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Research Paper

FORCE DISTRIBUTION ON TELESCOPIC BOOM OF CRANE

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This paper gives the introduction about the construction of telescopic boom and different forces and moment acts on the different parts and area while picking up the load. The telescopic boom is fitted on front end of the crane for lifting of load from different radius. More the distance of the load from the front axle of crane, less would be the load taking capacity. Accordingly boom of crane is designed. Here in this paper we shall consider one load case, i.e., when load lifted will be taken on the Jib Head.

Keywords: Telescopic boom, Load, Radius, Capacity, Front axle, Jib head

INTRODUCTION

Boom is the main part in the crane, which is used to lift the load. This is generally connected to the front end of the crane. This part consists of multisections, connected with each other with cylinder and ropes. The number of section depends on the specification required for the crane. Here we will discuss the force distribution in the telescopic boom, while lifting the load.

Boom parts and mechanism can be seen in the below given picture. The main parts of the boom are:

Mother Boom: This is the outer most portion of the system, consisting of other sections and extension, retraction system. Winch is mounted on the left side of the boom. Extension cylinder rear end is connected from the inside.

Middle Boom: This is the second section of booms comes inside the mother boom. The other end of the extension cylinder is connected with the Middle Boom.

Inner Boom: This is the third section of booms comes inside the Middle boom. Inner Boom and Middle booms are connected with each other with rope mechanism. This rope mechanism is known as boom extension and retraction system.

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Extension Cylinder: Extension cylinder is attached in between mother boom and first extension. This is to extend the boom, to pick up the load from long distance, i.e., from more radius.

Winch: This is the part present on the mother boom. This is the winch drum on which rope is wounded. Winch motor is present inside the housing. This is to rotate the winch drum for winding and unwinding of rope. The other end of the rope is connected with the snatch block hanging from the boom.

Snatch Block: The hanging part from the Jib area is used to pick up the load. Crane hook is installed in the snatch block.

Below is the given picture (Figure 1) shows the three section boom, used for lifting the load. The Load lifting will be considered on the Jib head, and correspondingly load distribution on all the sections will be studied. Following are the standard nomenclature used in this paper.

P = Externally applied Load (i.e., load lifted).

P_X = Lateral/side load component.

P_Y = Vertical load component.

P_Z = Axial load component.

P_A = Axial load on section.

W = Total weight of component (i.e., individual booms).

T = Torsional moment.

M = Bending moment.

R_X = Reaction load in the lateral direction.

R_Y = Reaction load in the vertical direction.

R_Z = Reaction load in the axial direction.

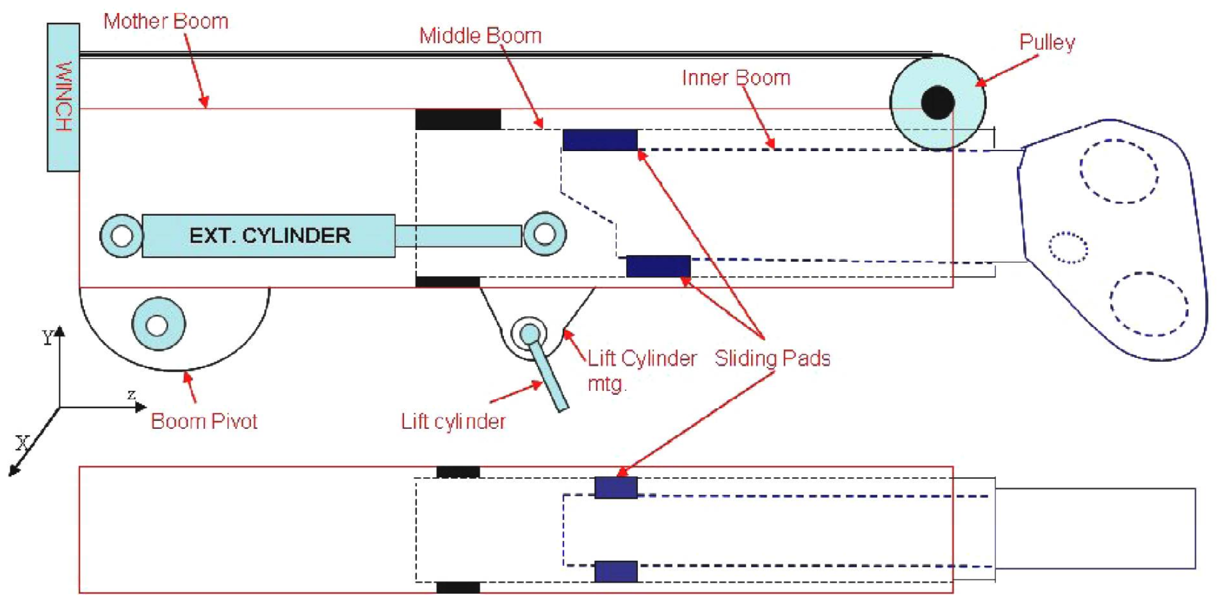
g = Wind load, lb/in2.

