Design and Analysis of Structural Members of the Jib Crane

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Abstract:- This study has been undertaken to investigate and estimate design needs and propose optimum solution for lifting facility, and detailed calculation for lifting facility at Water Treatment Plant. Prior to decide optimum solution for the problem, evaluation of design concept has been done through various steps. Function decomposition and identification of individual function of the each subsystem, internal and external search for creating solution domain, next, best optimum solution has been selected via logical approach which was pairwise comparison and weighted decision matrix, and detailed calculation is performed as final step of the research.

Keywords:- *Jib Crane, Payload, Tensile Strength, BS Standards.*

I. INTRODUCTION

Lifting facility availability is essential for the routine and breakdown maintenance work at pumps station, without having proper lifting facility; stakeholders face difficulties, consequently, safety issues also shall be raised during the maintenance work. Boom and mast are the major structural members of the jib crane, with this study; detailed calculation is conducted for performing proof-of-competence determinations of the steel structures of cranes in term of material selection, requirements, methods, and parameter values. [1]

II. KEY TECHNICAL FEATURES OF THE JIB CRANE

- *Lifting and Lowering Movement of Payload*

Lifting, lowering of the load should be electric powered hoist unit that can handle maximum load approximately 1.5 Ton and maximum lifting height is 7m.

- *Trasverse Movement of Payload*

Transverse movement approximately 15m distance along one axis with bi-directional movement by considering area where lifting facility should access.

III. METHODOLOGY

Extracted deign parameters for the jib crane and loads acting on the structural members were evaluated, next, possible load combinations also estimated to obtain maximum loads and bending moments. Then, critical section of the boom and mast was determined, design stresses have been calculated accordingly, buckling and verticality of the mast has also been considered. Finally welded and bolt joint competence calculation was performed while power requirement for hoisting and travelling were also calculated.

IV. MATERIAL, METHOD AND CALCULATION

Design parameters as indicated in table I, when selected the structural members, following parameters have been taken into consideration.

Table 1 Design Parameters

Maximum Lifting Height	H_L	$7m$
Jib Crane Total Column Height	H_c	$3m$
Jib Crane Boom Length	H_s	$3.1m$
Slewing Angle	α_{Slew}	180°

- *Section of mast and boom*

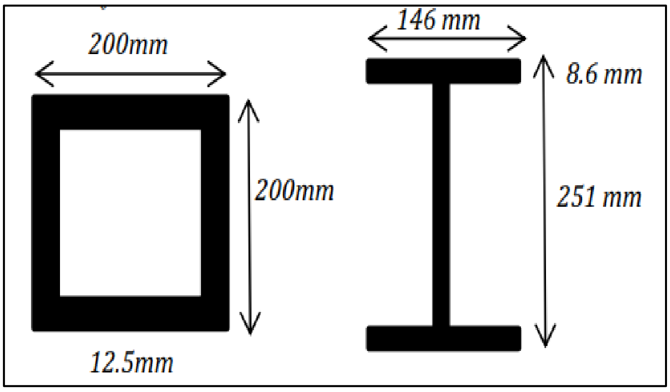

Table 2 Specification of the Mast

Mass per meter	**72.3 *kg/m***
Area of section (A)	92.1 cm^2
Second moment of inertia (I)	5340 cm^4
Height of the mast	4.25m
Base plate size	600×600
Material	S275

Table 3 Specification of the Boom

Mass per meter	**31.1 *kg/m***
Area of section (A)	39.7 cm^2
moment of inertia(I)-Y-Y axis(2^{nd})	4410 cm^4
Length of the mast	3.1m
Material	S275

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Dead weight, unrestrained grounded load, sudden release of the loads, tilted loads were taken into account for the jib crane according to the *ISO 8686-1:2012 E [2]*, and calculated load combination using limit state method, maximum forces acting along X, Y and Z direction of the coordinate system were 0.855*kN*. 0.855*kN* and 17.78*kN* respectively as indicated in the Figure 1,

