Analysis& Optimizationof Jib Crane under Influenceof Various Slewing angles&load position by limit state method.

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Received xx/xx/xxxx; Revised xx/xx/xxxx; Accepted xx/xx/xxxx

***Abstract*—: The existingJib cranes have high deflections which are not suitable for machine shop applications. The Jib are standardised for certain heights, however in actual the heights are altered suitable to different site conditions and applications. Under such conditions the existing deflection values change and generate lower natural frequency. Due to this the dampening time of the load during accelerationand deceleration increase and creates operational problems. The attempts in the research problem is to generate algorithm to find out the deflection and stress of complete pillar mounted crane under various slewing angles and load position by using limit state method. The limit state method is different to general allowable state method where the partial duty factors are multiplied on load side is and the permissible stress is closer to yield or ultimate stress. This method is adopted by ISO 12100 and European standards EN 13100 and latest state of the art methods.**

Keywords— Krasta Analysis, Finite element approach, Jib, Pillar, Stress analysis, Deflection analysis.

I. INTRODUCTION

Today's Industry demands versatile, efficient and cost effective equipment while at the same time providing more flexibility along with significant savings through increased productivity. A jib crane can help to improve material handling efficiency and work flow. Serious consideration should be given to jib cranes for applications requiring repetitive lifting and transferring of loads within a fixed arc of rotation. The need of continual improvement in material handling technologies is a common feature of many modern engineering endeavors.

The purpose of this research is to optimize the deflection of the Jib crane without influence to ergonomically feature of easy maneuvering in an extremely cost sensitive marketas modeling and then analysis.

Objective of the research is to develop calculation methodology for optimization of jib cranes and to investigate various analytical calculation methodology develop various calculation for pillar mounted over braced jib cranes.

The project involves development of mathematical modelin C++ based on En 13001 which emphasis on limit state theory.

The algorithm is developed so that user can enter various height of the pillar and outreach. The program will calculate whether the jib crane suffice stiffness ratio which is required as per the application demand. The calculations are done at various angles of the Jibs and position of the loads on the Jibs.

The base results are validated through KRASTA and Ansys Classic. The results through FEA software should match with the analytical since the analytical calculations are the basis of user friendly design approach for future jib cranes. The FEA software approach needs higher skills and knowledge which is not readily available. Similarly this is a time consuming approach and cannot be adapted to a standard series product like jib crane.

The knowledge boundary conditions and transfer of the internal forces from one sub system to another sub system should be well understood which otherwise shall give very wrong results.

Hence the basis of the calculations is, well understanding of system approach which is further enhanced with FEA approach for calibration of the results.

II. LITERATURE REVIEW

Vlada Gašić,[1]: The thesis examines the dynamics of a two dimensional jib crane structure subject to moving trolley with hoist and payload. Dynamic responses of the structure in both X and Y directions are calculated using FEA method and direct integration method. Instead of conventional moving effect, the paper deals with 2 dimensional inertia effects due to due to mass of trolley, hoist load and pay load. The researcher has calculated moving mass matrix for this case. The efforts are made to calculate Vibration response from time depended mass while subjected over all moving force. The trolley is assumed to be defined as lumped mass system. The author calculated equivalent nodal force generated due to lumped mass system. The time history displacement in influence of moving load and moving mass has been evaluated

Simon Bucasa,[2]: Stress Strength interference method applied for fatigue design of tower cranes. The goals of these projects were to experiment and to develop reliability approaches for the mechanical design against fatigue of industrial applications. Based on these previous works, the aim here is to quantify and optimize the safety margins with respect to fatigue of tower crane steel structures, by means of probabilistic approach. The author has taken different force combination and position of Tower crane jib using actual working cycles with different configurations. The calculations have done using FEA of modelling using shell elements. The fatigue criteria are then applied using random variables.

Nenad D.Zrnic [3]: Failure of crane structural parts can lead to collapse of complete crane. The thesis investigates the failure incident report of a gusset plate failure. The failure analyzed due to influence of parent material hardening with declining of toughness values due to low temperature conditions. Additionally influence of weld seam perpendicular to direction of force. The proximity of weld joint to the connection point also had increased the notch sensitivity in this case. The case study is a perfect combination of Designing defects, manufacturing defects and environmental effects.

IS: 15419 Jib Cranes [4]: This code gives the various types of jib cranes, safety features, factor of safety on bolted design and local bending calculations. The Limiting defection criterion is also specified to Indian reference. The code gives general awareness of various types of Jib cranes and dimensional parameters are listed in the code. Additionally a Test load criterion is generally given for the crane.

EN 13001[5]: Thiscode is a recent international norm emphasizing limit state theory for calculation of various load and load combinations. This code is described in part 1, 2, 3 and additional reference of EN 15001 is given where ever necessary. The Part 2 gives all load and load conditions and methodology to use Limit state theory. Limit state theory is different to allowable stress theory where in partial duty factors are considered on load side and very limited factors are considered on limit state limit. The different load includes. a) Hoisting and gravity effects acting on the mass of the crane; b) inertial and gravity effects acting vertically on the hoist load; c) loads caused by travelling on uneven surface; d) loads caused by acceleration of all crane drives;

e) Loads induced by displacements. Similarly occasional load which can also create detrimental effects on structures are specified in this code. a) Loads caused by hoisting a grounded load under exceptional circumstances; b) loads due to out-of-service wind; c) test loads; d) loads due to buffer forces; e) loads due to tilting forces; f) loads caused by emergency cut-out; g) loads caused by failure of mechanism or components; h) loads due to external excitation of crane foundation; i) loads caused by erection and dismantling. Similarly conditions for rigid body stability are also indicated in the code. Thus this code tries to minimize the risk generated from a) rigid body instability of the crane or its parts (tilting and shifting); b) exceeding the limits of strength (yield, ultimate, fatigue); c) elastic instability of the crane or its parts (buckling, bulging); d) exceeding temperature limits of material or components; e) exceeding the deformation limits.

