane

1 Designing of this new concept i.e. a crane balancing using a wire rope or without counter weight.
2 Good ergonomic design theme.
3 The overall working space is more in this type of design.
4 Manufacturing or fabrication is much easier and suitable for working.
5 Comparatively assembly time is less considering the overall assembly.
6 Working capability as per initial requirement completed.
7 User friendly working.
8 Less dismantling time.
9 Low manufacturing cost.
10 Nice protective painting yellow coat.

CHAPTER 4: REFERENCES

4.1 Books:

1. Design Of Structural Steel by Prof. A. S. Arya and J. L. Ajmani
2. Analysis Of Structures by V. N. Vazirani and M. M. Ratwani
3. Design of Machine Elements by V. B. Bhandari.
4. Strength of Materials by R. S. Khurmi.
5. Cranes – Design, Practice, and Maintenance by Ing. J. Verschoof.

4.2 Journal Papers:

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