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TOWER CRNE MAST ANCHORAGE TIE DESIGN

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Abstract: One variant is piled base cast in fixing angle type with top slewing tower crane which needs mast anchorage tie to ascertain stability beyond working manufacturer specified freestanding mast height. Major challenge arises at the time of fixing ties with the existing building or structure as shape, location, distance, load bearing capacity of the structure may differ from project to project. Consulting manufacturer service department may not be possible all the time. Attempt is made to find an approximate value of the forces to be encountered by the ties in service condition and designing the ties.

Keyword - Tower Crane, Mast Anchorage Tie, In service condition, Propped Cantilever, Designing the ties.

1. INTRODUCTION

Among different types of lifting gear tower cranes are most popular and most effective for high rise buildings, chimneys, towers, power plants etc. Space requirement is less. Loads can be lifted at a greater height with wide coverage area. Selection of tower crane type depends on site conditions and requirements.

In Service Condition:

- Self weight of the crane
- Lifted load
- Wind load
- Dynamic effects for hoisting, slewing and trolleying.

Out of Service Condition:

- Self weight of the crane
- Wind loading

2. CRANE SPECIFICATION

- Maximum lifting capacity up to 14.7m radius : 6 MT
- Maximum lifting capacity up to 50m radius : 1.3 MT
- Maximum lifting speed : 18.8 m/min
- Free standing mast height : 48 m
- First mast anchorage tie from base : 27 m
- Slewing speed (max.) : 0.7 r/min
- Slewing torque (max.) : 120 N.m
- Trolleying speed : 15 m/min
- Maximum possible mast height : 138.7 m
- Maximum jib length : 50 m

Considering a dynamic load co-efficient: 1.1

3. FINDING CG OF THE CRANE IN SERVICE CONDITION

Counter clockwise moments:

S. No.	Item description	Weight of the component (Kg)	Lever from true geometric vertical axis of the mast (m)	Moment (Kg. m)
1	Counter jib	3320	6.475	21497
2	Ballast	11300	11.5	129950
			Total counter clockwise moments	**151447**

Clockwise moments:

S. No.	Item description	Weight of the component (Kg)	Lever from true geometric vertical axis of the mast (m)	Moment (Kg. m)
1	Jib foot section	1838	5.15	9466
2	Jib section – 2	1400	15.45	21630
3	Jib section – 3	925	25.75	23818
4	Jib section – 4	825	36.05	29741

5	Jib section – 5	220	43.815	9639
6	Jib section – 6	220	49.045	10789
7	Jib nose	85	51.93	4414
8	Jib trolley (13 m radius)	590	14.7	8673
9	Tower head, ladder and monorail	2000	0	0
10	Lifted load	6000 X 1.1	14.7	97020
			Total clockwise moments	**215190**

$$\text{CG (service condition)} = \frac{151447 - 215190}{\text{Total Weight}} = \frac{-63743}{29323} = -2.17 \text{ m (clockwise)}$$

Load eccentricity, e = - 2.17 m

4. FINDING CG OF THE CRANE OUT OF SERVICE CONDITION

Counter clockwise moments:

S. No.	Item description	Weight of the component (Kg)	Lever from true geometric vertical axis of the mast (m)	Moment (Kg. m)
1	Counter jib	3320	6.475	21497
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7	Jib nose	85	51.93	4414
8	Jib trolley (13 m radius)	590	14.7	8673
8	Tower head, ladder and monorail	2000	0	0
			Total clockwise moments	**118170**

$$\text{CG (out of service condition)} = \frac{151447 - 118170}{\text{Total Weight}} = \frac{33277}{22723} = 1.46 \text{ m (anti-clockwise)}$$

Load eccentricity = e = 1.46 m

5. WIND EFFECT

Wind load in KN, $F = A\,p\,C_f$

- A is the solid surface area perpendicular to the wind direction.
- C_f is the force coefficient, depends on the shape of the element facing wind.
- P is wind pressure in KN/m^2 calculated using the formula, $P = 0.613 \times 10^{-3} \times v_s^2$.
  Where, v_s is the calculated wind speed in m/s.
- ➢ In service wind speed varies from 14 to 28 m/s.
- ➢ Out of service storm wind speed varies between 36 to 46 m/s depending upon height above ground level.