Basic Structural Analysis [6]: Displacement Energy method, Rolling load and influence lines.

Mechanics of structures Volume II [7]: Unit load method, influence lines , Analysis of frame structures.

III. Problem Statement and Objective

Optimizing deflection of Jib cranes without influence to ergonomically feature of easy maneuvering in an extremely cost sensitive market.

1. Optimization of jib crane deflection which has influence to structural weight and production cost.
2. Keeping the cranes light as possible for easy maneuvering due to manual slewing. 80% of the Jibs are less than 1000 kg safe working load. These jibs are manually operated and need to be light as possible to avoid worker fatigue.
3. Keep the cost sensitivity in mind while making the optimization process. There are various methods to produce a jib crane. Some use bolted versions and some uses welded version. Cost calculations become some time deciding factor to accept certain design changes.

Objective of this project is to develop a calculation methodology for optimization of jib cranes and to investigate various Analytical calculation procedures for design of a pillar mounted Jib cranes for various angle of rotation. Preparation of mathematical model shall be based on EN-13001, which emphasis on limit state theory. The stress & deflection shall be analyzed using KRASTA software. The local stress if needed can be further evaluated with Ansys depending on the stress results from KRASTA.Once the mathematical model is developed the same shall be converted using C++ as a user friendly input and output interface.

IV. Theoretical Analysis

A. The sample Jib crane

TABLE I
DIMENSIONS OF CRANE

Parameters	Dimensions/ Load	Units/Remarks
SWL(GH)	500	kg
Trolley weight (p)	71	kg
Total Load (GGH)	571	kg
Outreach (l)	6000	mm
Track	KBK-II	Profile type
Pillar Type	6	Pillar Profile
Pillar Height(h)	5516	mm
Hook Approach(Lan 2)	240	mm
Vertical Bearing centre	1000	mm
Vertical height from track centre(W)	801	mm
La (Rib end)	5262	mm
Rib Inclined length(Lstr)	5307	mm
Rigid length(y0)	112	mm
Rib angle (α)	7.44	degrees

B.Track Profile properties

TABLE IIIII
PROPERTIES OF TRACK

Parameters	Dimensions/ Properties	Units/Remarks
Height	180	mm
I xx (Io)	6600000	mm^4
Zxx (Wo)	73333	mm^3
Ao	2080	mm^2

C Rib properties

TABLE IVVVI
PROPERTIES OF RIB

Parameters	Dimensions/ Properties	Units/Remarks

Height	80	mm
Thickness	10	mm
I xx (Is)	426666	mm^4
Zxx	10666	mm^3
As	800	mm^2

D Pillar properties

TABLE VIIV
PROPERTIES OF PILLAR

Parameters	**Dimensions/ Properties**	**Units/Remarks**
Height	435	mm
width	435	mm
Thickness	5	mm
I xx (Is x)	238451000	mm^4
I yy (Is y)	218476000	mm^4
WXX1,5	1096326	mm^3
WXX2,8	1276846	mm^3
WXX3,7	0	mm^3
WXX4,6	1276846	mm^3
WYY1,5	0	mm^3
WYY2,8	1169884	mm^3
WYY3,7	1004487	mm^3
WYY4,6	1169884	mm^3
As	8220	mm^2

E .The material properties of steel

The most commonly used material for the Jib crane is FE 250, IS: 2062 GR A

TABLE V
MATERIAL PROPERTIES

Material	FE 250 (IS: 2062 GR A)
Young's modulus	2.1e5MPa
Poisson's ratio	0.3
Density	7.850×10-6 kg/mm^3.
Yield strength	250 MPa

There 2 –sub system considered in the crane calculations.

1) Pillar and 2) Jib

Pillar Calculations;

As the jib rotates the moments on the pillar has different influence. The influence on the pillar depends on the different angle of the Jib.

Proof of the Pillar:General stress analysis

The moments in the Pillar are computed for various Jib positions. At this point, only the, magnitude are determined. Signs are only in Force and stress analysis considered.