A = Boom angle with horizontal plane.

D = Diameter of the various section.

N = No. of falls.

Figure 1: Construction Detail of Telescopic Boom



Consider P is the load Lifted from the Jib head (i.e., from snatch block). For this condition, here we will discuss the force distribution on all the sections from jib to the rear most portion. For above mentioned condition free body diagram for Jib head (Figure 2) would be:

Wind/Side Load

Side Load P_x = 0.02 P (As Per SAEJ1078 side load is taken 2% of actual working load).

Moments

$$M_1 = P_Y * L_1 + P_Z * L_2 - P/N * L_4 + W\cos\alpha * L_5$$

$$M_2 = P_X * L_1$$

Torsional Moment

$$T = P_X * L_2$$

Here $R_{x1} = P_x$

Axial Load

Axial load acting on the jib head $R_{Z1} = P_Z + P/N + W\sin\alpha$

Shear Load

Vertical load acting in Jib head $R_{y1} = P_y + W\cos\alpha$

Horizontal direction = P_x

Force transfer from jib head to Inner Boom (Figure 3) and other acting force will be explained below.

H_r = Ref. height at which the wind velocity is measured (= 20 feet) = 6.096 meter

(This height is usually measured at the 60% of the total extended length of boom)

H_o = Height of boom pivot point from the ground level FBD OF JIBHEAD

Figure 2: FBD of Jib Head

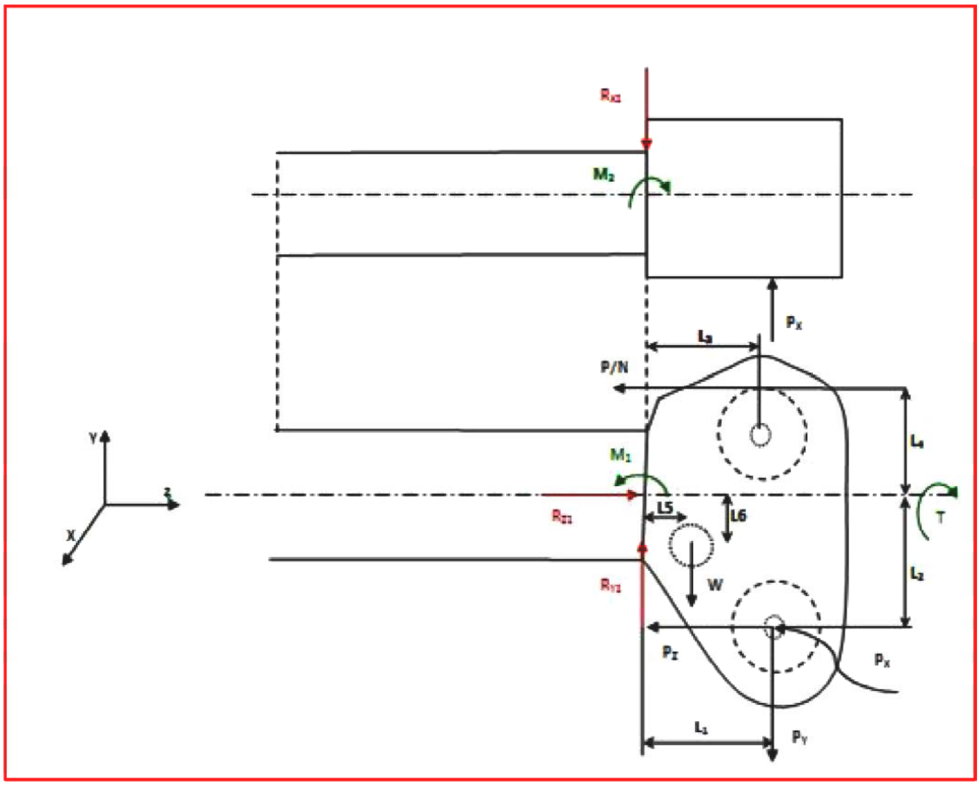
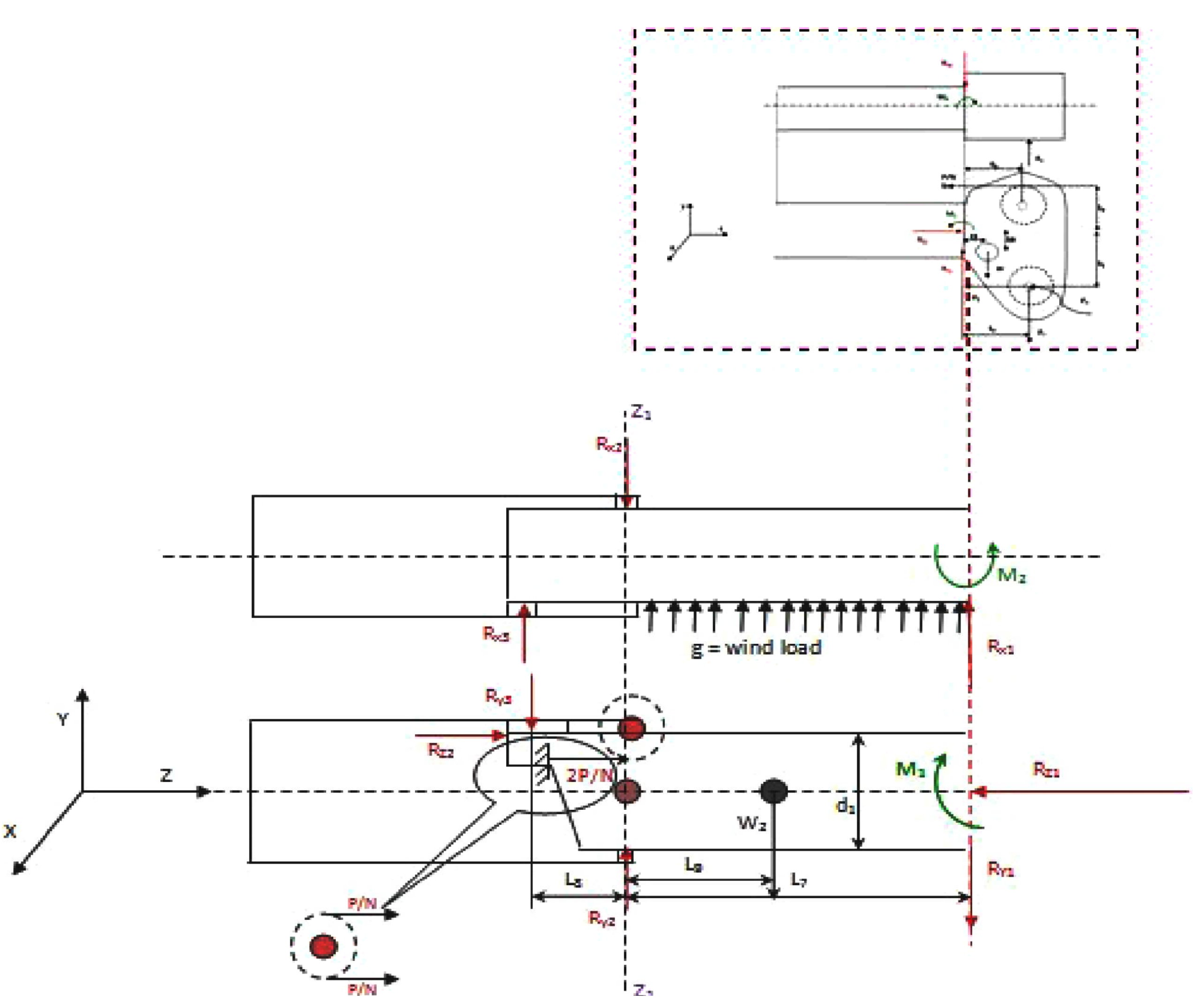


