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Comparative Design and Analysis of Self Supporting and Guyed Steel Chimney

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Abstract

The area proposed for the construction of this chimney is at an industry in Metter. They have already provided 43m self-supporting steel chimney. In addition to that, analysis and design of 72m steel chimney (Self-supporting Vs Guyed) for eco-friendly purpose. Here we design and analysis a steel chimney having a height of 72m steel chimney and structural elements of the chimney such as foundation are designed. By comparing the moments of self-supporting steel chimney and guyed steel chimney from manual design. The base moment of guyed steel chimney is less than the self-supporting steel chimney and hence Guyed Steel Chimney is safe at that site.
Keywords: Auto CADD, STAAD pro, guy ropes, cylindrical shell

I. INTRODUCTION

Our project deals with the design of a steel structure. The type of chimney that we have taken for our project is industrial chimney with steel. Here design of loads and the design of self weight and foundation were carried out manually. The various drawings were drafted by AutoCAD 2013.And the analysis is done by STAAD pro 2007. Usually the design of the structural elements carried out manually and it takes more time but we can learn more things. If the structure is small than the calculation will be simpler and can also be completed quickly. But for the chimney, the calculation for the design of the structural elements will be tedious and time consuming. Chimneys are used to emit the exhaust gases, higher up in the atmosphere, so that diffusion of gases takes place. There are mainly three types of chimney structures: - R.C.C chimney, Steel chimney, Brick chimney. For project, considered steel chimney structure.

II. DESIGN OF SELF-SUPPORTING STEEL CHIMNEY

A. *Basic Dimensions of Chimney:*

Total height of chimney = 72m
Height of flare = H = 1/3(72) = 24 m
Diameter of the flare =1.6x3 = 4.8m.
Computation of wind pressure:
The design wind speed at any height z is given by
$V_z=Vb.k_1.k_2.k_3$
Where, V_b = basic wind speed at the site =47m/s for salem.
k_1=probability factor (risk coefficient) =1.0for general buildings and structures.
k_3=topography factor =1.0 for flat topography
k_2=terrain, height and structure size factor
V_z= 47 x 1 x 1 x k_2
Now design wind pressure $P_z= 0.6V_z^2 N/m^2$
$P_z=0.6(47k_2)$ x10^{-3} kN/m^2= 1.3254k_2^2 KN/m^2
For chimney, adopting a shape factor of 0.7
$P_z= (p_z.D.\Delta_z)0.7$

Table – 1
Moment at each section

Section	*H (m)*	*D (m)*	*k_2*	*$p=1.3245\ k_2^2$*	*P=pxDxh'xSF (kN)*	*h*	*M_W=Pxh1 (kNm)*	*M_{wxx}*
1	*72*	*3*	*1.201*	*1.910*	*32.096*	*68*	*2182.510*	*128.383*
2	*64*	*3*	*1.19*	*1.876*	*31.510*	*60*	*1890.629*	*511.191*
3	*56*	*3*	*1.178*	*1.838*	*30.878*	*52*	*1605.666*	*1143.553*
4	*48*	*3*	*1.165*	*1.798*	*30.200*	*44*	*1328.819*	*2020.230*
5	*40*	*3*	*1.145*	*1.736*	*29.172*	*36*	*1050.207*	*3134.399*
6	*32*	*3*	*1.125*	*1.676*	*28.162*	*28*	*788.541*	*4477.905*
7	*24*	*3.3*	*1.09*	*1.574*	*29.081*	*20*	*581.617*	*6050.384*
8	*16*	*3.9*	*1.054*	*1.471*	*32.136*	*12*	*385.627*	*7867.728*
9	*8*	*4.5*	*1*	*1.325*	*33.377*	*4*	*133.510*	*9947.124*
					TOTAL		*9947.124*	

Where
H = Height from bottom
D = Diameter of section
h1 = 'P' acts at a height from above the base
Mw = overturning moments at the base
h' = Height difference between two station ($H_1 - H_2$)