Force coefficient for square lattice tower with flat sided sections given by,

$$C_f = 1.7 \times (1 + \eta)$$

Shielding factor, $\eta = 0.43$
Force coefficient, $C_f = 1.7 \times (1 + 0.43) = 2.431$
Wind facing frontal area of the tower mast = 33 m^2

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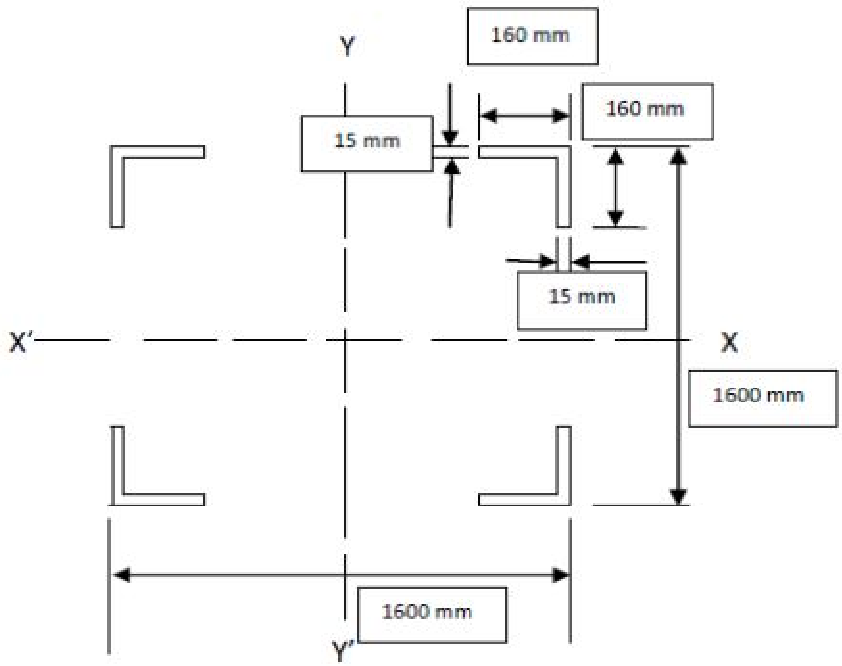
In service wind force on the tower crane mast:
For 20m/s wind speed (Normal crane in service wind speed),
$P = 0.613 \times 10^{-3} \times v_s^2 = 0.613 \times 10^{-3} \times 20^2 = 0.25$ KN/m^2
Maximum in service wind force, $F = A \times p \times C_f = 33 \times 0.25 \times 2.431 = 20$ KN
Out of service wind force on the tower crane mast:
For 46 m/s wind speed (Storm wind speed),
$P = 0.613 \times 10^{-3} \times v_s^2 = 0.613 \times 10^{-3} \times 46^2 = 1.297$ KN/m^2
Maximum in service wind force, $F = A \times p \times C_f = 33 \times 1.297 \times 2.431 = 104$ KN

- Pressure intensity increases from bottom to top. For simplicity of calculation let us assume that it is uniform throughout the height.
- Pressure point is the mid -point of the mast.

6. MOMENT OF INERTIA OF MAST CROSS SECTION



Cross section of mast main cord:

Moment of Inertia about XX' = YY' $= \left[\left\{\frac{160 \times 15^3}{12} + (160 \times 15) \times 792.5^2\right\} \times 4\right]$

$$+ \left[\left\{\frac{15 \times 145^3}{12} + (145 \times 15) \times 712.5^2\right\} \times 4\right]$$

$$= 0.010461372 \text{ m}^4$$

7. FORCES ON MAST TIE IN SERVICE CONDITION

Maximum Bending Moment of mast without wind,

$$M = P.\ e \sec l \sqrt{\left(\frac{P}{EI}\right)}$$

$$= 29323 \times 9.81 \times 2.17 \times \sec \left\{48\sqrt{\frac{29323 \times 9.81}{2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372}}\right\}$$

$= 29323 \times 9.81 \times 2.17 \times \sec (0.5493)$
$= 29323 \times 9.81 \times 2.17 \times \sec (31.47^o)$
$= 731867$ Nm

$$\text{Deflection at 48 m height} = \frac{M \times l^2}{2\,EI}$$

$$= \frac{731867 \times 48^2}{2 \times 2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372}$$

$= 0.38377$ m
$= 383$ mm

Deflection of mast due to 20 KN horizontal wind force on the mast acting at an height of 24 m(i.e., middle of the mast),

$$\delta = \frac{5 \times 20000 \times 48^3}{48 \times 2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372}$$