Figure 3: FBD of Inner Boom



H_P = Height of center point of wind pressure to the boom pivot point

$H = H_O + HP$ = Height of center of wind pressure from the ground level

p = Wind velocity exponent

$V = V_r(H/H_r)^p$

Wind load $g = 0.004\ (\text{mph})^2/144$

P_{ar} = Axial load on the right side of section $Z_1 - Z_1$

P_{al} = Axial load on the left side of section $Z_1 - Z_1$

W_2 = Weight of second extension

Moments

$M_X = M_3) = M_1 + R_{Y1} * L_7 + (W_2/L_7 + L_8) * L_7 * L_7/2$

$= M_1 + R_{Y1} * L_7 + 0.5\, L_7^2 * W_2/L_7 + L_8$

$M_Y = (M_4) = M_2 + R_{X1} * L_7 + g * d_1 * L_7 * L_7/2$

$= M_2 + R_{X1} * L_7 + 0.5 g d_1 L_7^2$

$T = P_X * L_2$

Axial Load

Axial Load acting on the pin $R_{z2} = R_{z1} + W_2 \sin\alpha$

Axial load on the right side $P_{ar} = R_{z1} + W_2 \sin\alpha * L_7/(L_7 + L_8)$

Axial load on the left side $P_{al} = R_{z1} + W_2 \sin\alpha * L_8/(L_7 + L_8)$

Lateral Reactions

$R_{x2} = R_{X1} + g * d_1 * L_7 + R_{X3}$

$R_{x3} = M_Y/L_8$

Vertical Reactions

$R_{Y2} = R_{Y1} + R_{Y3} + W_2 \cos\alpha$

$R_{y3} = M_X/L_8 - 0.5\ W_2 \cos\alpha * L_8/(L_7 + L_8)$

Shear Load

Load in x-direction P_{XR}(Right side) = $R_{X1} + g * d_1 * L_7$

Load in x-direction P_{XL}(Left side) = R_{X3}

Vertical Shear Force

$V_{YR} = R_{Y1} + W_2 \cos\alpha * L_7/(L_7 + L_8)$

$V_{YL} = R_{Y3} + W_2 \cos\alpha * L_8/(L_7 + L_8)$

Lateral Shear Force

$V_{xr} = R_{X1} + gd_1L7$

Forces on middle Boom (Figure 4) (i.e., forces transfer from inner boom to middle boom

The forces acting on the middle boom directly transfer from the inner boom thru nylon pads. Here on the middle boom wind load will act in same way as in inner boom.

g = Wind load = 0.004 (mph)^2/144

W_3 = Weight of the second extension

W_4 = Mass of the extension cylinder rod end

Moments

Moment about X-axis

$(M_4) = M_{XX} = R_{Y2} * L_{12} + W_3 \cos\alpha * L_{12} * L_{12}/2(L_{12} + L_{13}) - R_{Y3} * L_{17} - 2R_{Z2} * L_{18}$