B. Design of Chimney Shell:

Stress due to chimney weight, f_s=0.0785ht N/mm²
Stress due to weight of lining, f_l=0.002ht/t N/mm²
Stress due to wind, f_w=(0.004M_{wxx})/(πD^2 t) N/mm²
Minimum thickness of shell from stability point of view=D/500=3000/500=6mm.
It is assumed that the design life of steel chimney shell will be 20 years and coal is used for boiler. Hence add additional 4mm Thickness to account for corrosion. Hence total minimum thickness of plate=6+4=10mm.
Effective thickness =10-4=6mm

Table - 2
Determination of stress

Section	*D (m)*	*t (m)*	*ht*	*fs*	*Fl*	*Fw*	*fc max*	*ft max*	*fc max < σcxη1*	*D/t*	*ht/D*	*σc (From IS 6533)*
1	*3*	*0.006*	*8*	*0.63*	*2.67*	*3.03*	*6.32*	*0.36*	*58*	*500*	*2.67*	*58*
2	*3*	*0.006*	*16*	*1.26*	*5.33*	*12.06*	*18.65*	*6.73*	*58*	*500*	*5.33*	*58*
3	*3*	*0.006*	*24*	*1.88*	*8.00*	*26.98*	*36.86*	*18.98*	*58*	*500*	*8.00*	*58*
4	*3*	*0.006*	*32*	*2.51*	*10.67*	*47.66*	*60.84*	*36.99*	*58*	*500*	*10.67*	*58*
5	*3*	*0.008*	*40*	*3.14*	*10.00*	*55.46*	*68.60*	*45.46*	*75.6*	*375*	*13.33*	*75.6*
6	*3*	*0.008*	*48*	*3.77*	*12.00*	*79.23*	*94.99*	*67.23*	*75.6*	*375*	*16.00*	*75.6*
7	*3.6*	*0.008*	*56*	*4.40*	*14.00*	*74.34*	*92.74*	*60.34*	*64*	*450*	*15.56*	*64*
8	*4.2*	*0.008*	*64*	*5.02*	*16.00*	*71.02*	*92.05*	*55.02*	*58*	*525*	*15.24*	*58*
9	*4.8*	*0.008*	*72*	*5.65*	*18.00*	*68.75*	*92.40*	*50.75*	*58*	*600*	*15.00*	*58*

C. Computation of Actual Weight:

Self Weight of chimney W_s = Density of steel (78.5kN/m^3) x Volume of steel in chimney
W_s = (4xπx3x8x0.01x78.5) + (2xπx3x8x0.012x78.5) +3xπx ((3+4.8)/2) x8x0.012x78.5
= 236.75 + 142.05 + 277 = 656.25 kN
W_l = (48xπx2.90x0.1x20) + (24xπx ((2.9+4.7)/2)x0.1x20 =1447.646 KN
Total W=656.25+1447.646=2103.896 KN
Increase the weight by 5% to account for lap, stiffeners, platforms, ladder etc.
Total W= (2103.896 +105.195) =2209.091 KN

D. Check for Earthquake Forces:

Area of cross-section at the base =πx4.8x0.016 =0.241m^2
Factor $\sqrt{2}\frac{H}{r} = \sqrt{2}\frac{72}{2.4} = 42.43$
$C_T \approx 78.2$ and $Cv \approx 1.45$
$T = C_T\sqrt{\frac{WH}{EAg}}$
$T = 78.2\sqrt{\frac{2330*72}{2*10^8*0.241*9.81}}$
T=1.473 sec
Hence for 2% damping, $\alpha = \frac{S_a}{g} \approx 0.1$

For medium soil, with isolated footing, β=1.2
Importance factor I=1.Seismic zone factor for zone IV,
F=0.25
αh= α β F I=0.1x1.2x0.25x1=0.03
M_x=αh Wħ $[0.6(\frac{x}{H})^{0.5} + 0.4(\frac{x}{H})^{4}]$
At the base, x=4
Also $ħ = \frac{1}{2219.452}$[236.75(72.16)+71.025(72-36)+94.7(72-44) +369.331x12 +874.619x48+573.027x12]
ħ=32.33 m
M_{base} =0.03x2330x32.33(0.6+0.4)
=2259.867 KN-m
Moment at top of flared portion (x=48m)
$M_{X=48}$=2259.867$[0.6(\frac{48}{72})^{0.5} +0.4(\frac{48}{72})^{4}]$
=2259.867(0.4899+0.079)
=1285.662 KN-m
Comparing these moments with the corresponding moments due to wind, it found that wind governs the design. Hence the thicknesses found on the basis of wind loads are OK, and further detail may be worked out for wind force and not for earthquake force.