Jib Position

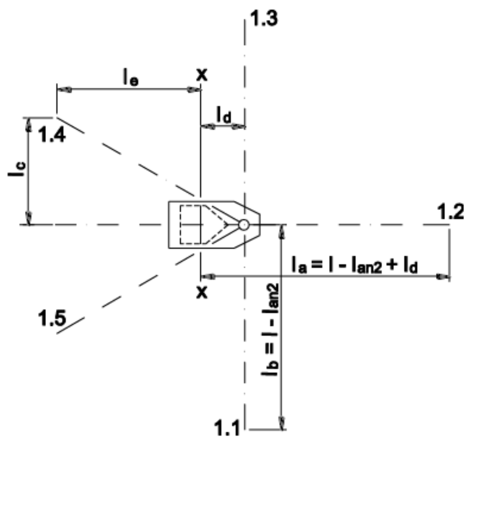

Fig 1 Jib orientation

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$$M_x = (G_{GH}.\psi \cdot +1.1.G_A) \cdot l_d \quad (1)$$

$M\,x$ = 4299 Nm

$$M_y = (G_{GH}.\psi \cdot l_b + 1.1.G_A \cdot l_A) \quad (2)$$

$M\,y$ = 51087.73 Nm

Document Generation 1.2

$$M_x = [G_{GH}.\psi \cdot l_a + 1.1.G.(l_A + l_d)] \quad (3)$$

$M\,x$ = 55386.88 Nm

$M_y = 0$

$M\,y$ =0Nm

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$$M_x = (G_{GH}.\psi \cdot l_e + 1.1..G_A \cdot (l_A \cdot \cos 30^\circ - l_d)) \quad (4)$$

$M\,x$ = 39944.11 Nm

$$M_y = (G_{GH}.\psi \cdot l_c + 1.1.G_A \cdot l_A \cdot \sin 30^\circ) \quad (5)$$

$M\,y$ = 25543.86 Nm

$$\sigma_{xe} = \frac{\pm M_x}{W_{xe}} - \frac{Fa}{Ap} \quad (6)$$

$$\sigma_{ye} = \frac{\pm M_y}{W_{ye}} - \frac{Fa}{Ap} \quad (7)$$

$$\sigma_e = \sigma_{xe} + \sigma_{ye} \quad (8)$$

Extreme value needs to be considered.

σ_e =54.77N/mm^2

Moments on section points:

TABLEVI

Jib Position	Moments	1	2	3	4	5	6	7	8
1.1,1.3	M x	+	+	0	0	-	-	0	+
	My	0	+	+	+	0	-	-	-
1.2	M x	+	+	0	-	-	-	0	+
	My	0	0	0	0	0	0	0	0
1.4,1.5	M x	-	-	0	+	+	+	0	-
	My	0	-	-	-	0	+	+	+

+= Tension, -= compression

Proof of Jibs:

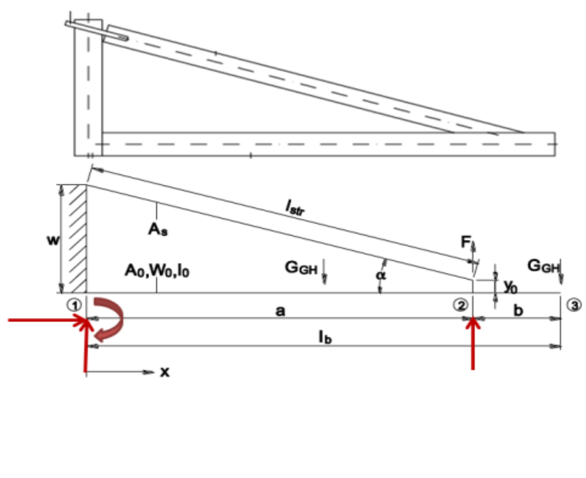


Fig 2 Jib system representation

Jib resembles statically indeterminate structure.
Due to statically indeterminacy there are 4 unknowns and the indeterminacy level is of the order 1.

In the above figure there are two fields Field 1-2 and Field 2-3. The bending moments when the load GGH is in Field 1-2 is different to when the load GGH 2-3.A typical BM diagram is represented below when load is in different fields.

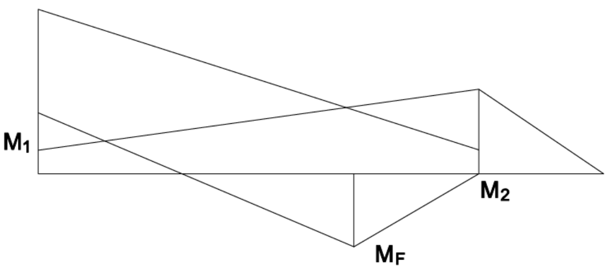


Fig 3 Jib moment diagrams

M2 represents the moment when the Load GGH is in Field 2-3 and MF represents the moment when Load GGH is in Field 1-2. M1 represents the moment at the track end due to its indeterminacy.

For M2 the Load GGH is at Lan 2. (Load in Lan 1) is ignored after Conclusion of Krasta Analysis.)

MF has 3 load positions
1) 0.42 X a
2) 0.58 x a
3) 0.63 X a

(The load positions are determined after statically analysis)
For calculations we use unit load method. The formulas are determined by unit load method.

$$S = -\frac{\delta_{10}}{\delta_{11}} \tag{9}$$

$$E \cdot I_0 \cdot \delta_{10} = \frac{I_0}{I_{12}} \cdot \int_{s_1}^{s_2} M_0 M_1 ds = \delta_{10}^{'} \tag{10}$$

$$E \cdot I_0 \cdot \delta_{11} = \frac{I_0}{I_{12}} \cdot \int_{s_1}^{s_2} M_1 M_1 ds = \delta_{11}^{'} \tag{11}$$

$$\delta_{11}^{'} = \frac{1}{3} \cdot \sin\alpha^2 \cdot a^3 \tag{12}$$

$$\delta_{11}^{'} = \frac{1}{3} \cdot \sin^2\alpha \cdot a^3 + \frac{I_0 \cdot l_s}{A_s} \tag{13}$$