$= R_{Y2} * L_{12} + 0.5W_3L_{12}^2/(L_{12} + L_{13}) - R_{Y3} * L_{17} - 2R_{Z2} * L_{18}$

Moment about Y-axis

$(M_5) = M_{YY} = R_{X2} * L_{12} - R_{X3} * L_{17} + g * d_2 * L_{12} * L_{12}/2$

$= R_{X2} * L_{12} - R_{X3} * L_{17} + 0.5gd_2L_{12}^2$

Axial Load

Axial load $R_{Z3} = 2R_{Z2}$

Axial load on the right hand side of section $Z_2 - Z_2$

$(P_{ar}) = 2R_{Z2} + W_3 \sin\alpha * L_{12}/L_{12} + L_{13}$

Axial load on the Left hand side of section $Z_2 - Z_2$

$(P_{al}) = R_{Z3} - W_3 \sin\alpha * L_{12}/L_{12} + L_{13} - W_4 \sin\alpha$

Vertical Reactions

$R_{y5} = M_4/L_{13} - 0.5W_3 \cos\alpha * L_{13}/L_{12} + L_{13} - R_{Z3} * L_{19}/L_{13}$

$R_{Y4} = R_{Y5} + R_{Y3} - R_{Y2} + W_3 \cos\alpha + W_4 \cos\alpha$

Lateral Reactions

$R_{X5} = M_4/L_{13}$

$R_{X4} = g * d_2 + R_{X5} + R_{X2} - R_{X3}$

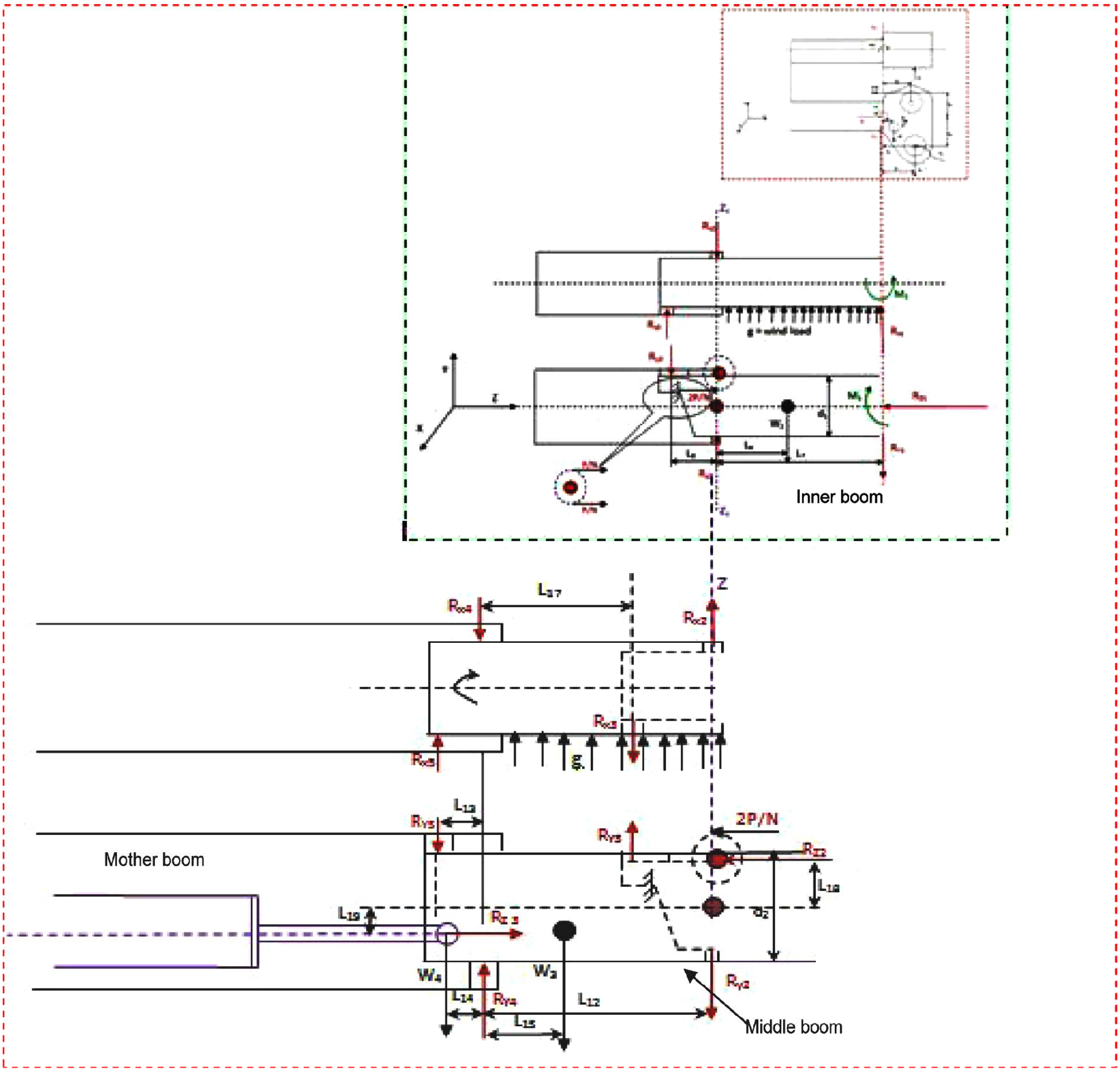
Vertical shear force right hand side of section