E. Design of Joint:

1) Up to top 32m height:
Thickness of plates =10mm. Use 18mm dia. rivets.
Strength in single shear=$\frac{\pi}{4}(18+1.5)^2$x100x10^{-3}=29.865 KN
Strength in bearing = (18+1.5)x10x300x10^{-3}=58.5 KN
∴ Rivet value =29.865KN
Required strength of plate=$\sigma_t * \eta_2$ =150x0.7=105N/mm^2
∴ Strength per unit length=105x10=1050N/mm
Using double rivets lap, joint,
Pitch of rivet= $\frac{29.865*2*1000}{1050}$ =56.89 mm.
Maximum pitch=10t=10x10=100 mm.
However, provide double riveted lap joint, joint, using 18 mm dia. rivets at a pitch of 55 mm c/c.
2) For Lower Portion
Thickness of plate =16 mm, use 22 mm dia. rivets.
Strength in single shear =$\frac{\pi}{4}(18 + 1.5)^2$x100x$10^{-3}$=43.374 KN
Strength in bearing =23.5x16x300x10^{-3}=112.8 KN
$$\therefore Rivet\ value = 43.374\ KN.$$
Required strength of plate=105 N/mm^2
Strength for unit length =105x16=1680N/mm
Using triple riveted lap joint,
Pitch of rivets = $\frac{43.374*3*1000}{1680}$= 77.45
Maximum pitch =10t=10x16=160 mm
However, provide triple lap joint, using 22 mm dia. rivets at a pitch of 75 mm c/c.

F. Design of the Flue Opening:

Area of cross-section of chimney =$\frac{\pi}{4}(3^2)$=7.069 m^2
∴ Area of breech opening = 1.2x7.069=8.483 m^2
Max. Width of opening = $\frac{2}{3} * 3 = 2\ m$
Keep 1.8 m wide 4.6 m high opening.
∴ Actual area provided=1.8x4.6=8.28m^2 which is about 17% greater than the area of cross section of chimney.
Area of stack plates removed=16x1800=28800mm^2
Length of chord=R+R cos θ (or)
L=R (1+cos θ)
$\theta = \tan^{-1}\frac{0.9}{1.5}$=30.934
cosθ = 0.8575
∴ L=1.5(1+0.8575)=2.786 m

$\therefore \frac{\text{Dia}}{L}=\frac{3}{2.786}=1.0767$

$\therefore$ Area of reinforcement =28800x1.0767≈ 31000 mm^2

$\therefore$ Reinforcement of each vertical side $=\frac{1}{2}$x31000=15500mm^2

Provide 2L 150x150x18 @ 5780 x2 =11560 mm^2

1plate 300x16 =4800 mm^2

Total =16360 mm^2

The same reinforcement is provided at top and bottom of breech opening.

Tensile stress in stack plates = $\sigma_t \eta_2$=150x0.7=105 N/mm^2

Force in each vertical side $=\frac{1}{2}$x31000x104x10^{-3}=1627.5 KN

Strength of 22 mm dia rivet in double shear =2x43.374

=1627.5 KN

Rivet value of 22 mm dia. rivets (bearing on mm plates)

=112.8 KN

Rivets value =86.748 KN

NO. Of rivets =18.76

Provided two rows of 10 rivets on each vertical side at a pitch of 80 mm in each of the extended portion of vertical reinforcement. Thus, the vertical reinforcement will extent above and below the opening by a distance of a 10x80=800mm. in the vertical and horizontal reinforcement, use 22 mm dia. Rivets at a pitch of 10x16=160 mm c/c.