➢ *Analysis of Structural Member-Boom*

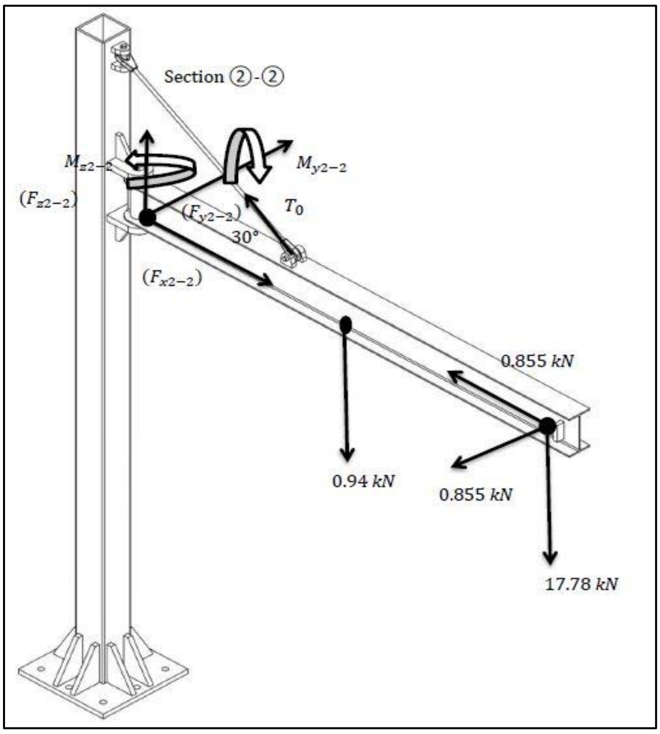

Fig 1 Free Body Diagram of Section 2 of the Boom

Free body diagram of the boom expressed possible force and moments acting on the boom, all forces acting along X, Y, and Z obtained from equation of equilibrium, bending moments were calculated accordingly.

Bending moment around x, y and z axis,

$$M_{x2-2}, M_{y2-2} = 0, M_{z2-2} = 2.65\ kNm \quad (1)$$

Normal stress calculated as follows

$$\sigma = \frac{P}{A} = 24.899\ MPa \quad (2)$$

Maximum normal stress due to M_{z2-2};

$$\sigma_{z-max} = \frac{M_{z2-2}C_y}{I_z} = 4.32\ MPa \quad (3)$$

By inspection the normal stress at section ②-②;

$$\sigma_{\max ②-②} = 29.219\ MPa \quad (4)$$

Calculating shear stress at section ②-②;

$$\tau_{2-2} = \frac{VQ}{It}, \tau_{2-2} = 27.7\ MPa \quad (5)$$

Proof for structural, boom according to the *BS ISO 20332:2016* [3]

$$\sigma_{\max ②-②} \leq \text{ Tensile stress of the material} \quad (6)$$

$$\tau_{\max ②-②} \leq \text{ Shear stress of the material} \quad (7)$$

Deflection of the boom was calculated to check whether boom is in order to accept the structural member according to standards;

$$\delta_{B1} = \frac{qL^4}{8EI}, \delta_{B1} = 0.07\ mm \quad (8)$$

At the end of beam, maximum deflection due to weight of the load and hoist;

$$\delta_{B2} = \frac{FL^3}{3EI}, \delta_{B2} = 2.45\ mm \quad (9)$$

The maximum deflection of the beam produced by the dead weight and weight of the trolley and rated load shall not exceed 1/600 of the span of the crane as per the *IS 807-2006* [4], therefore, deflection limit is satisfied.