$V_{yr} = R_{Y2} - R_{Y3} + W_5 * \cos(\alpha) * L_{12}/(L_{12} + L_{13}) + P_b * \cos(\alpha)$

Vertical shear force left hand side of section

$V_{yL} = R_{y5} + W_5 * \cos(\alpha) * L_{13}/(L_{12} + L_{13}) + W_6 * \cos(\alpha)$

Figure 4: FBD of Middle Boom



Lateral shear force right hand side of section

$$V_{xr} = R_{x2} - R_{x3} + g * d_2 * L_{12} + 0.02 * P_b$$

Lateral shear force left hand side of section $V_{xL} = R_{x5}$

Axial load on the Left hand side of section Z_2 - Z_2

$$P_{ar} = R_{Z3} - W_3 \sin\alpha * L_{12}/L_{12} + L_{13} - W_4 \sin\alpha$$

Vertical Reactions

$$R_{y5} = M_4/L_{13} - 0.5W_3 \cos\alpha * L_{13}/L_{12} + L_{13} - R_{Z3} * L_{19}/L_{13}$$

$$R_{Y4} = R_{Y5} + R_{Y3} - R_{Y2} + W_3 \cos\alpha + W_4 \cos\alpha$$

Lateral Reactions

$RX_5 = M_4/L_{13}$

Vertical Shear Force

Vertical shear force right hand side of section

$V_{yR} = R_{y2} - R_{y3} + W_3 * \cos(\alpha) * L_{12}/(L_{12} + L_{13})$

Vertical shear force left hand side of section

$V_{yL} = R_{y5} + W_3 * \cos(\alpha) * L_{13}/(L_{12} + L_{13}) + W_4 * \cos(\alpha)$

Lateral shear force right hand side of section

$V_{xr} = R_{x2} - R_{x3} + g * d_2 * L_{12}$

Lateral Shear Force

Lateral shear force left hand side of section $V_{xL} = R_{x5}$

Forces on mother boom (Figure 5) (i.e., forces transfer from middle boom, winch and ropes to mother boom)

Following are the terms shall be used during the force calculation on mother boom:

R_H = Hoist cylinder reaction

β = Angle at which Lift RAM is mounted

W_5 = Weight of Base section

W_6 = Weight of welding

W_7 = Weight of extension cylinder on head side

R_{Z8L} = Reaction on the left side of winch mtg. area on boom in Z-axis

R_{Z8R} = Reaction on the Right side of winch mtg. area on boom Z-axis

R_{Y8L} = Reaction on the left side of winch mtg. area on boom in Y-axis

R_{Y8R} = Reaction on the Right side of winch mtg. area on boom in Y-axis

Free body diagram is shown below

Moments

Moment about $X - X$ "M_6" = "Mx" = $R_{y6} * L_{21} - R_{y7} * L_{25} + 0.5 * W_5 * \cos(\alpha) * L_{21}$^2/$(L_{21} + L_{22}) + R_{Z6} * L_{26} - R_{Z2} * L_{21} + W_6 * \cos(\alpha) * (L_{21} - L_{22})$

Moment about $Y - Y$ "M_7" = "My" = $R_{x6} * L_{21} - R_{x7} * L_{24} + 0.5 * g * d_4 * L_{21}$^2