G. Design of Base Plate:

The maximum compressive force per unit length

$F_c=\frac{W_{s+}W_l}{\pi d_c}+\frac{4M_w}{\pi d_c^2}$ KN/m

$=\frac{2330}{\pi*4.8}+\frac{4*8757.93}{\pi*(4.8^2)}$

=154.51+483.98

=638.48KN/m =638.48N/mm^2

Allowable bearing pressure, σ_c=4N/mm^2

$\therefore$ m $=\frac{F_c}{\sigma_c}=\frac{638.49}{4}$ = 159.6 mm

Provide 160mm wide base plate. Use two 70x70x10mm angle for connecting the stack to the base. Using 22mm dia, rivets for connection, strength of rivet in double shear = 2x43.37 = 86.748KN which strength of rivet in bearing against 16mm plate is 112.8KN. Hence rivet value = 86.748KN.

$\therefore$ Pitch of rivet = $\frac{\text{Rivet value}}{F_c}=\frac{86.748*10^3}{638.49}$ = 135.86mm

Maximum permissible pitch = 10t = 10x16 =160mm

Hence provide 22mm dia. rivets @ 130mm c/c.

Projection c = $\frac{160}{2}$ - (10+8) = 62mm.

Actual bearing pressure = $\frac{638.49}{160}$ = 3.99N/mm^2

$\therefore t_b=\sqrt{\frac{3\sigma_c}{\sigma_{bs}}}$ xc = $\sqrt{\frac{3*3.99}{185}}$ x62 = 15.77mm

Provide 16mm thick base plate.

H. Design of Anchor Bolts:

Maximum uplift force per unit length of circumference

$F_t=\frac{4M_w}{\pi d_c^2}-\frac{W_s}{\pi d_c}$

As per IS 6533 (part 2): 1989, the overturning moment M_w should be increased to 1.5 times from stability consideration

$F_t=\frac{4(8757.93*1.5)}{\pi*4.8^2}-\frac{771.806}{\pi*4.8}$ = 674.8KN/m

Let us provide 39mm dia. ISO fine threaded bolts having effective area = 1028mm^2, at root of thread. Taking permissible tensile strength of 120N/mm^2at the root of thread.

Strength of each bolt = 1028x120x10^{-3} =123.36KN.

No increase in stress is recommended since wind is the major load in the case of chimneys.

$\therefore$ Spacing of bolts $=\frac{123.36}{674.8}$ x1000 = 182.8mm

$\therefore$ No. of bolts ≈ $\frac{\pi*4.8*1000}{182.8}$ =82.5

However, provide 85 bolts of 39mm nominal diameter on a circle diameter

≈ 4.8+0.7≈ 4.87m

Actual spacing of bolts = $\frac{\pi*4.87*1000}{85}$ =180mm
Alternatively use HTFG bolts M 30(10K) having proof load of 392.7KN
Spacing of bolts = $\frac{392.7*1000}{674.8}$= 582mm
No. of bolts ≈ $\frac{\pi*4.8*1000}{582} = 25.9$
However, provide 30 HTFG bolts of dia. of 10K grade, on a bolt-circle diameter of 4.87m
Actual spacing = $\frac{\pi*4.87*1000}{30}$= 510mm.

I. Design of Foundation Block:

Let us provide solid foundation in the form of frustum of a cone. Let the upper diameter be 6m. Keeping a slope of 45°(equal to maximum permissible value for plain concrete),and a depth of 3m, the diameter at base = 6+2x3=12m
Volume of pedestal = $\frac{\pi h}{12}(d_1^2 + d_2^2 + d_1 d_2)$
= $\frac{\pi*3}{12}(6^2 + 12^2 + 6*12) = 197.92\text{m}^3$
Weight of pedestal = 197.92x24 = 4750.09 KN
Volume of earth fill = $\frac{\pi}{4}(12)^2 * 3.0 - 197.92 = 141.37m^3$
Taking unit weight of earth fill as 17KN/m^3
Weight of earth backfill = 141.37x17= 2403.32 KN
Weight of foundation plus stack = 771.81+4750.09+2403.32 = 7925.22KN
Total wind force =28.473+27.911+27.356+26.65+25.493+24.362+
25.283+27.574+28.888= 24.99
Wind moment at base = 8757.93+241.99x3.0 = 9483.9KN-m
e = $\frac{9483.9}{7925.22}$ = 1.197< $\frac{1}{8} * 12$
$\sum W$ = foundation + (stack + lining) = 4750.09 + 2330 = 7080.09KN
Max base pressure = $\frac{7080.09}{\frac{\pi}{4}(12)^2} + \frac{9483.9}{\frac{\pi}{32}(12)^3}$ = 62.60+55.90 = 118.5KN/m^2