Load in Field 2-3

$$\delta_{10}^{'} = -\frac{1}{6} \cdot G_{GH} \cdot x^2 \cdot \sin\alpha \cdot (3a - x) \tag{14}$$

Load in Field 1-2

$$\delta_{10}^{'} = -\frac{1}{6} \cdot \sin\alpha \cdot a^2 \cdot G_{GH} \cdot (2l_b + b) \tag{15}$$

Force in Field 1-2

$$S = \frac{\delta_{10}^{'}}{\delta_{11}^{'}} = 4778.75 \text{ kg} \tag{16}$$

Where $\delta_{10}^{'}$ to be calculated at 3 positions
1) 0.42 a
2) 0.58 a
3) 0.63 a

Force in Field 2-3

$$S = \frac{\delta_{10}^{'}}{\delta_{11}^{'}} \tag{16}$$

For 0.42 a=952kg, 0.58a=1703kg &for 0.63 a=1968kg

$$F = S \cdot \sin\alpha \tag{17}$$

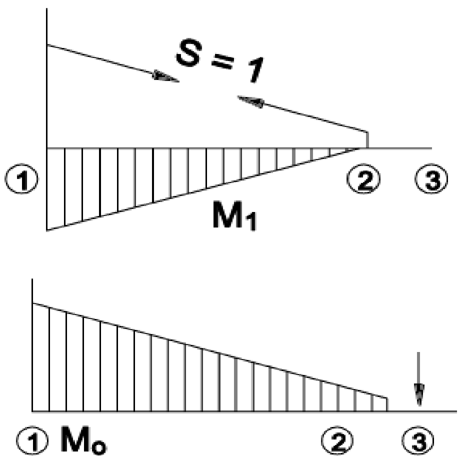


Fig 4 Unit load method

Field moment MF (Load in Field 1 – 2)

$$M_F = -F \cdot (a - x) \tag{18}$$

=2673N-M for 0.42 a
=6603N-M for 0.58a
= 8288N-M for 0.63a
F needs to be calculated 3 load position 0.42 a, 0.58a, 0.63a

Fixed end moments

$$M_1 = G_{GH} \cdot x - F \cdot a \tag{19}$$

=6104N-M for 0.42 a
=5710N-M for 0.58a
= 5413N-M for 0.63a

Field moment M2 (Load in Field 2-3)

Load at X=Lb

$$M_2 = \psi \cdot G_{GH} \cdot b = 2789\text{Nm} \qquad (20)$$

Respective stresses are computed by dividing the Moments M1, MF and M2 by Wo (Track).

$$\max \sigma = \frac{\max M_1}{W_0} = 82 \ \text{N/mm}^2 \qquad (21)$$

$$\max \sigma = \frac{\max M_2}{W_0} = 85.24 \ \text{N/mm}^2 \qquad (22)$$

$$\max \sigma = \frac{\max M_F}{W_0} = 172 \ \text{N/mm}^2 \qquad (23)$$

Rib stress are computed by dividing the axial force by Rib area

$$\max \sigma_z = \frac{\max S}{A_s} = 104.92\text{N/mm}^2 \qquad (24)$$

Deflection of Jib Crane:

$$fa = \frac{1}{3.E.Io} \cdot [G_{GH}.l_b{}^3 \cdot -F.a^2(l_b + b/2)] \qquad (25)$$

$$fs = \frac{1}{E.Is} \cdot [M.l_a.h] \qquad (26)$$

Where, M is different moments to be considered at different position of the Jib angle. Is is the modulus to be considered at x and y axis respectively

Total defection

$$fges = fa + fs = 38.9 \ \text{mm} \qquad (27)$$

V. SOFTWARE APPROCH

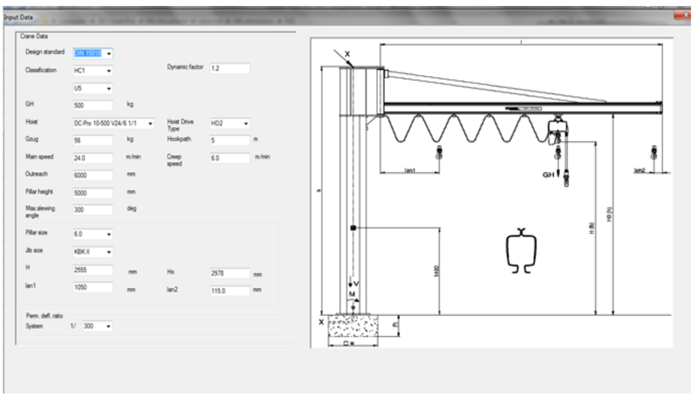


Fig 5 Program input screen

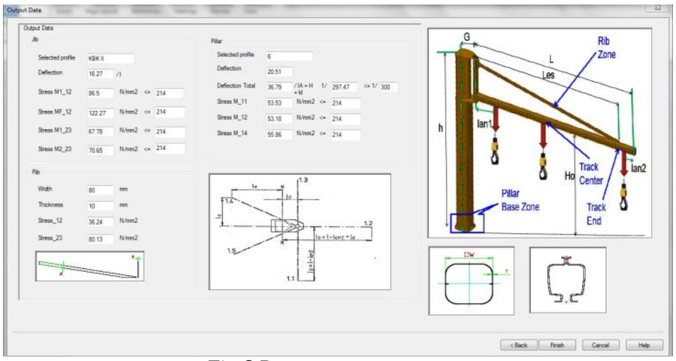


Fig 6 Program output screen

The algorithm is developed in terms of mathematical model and same is coded in the software. The software calculates all the stresses and deflection under different slewing angle and load position. The results of deflection are shown as under.