➢ *Analysis of Structural Member-Mast*

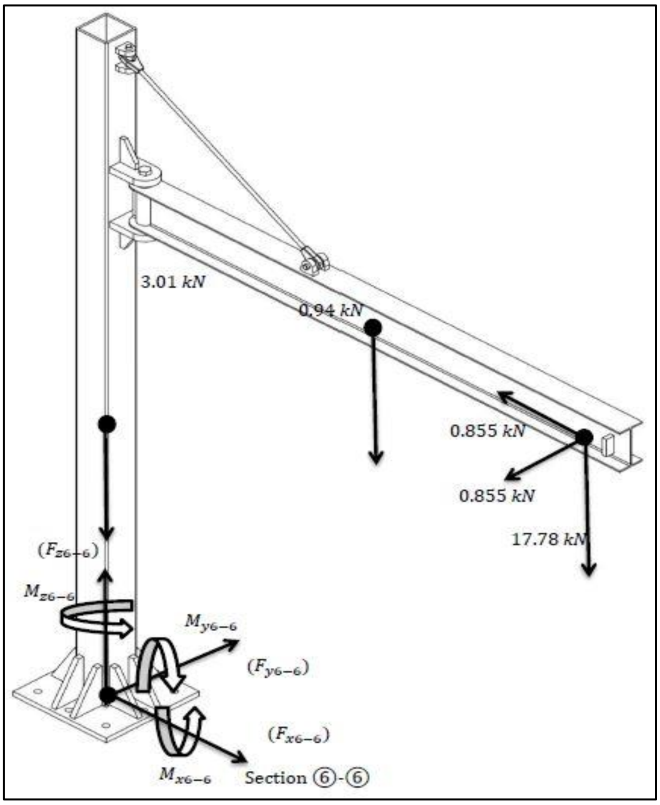

Fig 2 Free Body Diagram of Section 6 of the Mast

For the mast, forces and bending moments were calculated using free body diagram, possible highest compressive stress and shear stress were calculated using equation (1), (2), (3) and (5) proof calculation performed as per the condition (6) and (7) to verify competence of the structural member.

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Following design parameters have been calculated and listed below.

Table 4 Calculated Parameters for Mast

Parameter	Value
$(F_{x6-6}), (F_{y6-6}), (F_{z6-6})$	0.86 *kN*, 0.86 *kN*, 21.73 *kN*
$M_{x6-6}, M_{y6-6}, M_{z6-6}$	2.565 *kNm*, 52.55 *kNm*, *0 kNm*
$\sigma, \sigma_{x-max}, \sigma_{y-max}$	2.36 *MPa*, 4.8 *MPa*, 98.4 *MPa*
$\sigma_{\max ⑥-⑥}$	105.56 *MPa*
$\tau_{\max ⑥-⑥}$	0.3 *MPa*

Buckling of the mast, proof of stability calculation was performed to verify stability of the structural member in order to withstand the rated load.

Critical buckling load of the mast and slenderness are calculated by the equation (11), (12), as in [3, Table 12.];

$$N_k = \frac{\pi^2 EI}{4L^2} \quad (10)$$

Calculated value for the critical buckling load and slenderness of the mast are 1533.1 *kN* and 1.26 respectively.

Limit design compressive force, as in [3, eq. 47, eq. 46];

$$\lambda = \sqrt{\frac{f_y A}{N_k}} \quad (11)$$

$$N_{Rd} = \frac{K f_y A}{\gamma_m} \quad (12)$$

Calculated limit design compressive force as per equation (12) equal to 1082 *kN*.

Proof for elastic stability, following condition shall be satisfied according to *BS ISO 20332:2016*[3];

$$N_{Rd} \leq \frac{N_k}{1.2\, \gamma_m} \quad (13)$$

$$1082\ kN \leq 1161.44\ kN \quad (14)$$

Therefore, mast elastic stability is satisfied as per *BS ISO 20332:2016.*

Evaluating verticality of the mast due to buckling and horizontal loads, secant formula, as in [5, eq. 13-16];

$$v_{max} = e\left[sec\left(\sqrt{\frac{P}{EI}}\frac{L}{2}\right) - 1\right] \quad (15)$$

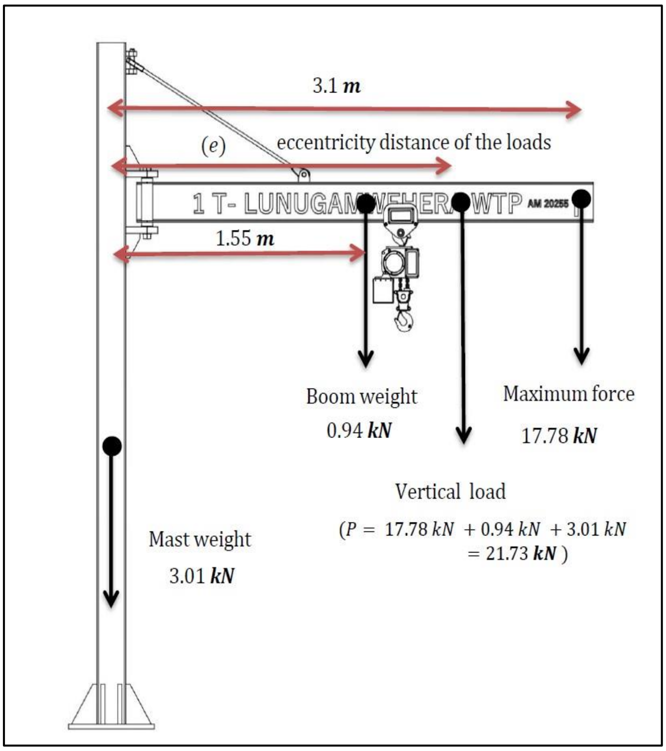

Fig 3 Diagram of Eccentric Loading to the Mast and the Boom

Calculating eccentricity of the load;

$$e = \frac{17.78\ kN \times 3.1\ m + 0.94\ kN \times 1.55\ m + 3.01\ kN \times 0\ m}{17.78\ kN + 0.94\ kN + 3.01\ kN} = 2.6\ m \quad (16)$$