J. Factors of Safety Against Overturning:

Overturning moment M_0 = 9483.9KN-m
Restoring moment = (4750.09+771.81)6
=33131.4KN-m
Factor of safety = 33131.4/9483.9 = 3.49>1.5 Hence safe.

K. Check Against Sliding:

Let μ=0.35
Friction force = (4750.09+771.81)0.35 = 5521.9>241.99 . Hence safe.

III. DESIGN OF GUYED STEEL CHIMNEY

A. Data:

Height of chimney =72m
Diameter of chimney =4m
Provide one set of three guy-ropes
For one set of three guy ropes, the collar is attached at a depth one-third from the top that is (72/3)=24m .
h_1=72-24=48m
H-h_1=72-48=24m

B. Horizontal Wind Pressure:

Assumed intensity of horizontal wind is 1kN/m^2 .
Total horizontal wind force
P_W=1x72x4
=228 KN/m^2

C. Bending Moment at the Level of Collar:

M =$\frac{1}{2}(\frac{P_W}{H}$(H-$h_1)^2$)
=$\frac{1}{2}\left(\frac{228}{72}\right)(24x24)$

=912KN-m

D. Reaction at the level of collar:

R_C= $3P_W/4$
=3x228 /4 = 171 KN

E. Reaction at the base:

R_B = P_W-R_C = 228- 171
R_B= 57KN

F. Position of Zero Shear Force:

Let x_1 be the depth from top where the shear force is zero.

$R_c-\frac{P_W}{H}*x_1$ =0

$(\frac{P_W}{2}*$ H)- $(\frac{P_W}{H}*x_1$) =0

$x_1=\frac{H^2}{2h_1}$

$x_1=\frac{72*72}{2*48}$

x_1 = 54m

G. Bending Moment at Base:

M = $(\frac{P_W}{2}*$ H) $(1-\frac{H}{2h_1})^2$

= $(\frac{228*72}{2})(1-\frac{72}{2*48})^2$

=513 KN-m

H. Pull in the Guy Rope:

Angle between the guy rope and horizontal may be kept 45°. Angle with the vertical shall also be45°.

P_G = $(\frac{P_W}{Sin\alpha})$ $(\frac{H}{2h_1})$

=$(\frac{228*72}{Sin45^\circ*2*48})$

= 214.83 KN

The base moment of guyed steel chimney is less than the self-supporting steel chimney and hence Guyed Steel Chimney is safe at that site.