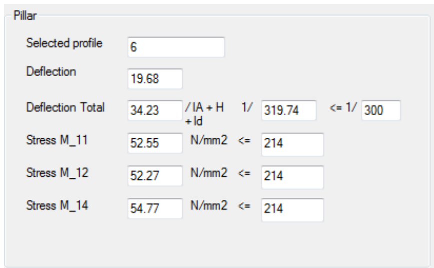
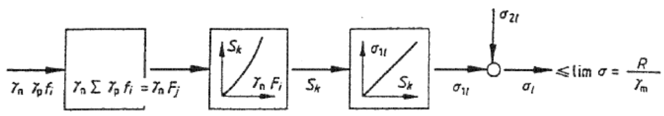


Fig 7 Pillar results

In the software we have considered the limit state approach with partial duty factors.



Key

f_i characteristic load i on the element component;

F_j combined load from load combination j including ϕ factors;

S_k load effects in section k of members or supporting parts, such as inner forces and moments, resulting from load combination F_j;

σ_{1l} stresses in the particular element/ as a result of load effects S_k;

σ_{2l} stresses in the particular element/ arising from local effects;

σ_l resulting design stress in the particular element l;

R_d specified strength or characteristic resistance of the material, particular element or connection, such as the stress corresponding to the yield point, limit of elastic stability or fatigue strength (limit states);

lim σ limit design stress;

γ_p partial safety factors applied to individual loads according to the load combination under consideration;

γ_n risk coefficient, where applicable;

γ_m resistance coefficient.

Fig 8Limit state approach

VI. FINITE ELEMENT ANALYSIS

Static stress analysis of the Jib crane is validated through different software Krasta and Ansys-Classic.

A. Krasta

Analysis is done in Krasta under 3 slewing angles and two load positions.

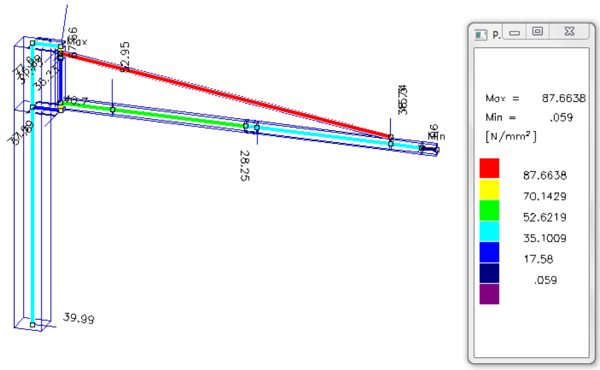


Fig 9 shows pillar stress of 39.99N/mm^2 with amplification coefficient of 1.43= 57.18N/mm^2 (Slewing angle 0 degrees).

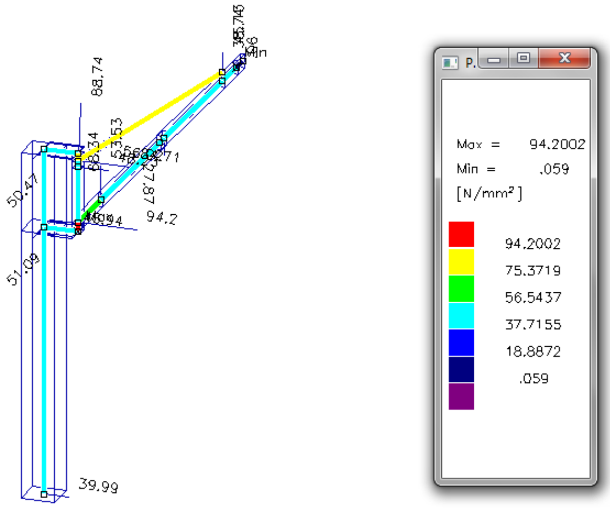


Fig 10 shows pillar stress of 39.99N/mm^2 with amplification coefficient of 1.43= 57.18N/mm^2 (Slewing angle 90 degrees).

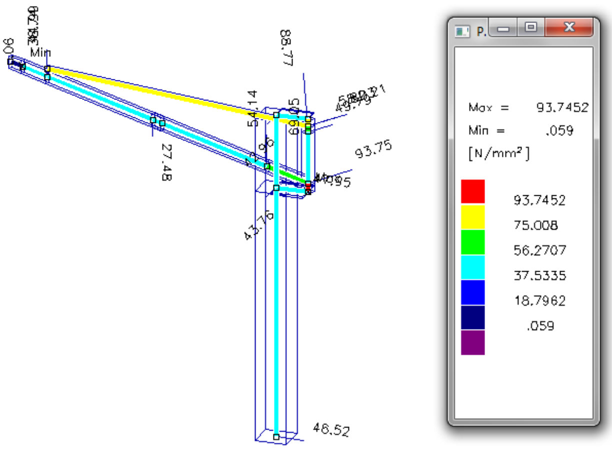


Fig11 shows pillar stress of 46.52 N/mm^2 with amplification coefficient of 1.43= 66.52N/mm^2 (Slewing angle 150degrees)