Axial Loads

Axial Load $(R_{z6}) = R_{z5} + W_7 * \sin(\alpha)$

Axial load, i.e., on right hand side of section

$P_{ar} = W_5 * \sin(\alpha) * L_{21}/(L_{21} + L_{22}) + R_{z2} + W_6 * \sin(\alpha)$

Axial load, i.e., on left hand side of section

$P_{aL} = R_{Z6} - W_5 * \sin(\alpha) * L_{22}/(L_{21} + L_{22}) + R_{z8R} + R_{z8L} - W_7 * \sin(\alpha)$

Vertical Reactions

Vertical shear force right hand side of section

$V_{yr} = R_{y6} - R_{y7} + W_5 * \cos(\alpha) * L_{21}/ (L_{21} + L_{22}) + W_6 * \cos(\alpha)$

Vertical shear force left hand side of section

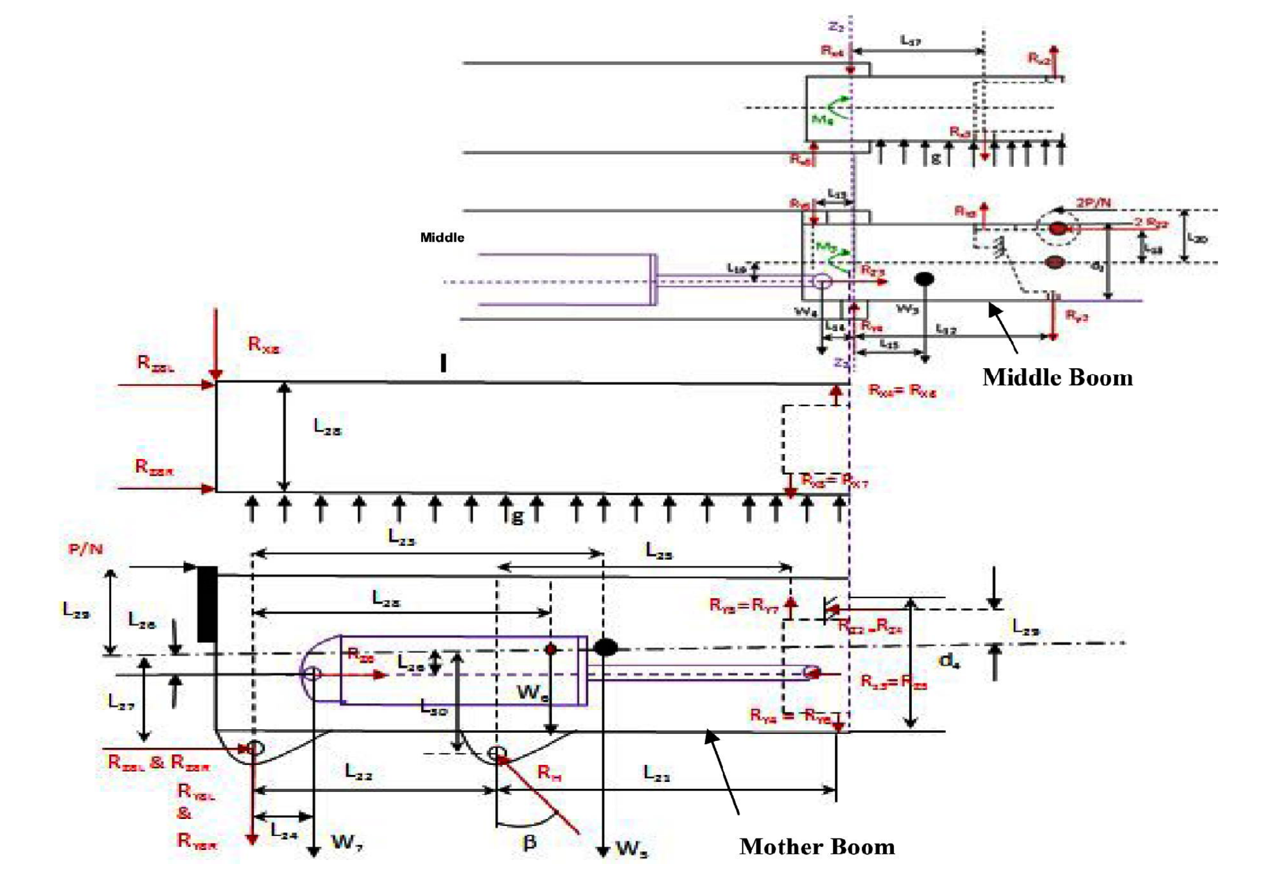
$V_{yL} = R_{y8r} + R_{y8L} + W_7 * \cos(\alpha) + W_5 \cos(\alpha) * L_{22}/(L_{21} + L_{22})$