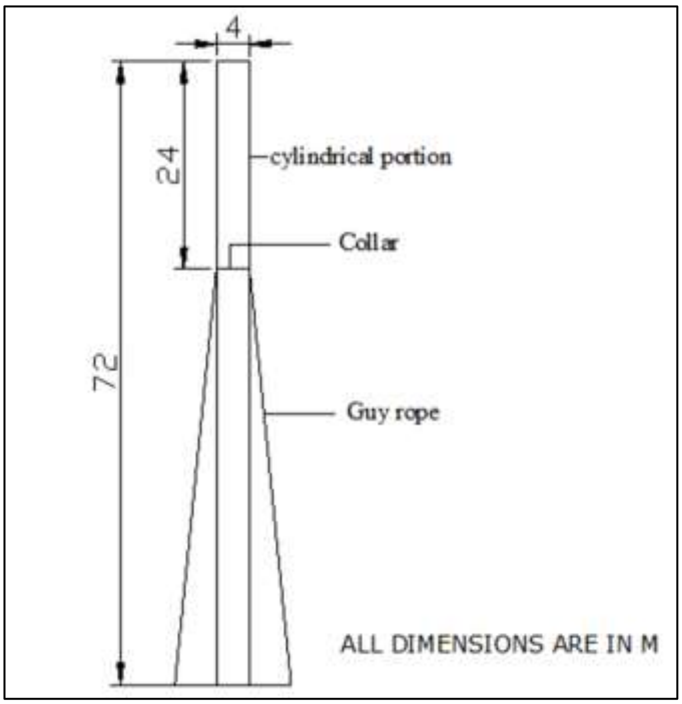


Fig. 1: Auto CADD Drawing of Guyed Steel Chimney

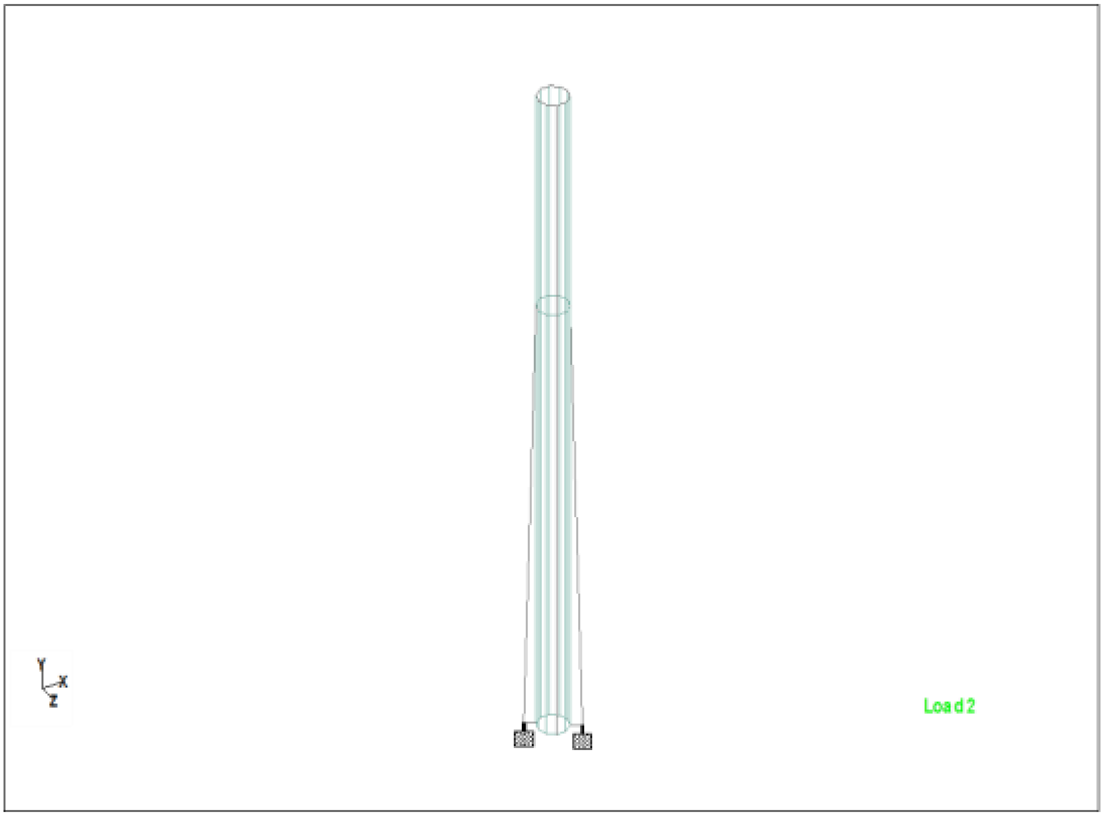