$= 0.10487$m
$= 105$ mm

Total maximum deflection in service condition = 383 +105 = 488 mm
As per manufacturer recommendation, first mast tie to be added at 27 m from base to resist deflection of the mast at top. Let us assume tie will exert a force P which deflects the mast to its vertical position,

$$\text{Opposing deflection} = \frac{P \times 27^3}{3 \times 2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372} + \frac{P \times 27^2}{2 \times 2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372} \times (48 - 27)$$

$= 2.9864971 \times 10^{-6} \times P + 3.4842466 \times 10^{-6} \times P$
$= 6.4707437 \times 10^{-6} \times P$

Net deflection of 48 m height = 0
Therefore,
$6.4707437 \times 10^{-6} \times P = 0.488$
Or, P = 75416 N
Or, P = 7688 Kg

8. FORCES ON MAST TIE OUT OF SERVICE CONDITION

Maximum Bending Moment of mast without wind,

$$M = P.\, e \sec l \sqrt{\left(\frac{P}{EI}\right)}$$

$$= 22723 \times 9.81 \times 1.46 \times \sec \left\{48\sqrt{\frac{22723 \times 9.81}{2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372}}\right\}$$

$= 22723 \times 9.81 \times 1.46 \times \sec (0.4835)$
$= 22723 \times 9.81 \times 1.46 \times \sec (27.7^o)$
$= 367579$ Nm

$$\text{Deflection at 48 m height} = \frac{M \times l^2}{2\,EI}$$

$$= \frac{367579 \times 48^2}{2 \times 2.1 \times 10^5 \times 1000 \times 1000 \times 0.010461372}$$

$= 0.1927$ m
$= 193$ mm

Deflection of mast due to 104 KN horizontal wind force on the mast acting at an height of 24 m (i.e., middle of the mast)

$$\delta = \frac{5 \text{ x}104 \text{ x } 1000 \text{ x } 48^3}{48 \text{ x } 2.1 \text{ x } 10^5 \text{ x } 1000 \text{ x } 1000 \text{ x } 0.010461372}$$

= 0.5453 m

= 545 mm

Total maximum deflection in service condition = 545 + 193 = 738 mm

As per manufacturer recommendation, first mast ties to be added at 27 m from base to resist deflection of the mast at top. Let us assume tie will exert a force P which deflects the mast to its vertical position,

$$\text{Opposing deflection} = \frac{P \text{ x } 27^3}{3 \text{ x } 2.1 \text{ x } 10^5 \text{x } 1000 \text{ x } 1000 \text{ x } 0.010461372} + \frac{P \text{ x } 27^2}{2 \text{ x } 2.1 \text{ x } 10^5 \text{ x } 1000 \text{ x } 1000 \text{ x } 0.010461372} \text{ X } (48 - 27)$$

$= 2.9864971 \text{ x } 10^{-6} \text{ x } P + 3.4842466 \text{ x } 10^{-6} \text{ x } P$

$= 6.4707437 \text{ x } 10^{-6} \text{ x } P$

Net deflection of 48 m height = 0

Therefore,

$6.4707437 \text{ x } 10^{-6} \text{ x } P = 0.738$

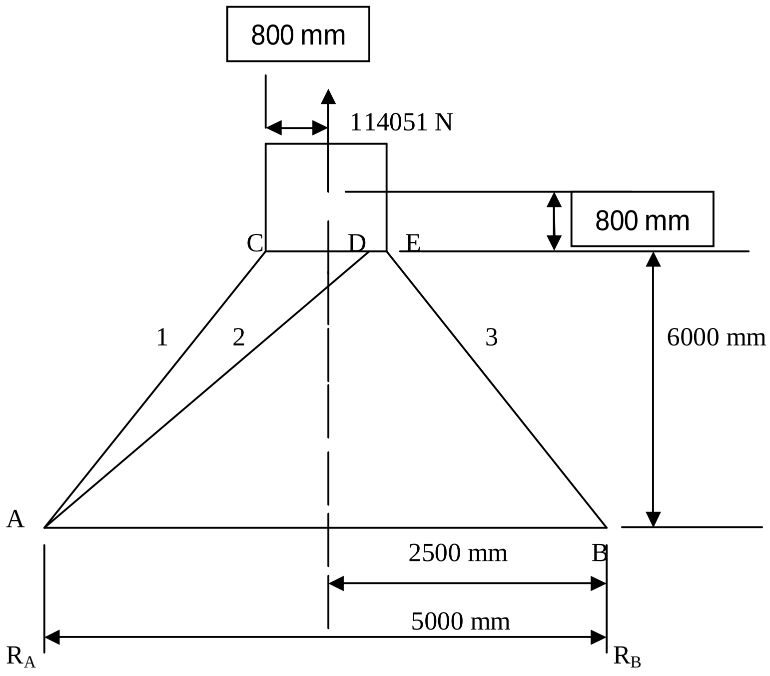
Or, P = 114051 N

Or, P = 11626 Kg

9. FINDING FORCE ACTING ON LEGS

Force acting from the geometrical axis of the mast at anchorage tie level and its effect on each leg has to be found out resolving reactions at each leg support.