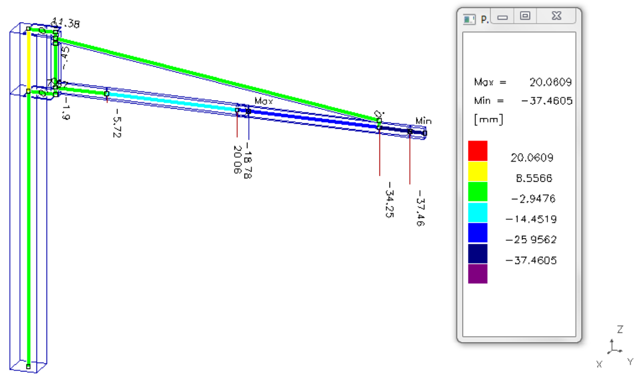


Fig 12shows pillar deflection of 37.46 mm.

*A. Stress*analysis

FEA Model is directly made in ANSYS Classic14.5. The Classic makes the model more controllable and effective.

1) Material properties
2) Geometry/Model
3) Meshing.
4) Loads and boundary condition.
5) Results

C. Mesh generation

The meshing of model was done in ANSYS 14.5(classic) software.

D. Boundary Conditions

Static structural analysis was performed to determine equivalent (von-mises) stresses and total deformation of Jib crane by ANSYS software. For this boundary conditions are used: Fixed support at the base.

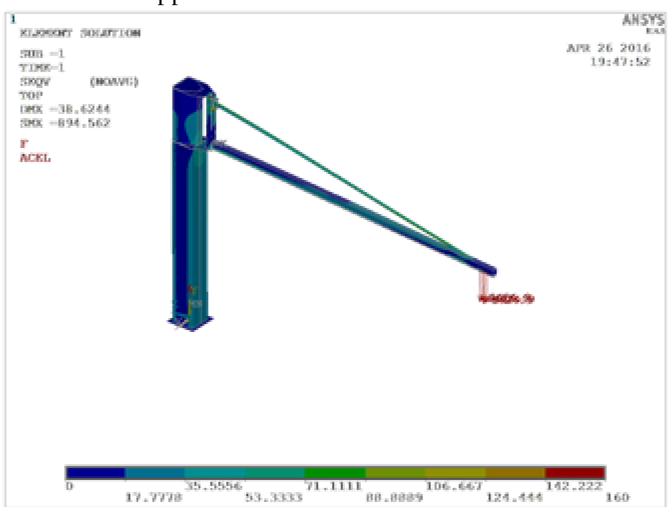


Fig. 13 Analysis of Pillar mounted Jib crane.

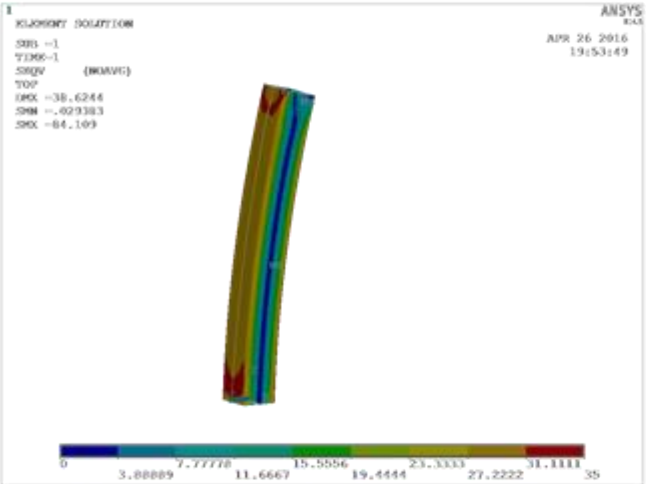


Fig. 14 Vonmises stress in pillar is 35 N/mm^2, with amplification factor of 1.43 = 50.05N/mm^2.

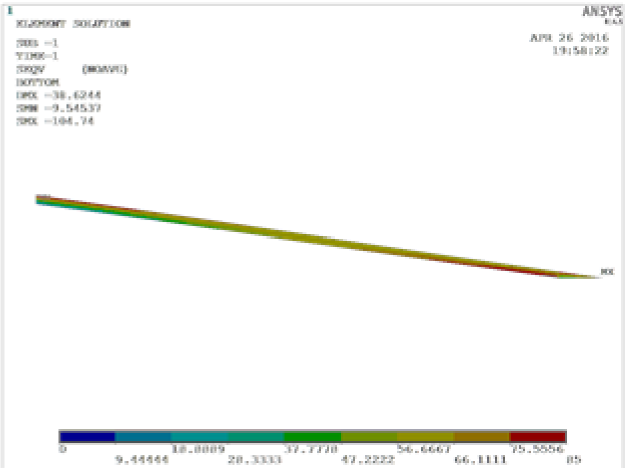


Fig. 15 Average Vonmises stress in Rib is 75.66 N/mm^2, with amplification factor of 1.43 = 108 N/mm^2.