Fig. 2: 2D View of guyed steel chimney

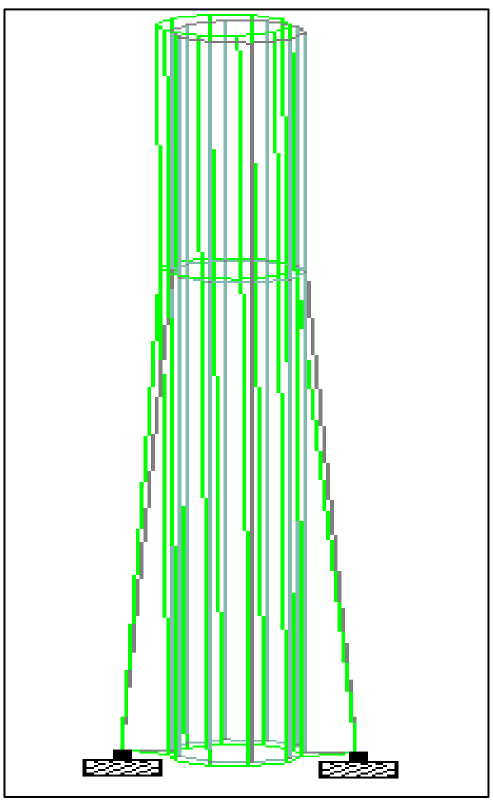
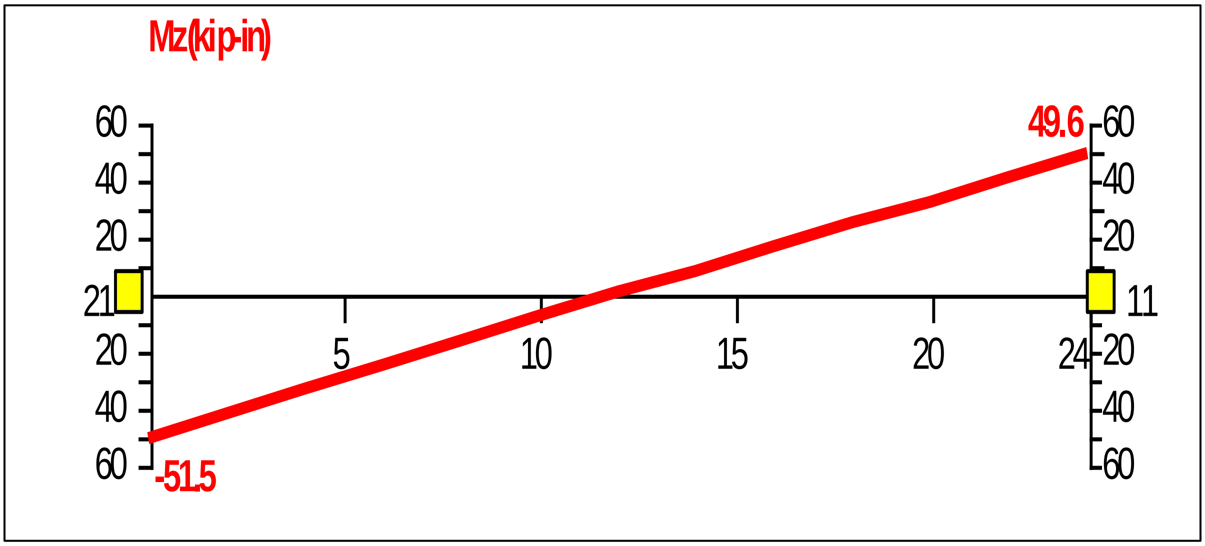
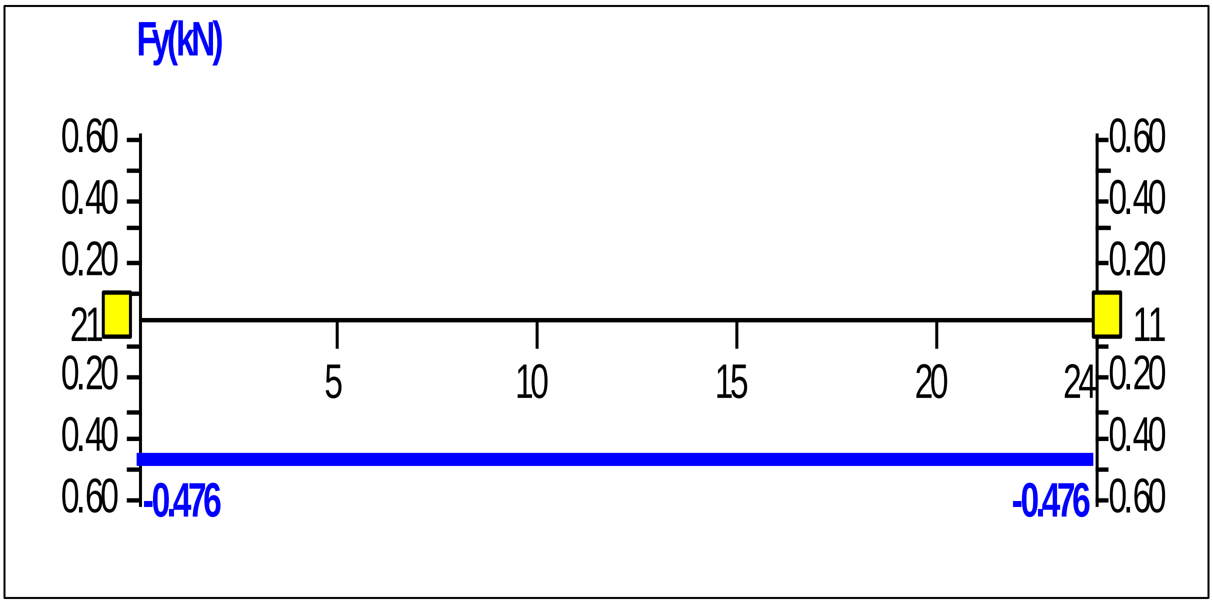