Condition 1: 114051 N force acting in the perpendicular direction from tie support wall and away from the wall:



AC = BE = 6236 mm

DE = 300 mm

AD = 6708 mm

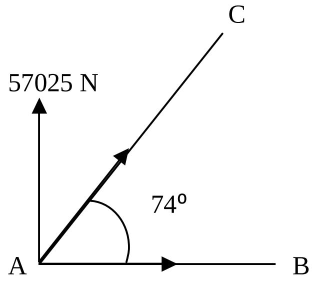
Taking moments about A,

R_B x 5 = 114051 x 2.5

Or, R_B = 57025 N↑

R_A = 57025 N↑

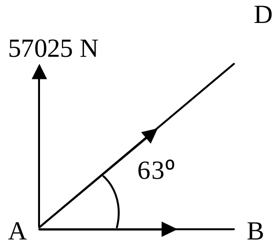
Free body diagram at joint A,



Force on AC = BE = $\frac{57025}{\text{Sin } 74^{o}}$ = 59323 N (Tensile)

Horizontal force at joint A = 59323 x cos74° = 16351 N →

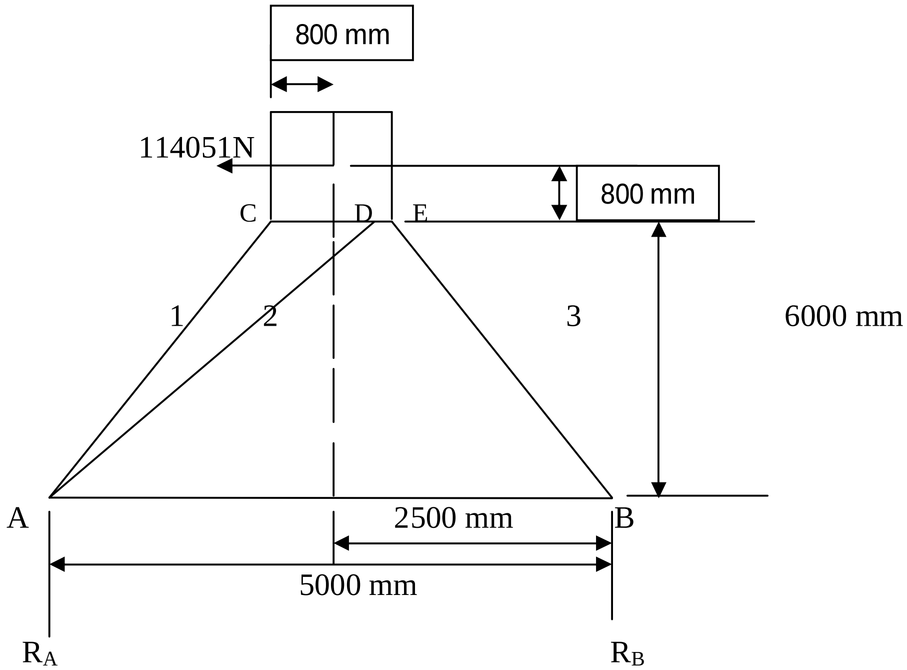
Free body diagram at joint A,



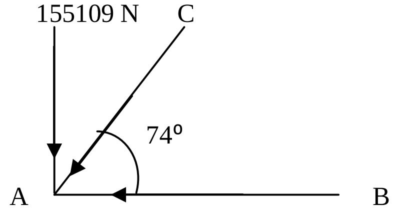
Force on AD = $\frac{57025}{\text{Sin } 63^{o}}$ = 64001 N (Tensile)

Horizontal force at joint A = 64001 x cos63° = 29056 N →

Condition 2: 114051N force acting from the mast axis and parallel to the wall / supporting structure:

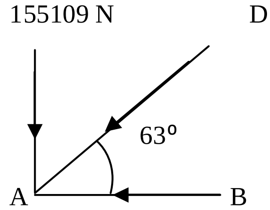


Taking moments about A,
R_B x 5 = 114051 x 6.8
Or, R_B = 155109 N↑
Taking moments about B,
R_A x 5 = 114051 x 6.8
Or, R_A = 155109 N ↓
Free body diagram at joint A,



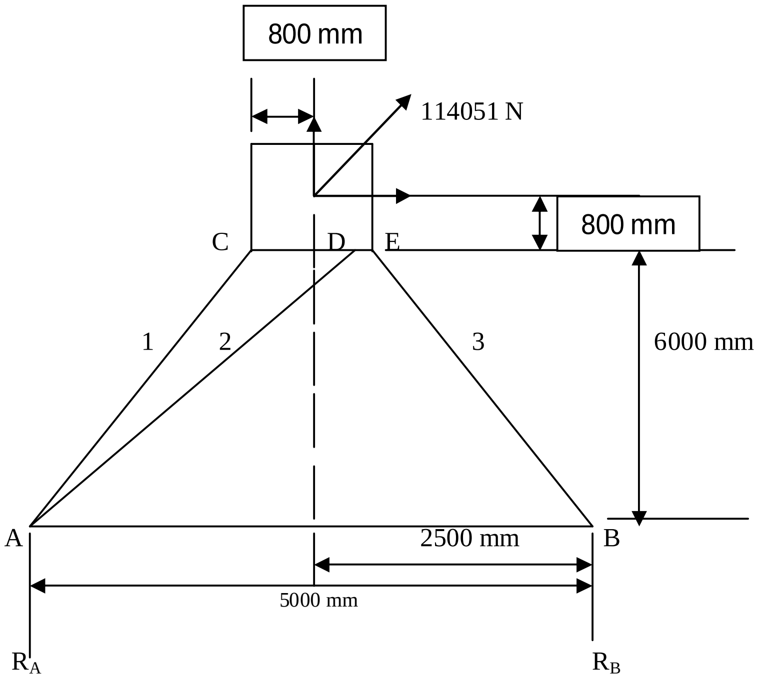
Force on AC = $\frac{155109}{\text{Sin } 74^{o}}$ = 161360 N (Compressive)

Horizontal force at joint A = 161360 x cos74° = 44476 N ←
Free body diagram at joint A,

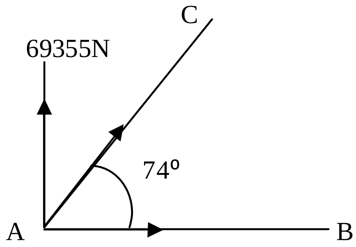


Force on AD = $\frac{155109}{\text{Sin } 63^{o}}$ = 174082 N (Compressive)

Horizontal force at joint A = 174082 x cos63° = 79032 N ←
Condition 3: 114051N force acting from the mast axis and at an angle 45°with the wall.

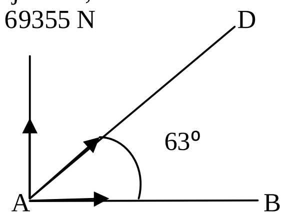


Net force = 114051 N
Resolving along vertically and horizontally,
Vertical component = 80646 N
Horizontal component = 80646 N
Taking moments about A,
R_B x 5 + 80646 x 2.5 = 80646 x 6.8
Or, R_B = 69355 N↓
R_A = 69355 N↑
Free body diagram at joint A,



$$\text{Force on AC} = \frac{69355}{\sin 74^\circ} = 72150 \text{ N (Tensile)}$$

Horizontal force at joint A = 72150 x cos74° = 19887 N →
Free body diagram at joint A,



$$\text{Force on AD} = \frac{69355}{\sin 63^\circ} = 77839 \text{ N (Tensile)}$$

Horizontal force at joint A = 77839 x cos63° = 35338 N →

Force Table:

Component	0°	45°	90°
AC	161360 N (Tensile)	72150 N (Tensile)	59323 N (Tensile)
AD	174082 N (Tensile)	77839 N (Tensile)	64001 N (Tensile)
BE	161360 N (Compressive)	72150 N (Compressive)	59323 N (Tensile)

10. CONCLUSION

1. Once forces on the legs are determined sections, pins, tie length etc. can be selected with factor of safety as per standard code of practice.
2. Mast should be tied in perfect vertical position to facilitate jacking and climbing.
3. Legs are considered to be on perfect level i.e., at an angle 90° with the vertical mast.

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