Using equation (15),

$$v_{max} = 2.5\ mm \quad (17)$$

Maximum deflection of the mast due to horizontal force acting on the mast can be calculated by the using following formula;

Total maximum deflection of the mast, using (17), (18);

$$\delta_{max} = \frac{PL^3}{3EI} = 0.7\ mm \quad (18)$$

$$(v_{\max}) + \delta_{max} = 3.2\ mm \quad (19)$$

The maximum deflection of the column produced by the horizontal and vertical load shall not exceed 1/600 of the span of the crane as per the *IS 807-2006.*

$$(v_{\max}) + \delta_{max} \leq Limit\ Design\ Value \quad (20)$$

Therefore, deflection limit is satisfied.

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V. CONCLUSION

Structural members, boom and mast have been subjected to essential analysis according to its behavior; payload and its predictive and un-predictive actions have also been considered to the load calculation. Considering all of them, boom and mast were analyzed capabilities to withstand under pre described conditions.

It was concluded, with supporting rope arrangement; boom sectional dimensions can be taken to optimum level using supporting rope wire rather than using large heavy sections for the said structural member.

REFERENCES

[1]. Cranes — Proof of competence of steel structures, ISO20332
[2]. BS-ISO-8686-1-2012- Cranes-Design principles for loads and load combinations
[3]. BS-ISO-20332-2016- Cranes-Proof-of-Competence-of-Steel-Structuress
[4]. IS 807: Design, erection and testing (structural portion) of cranes and hoists - Code of practice
[5]. Mechanics of Materials, R.C Hibbeler
[6]. Detail Design and Analysis of A Free Standing I Beam Jib Crane M.Dhanoosha1,V.GowthamReddy2
[7]. Design and Analysis of Wall Mounted Jib Crane 1Naveen.A.Hanchate, 2Akhil.A.Deshpande
[8]. Design Concepts for Jib Cranes, JAMES M. FISHER and STEVEN J. THOMAS
[9]. Design variations optimization of jib crane 24500 N using I beam, S Sirojuddin1,*, K Z A Nurfarihah1 and M Nurkhozin2
[10]. The Design and Construction of an Intelligent Power Assist Jib Crane Harry M. Pearce
[11]. American Institute of Steel Construction, Inc. (AISC), (1999), Load and Resistance Factor Design Specification *for Structural Steel Buildings*, Chicago, IL.
[12]. Briskorn D and Angeloudis P 2015 Scheduling Co-Operating Stacking Cranes With Predetermined Container Sequences Discrete Applied Mathematics. 201 70-85
[13]. Mechanics-of-Materials-Mcgraw-2012-Ed6-978-0-07-338028-5
[14]. Lee D H, Kim S J, Lee, M S and Paik J K 2019 Ultimate limit state based design versus allowable working stress based design for box girder crane structures Thin-Walled Structures. 134 491- 507
[15]. Design and Optimization of Jib Crane Boom S.D.Patil1, D.C.Mahale2 1P.G. Student, Department of Mechanical Engineering, SSVPS'S B.S.D. College of Engineering, Dhule, Mahar.,India 2Professer, Department of Mechanical Engineering, SSVPS'S B.S.D. College of Engineering, Dhule, Maharashtra, India
[16]. Gerdemeli I., K. Kurt S., Tasdemir B. "Design and analysis withfinite element method of jib crane", Faculty of Mechanical Engineering Istanbul Technical University, Turkey.
[17]. Chirag A. Vakani, Shivang S. Jani " Analysis and Optimization of 270° Jib Crane Deflection", International Journal for Scientific Research & Development, Vol. 2, Issue 10, 2014, ISSN (online):2321-0613
[18]. Ajinkya Karpe, Sainath Karpe, AjaykumarChawrai "validation of use of fem (ansys) for structural analysis of tower crane jib and static and dynamic analysis of tower crane jib using ansys", International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349- 2163, Volume 1 Issue 4 (May2014).