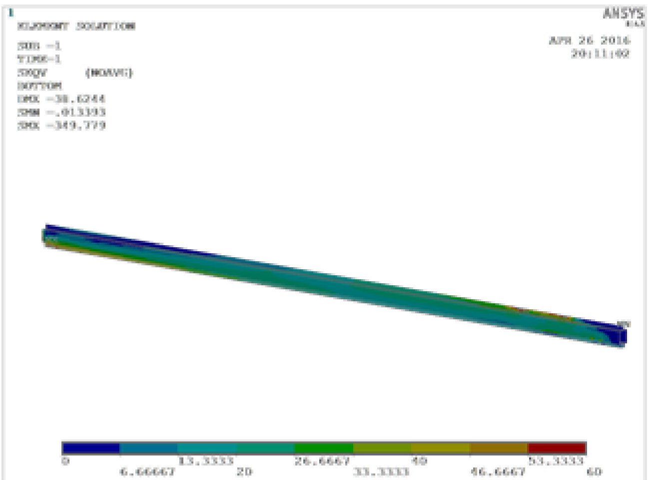


Fig. 16 Average Vonmises stress in Track connection is 60 N/mm^2, with amplification factor of 1.43 = 85.8 N/mm^2

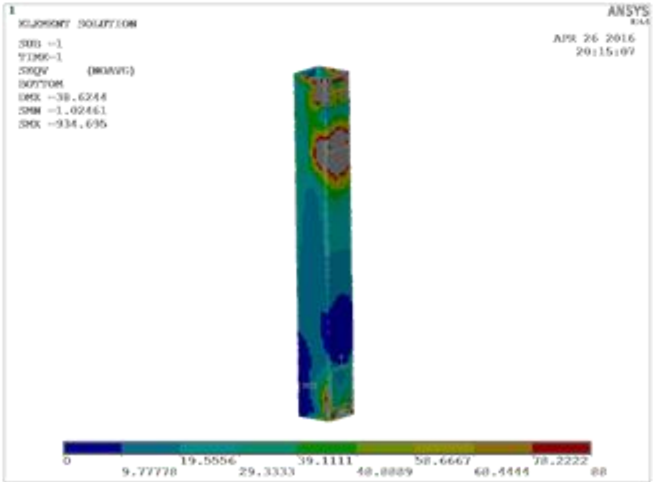


Fig. 17 A

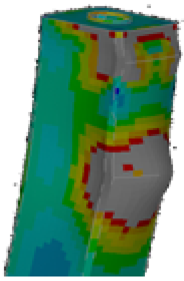


Fig. 17 B

Fig. 17 A & B shows Vonmises stress in Vertical tube showing local stress higher than 78.22 N/mm^2, with amplification factor of 1.43 = 111.8 N/mm^2.

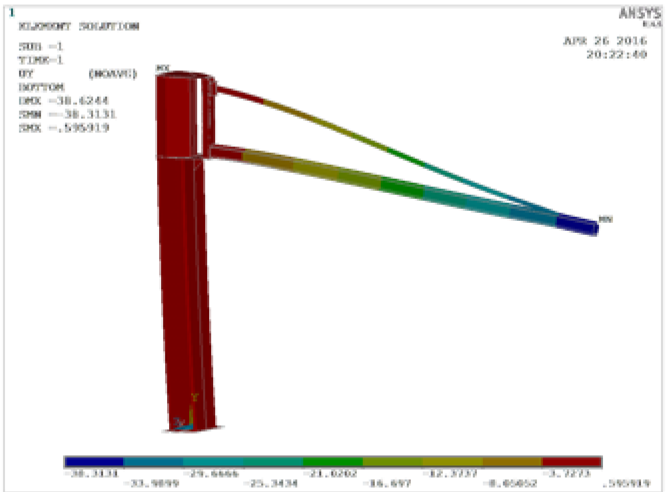


Fig. 18 Deflection in Jib crane is 38.34 mm.

VII. Experimental Analysis

To verify the stress values and stiffness of the jib crane the cranes was tested experimentally. The actual crane was load tested mounting on the pedestal at the factory. The readings from the crane testing are used to verify with the Finite element analysis results and calculate the stiffness of crane.

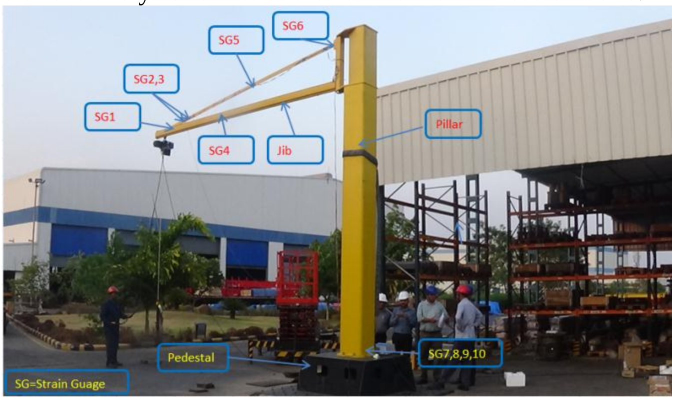


Fig. 19 a) Experimental setup for Strain measurements

b) 4-channel Digital Strain Indicator in micro strains& Strain Gauge mounting

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c) Defection Measurement

The stress value measured andthe same is compare with our Krasta, FEA and theoretical results at different slewing angles. Similarly the Deformation when load is at extreme end is measured and compared with Krasta, FEA and Theoretical calculations.

A.Experimental results

From experimentation, we validate the results and calibrate the software so that the same can be used for further anaysis.