Fig. 3: Displacement Diagram





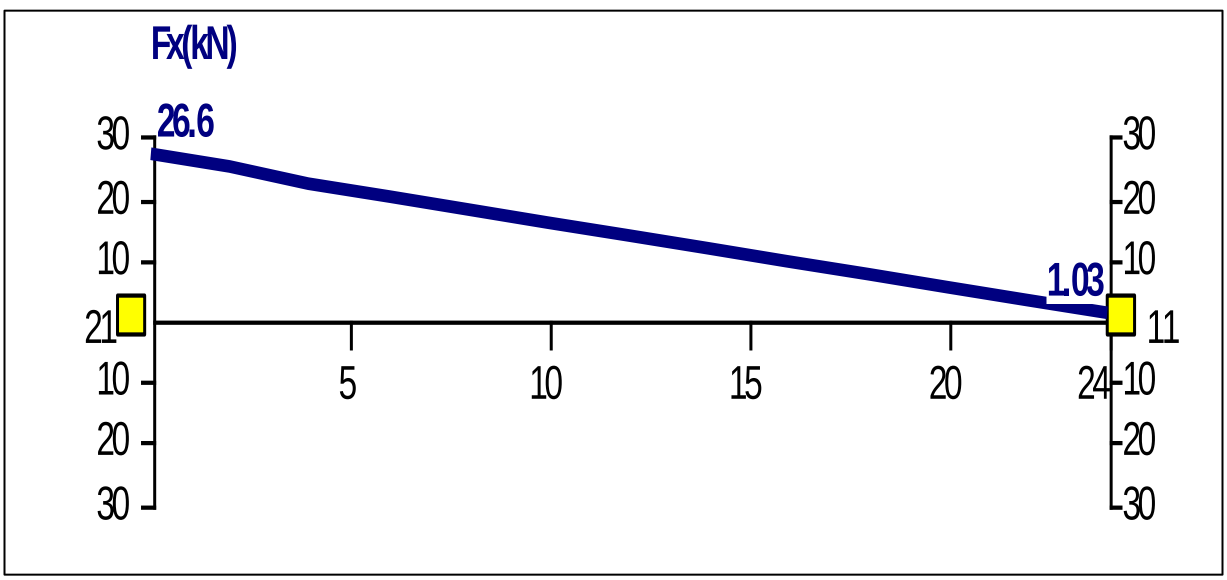


Fig. 4: Shear Force and Bending Moment Diagram

IV. CONCLUSION

The planning and design of the self-supported steel chimney and guyed steel chimney have been completed effectively in this project. By comparing the moments of both chimneys, the base moment of guyed steel chimney is less than the self-supporting steel chimney and hence GUYED STEEL CHIMNEY is safe at that site. And the displacement of guyed steel chimney is very less in this project and hence it is safe. As it is a height of 72m it doesn't affect the surrounding atmosphere. All the drawings were drafted by using Auto CAD 2013 software. And analysis of guyed steel chimney is done by STAAD.Pro 2007.

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