Lateral Reactions

Lateral shear force right hand side of section

$V_{xr} = R_{x6} - R_{x7} + g * d_4 * L_{21}$

Figure 5: FBD of Mother Boom



Cylindrical Reactions

Load on boom hoist cylinder "R_H" = $[R_{y6} * (L_{21} + L_{22}) - R_{y7} * (L_{22} + L_{25}) + W_5 * \cos(\alpha) * L_{23} - W_5 * \sin(\alpha) * L_{27} - W_7 * \cos(\alpha) * L_{24} - W_7 * \sin(\alpha) * (L_{27} - L_{26}) + R_{z6} * (L_{27} - L_{26}) - R_{z2} * (L_{27} + L_{29}) + W_6 * \cos(\alpha) * L_{28} - W_6 * \sin(\alpha) * L_{27}/\{L_{22} * \cos(\alpha) - \sin(\alpha) * (L_{30} - L_{27})\}$

Reactions on Boom Pivot Point

Lateral direction

Boom pivot point lateral reaction $R_{x8} = R_{x6} - R_{x7} + g * d_4 * (L_{21} + L_{22})$

Axial Reactions

Boom pivot pin axial reactions

$R_{Z8r} = R_H * \sin(\alpha)/2 - R_{x6} * (L_{21} + L_{22})/L_{28} + R_{x7} * (L_{22} + L_{25})/L_{28} - R_{z6}/2 + (W_7 + W_5 + W_6)/2 * \sin(\alpha) - 0.5 * g * d_4 * (L_{21} + L_{22})\text{^}2/L_{28} + R_{z2}/2$

Boom pivot pin axial reactions

$R_{z8L} = R_H * \sin(\alpha)/2 + R_{x6} * (L_{21} + L_{22})/L_{28} - R_{x7} * (L_{22} + L_{25})/L_{28} - R_{z6}/2 + (W_7 + W_5 + W_6)/2 * \sin(\alpha) + 0.5 * g * d_4 * (L_{21} + L_{22})\text{^}2/L_{28} + R_{z2}/2$

Vertical Reactions

Boom pivot pin vertical reactions $R_{y8r} = 0.5 * [R_H * \cos(\alpha) + R_{y7} - R_{y6} - \{W_7 + W_5 + W_6 + P_b\} * \cos(\alpha)] + g * d_4 * (L_{21} + L_{22}) * L_{27}/L_{28}$

RESULTS AND DISCUSSION

As we have obtained the various forces on different section, this can be taken as the basis for the designing of boom.

- The moment acting in the y-direction gives the thickness value of the side plates of boom.
- The moment acting in x - direction gives the thickness value of top and bottom plates.
- The RH value calculated above is the basis for designing of Lift cylinder. Although, this is the value calculated for one load case only. The worse load case can be taken as the basis of the designing of Lift cylinder.

CONCLUSION

- The load lifted from the Jib head, gives the loading on all the booms. Hence affects the design of each boom.
- The load lifted from other variable hook, gives the different force and moment on middle boom and mother boom.
- The worse loading and moment is taken for the basis of designing i.e. thickness calculation for each section of different locations.
- The load lifted on mother boom fixed hook, affects the designing of mother boom only.
- The above discussion of Boom pivot point gives the information of force criticality on the said point. The various reactions discussed is taken the basis for designing of Boom pivot point.

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