VIII. Results and Discussion

Stress analysis shows that the stresses are within permissible limits and the criterion of crane failure is deformation. From the below graph we can see that the existing pillar size 6 is suitable for height of 4500 mm and this is the border for stiffness ratio of 300. However if we change the size to 7 the deformation is well within the stiffness ratio of 300. Additionally in fig. 22 shows that if we adjust the approach lan2 from 115 to 240 mm we get better deflection ratio with same pillar size.

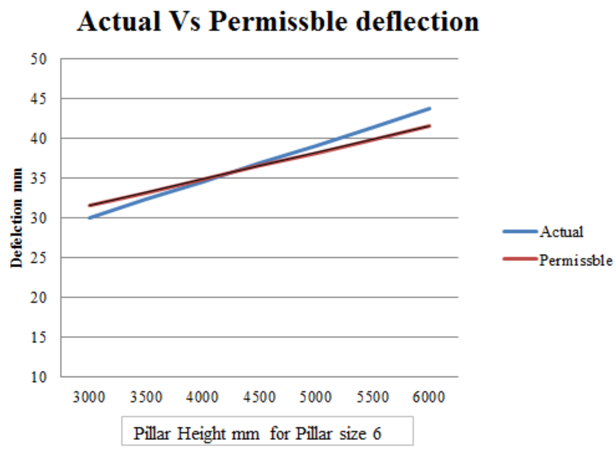

Fig.20 Graph of actual vs. perm. defection for size 6with Lan2=115mm

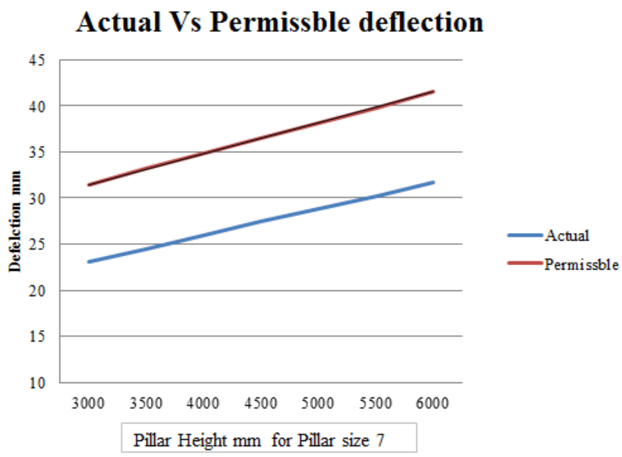

Fig.21 Graph of actual vs. perm. defection for size 7with Lan2=115mm

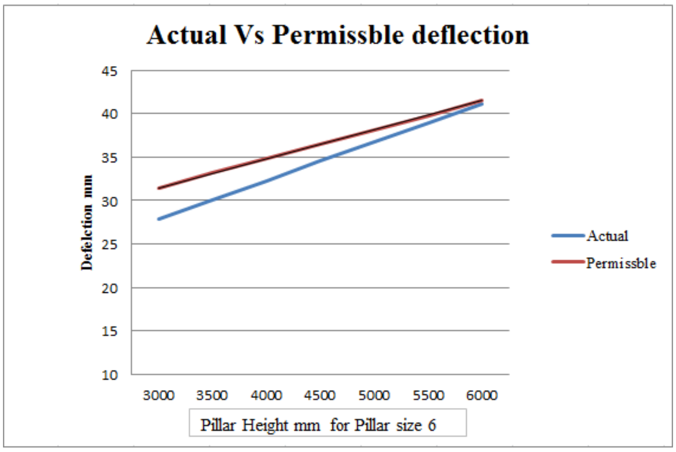

Fig.22 Graph of actual vs. permissble defection for size 6with Lan2=240mm

As per limit state theory, since the partial duty factors are used on the load side the allowable stresses are calculated by below formula.

Limit design stress $= Fy \Big/ (\lambda m * \lambda sm)$ (28)

Where Fy =yield stress, λm= general Material resistance and λsm= Special material resistance.

In case of Jib crane λm=1.1 and λsm=1

= 235/1.1

= 213 N/mm^2

So, the calculated stress <limit sate stress. i.e. hence the design is proved to be safe.

TABLE VII
RESULT ANALYSIS

Result Analysis					
Sr. No.	**Component Stress/ Deflection**	**Analytical**	**FEA**	**KRASTA**	**Experim-entation**
1	Pillar	54.77 N/mm^2	50.05 N/mm^2	57.18 N/mm^2	55.04 N/mm^2
2	Rib	104.92 N/mm^2	108 N/mm^2	122.67 N/mm^2	110.51 N/mm^2
3	Track	85.24 N/mm^2	85.8 N/mm^2	81.2 N/mm^2	84.98 N/mm^2
2	Deflection	38.9 mm	38.34 mm	37.46 mm	39.8 mm

IX. CONCLUSION

Stress and deformation are well within limits. Experimental stress &deformation is also matching with results of Analytical calculation, Krasta analysis and FEA.

The analytical software in C++ is validated with Krasta and FEA.

The deflection becomes the qualifying criteria for the jib cranes as compared to stress. The analytical software can be now used to calculate the pillar defection by changing the height of the pillar in software or adjusting the approach. This shall have user friendly input and the crane can be validated in very less time and avoid any unsafe design and product failures.

ACKNOWLEDGMENT

I take this opportunity to thanks Prof. A. N. Patil for valuable guidance and for providing all the necessary facilities, which were indispensable in completion of this work. Also I sincerely thanks to all the authors who worked on jib cranes and structural analysis papers.

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