To Study optimization of Steel Chimney in Increasing the Segmentation and Reducing the Section Diameter

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Abstract -In today's highly competent world, it has become very important to design an efficient and cost effective system. Proper analytical and optimum design concepts are needed to design such systems. Steel stacks play an important role in this areaof industrialization. Stacks are vertical tall slender structures which discharge chemical waste gases from industries to the atmosphere. The main aim is to minimize total weight and thus, cost of the steel chimney. Our attempt is to generate data and optimize the various design parameters of steel stack. Weight reduction of steel stack will occur by reducing values of the design variables but to an extent such that the steel stack continues to stand and it does not fail in stress analysis. Wind force calculations, stress calculations and have been done in excel sheet referring to IS 875 and IS 6533.The analysis process and optimization of a steel chimney in accordance with IS codes.

Keywords:Chimney,Optimization, Steel Stack.

1. INTRODUCTION

Steel Chimneys are frequently known as steel stacks. The steel chimneys are made of steel plants and supported on foundation. The steel chimneys are cylindrical in shape. To provide larger base and greater stability, and to allow for easy entrance of flue gases, the lower portion of the steel chimney is widened or flared out. The widened section of the chimney at the base reduces the unit stresses in the steel at the base of the chimney. The steel chimneys are constructed for the emission of flue gases to such a height that the gases do not contaminate the surrounding atmosphere.

The cross-sectional area of the steel chimney is kept large enough to allow the passage of burnt gases. The cross-sectional area of the steel chimneys depends on the type and quantity of fuels to be used in plant, available draft for carrying the burnt gases up the chimney. The height of the steel chimney is kept to provide the required draft. "The draft is defined as the difference between the absolute gas pressure at any point in the steel chimney and the ambient atmosphere pressure." The draft depends on the height of the steel chimney above sea level, the type of fuel to be burnt, the type of furnace and the temperature of the burnt gases.

1.1 Types of Steel Chimney

The steel chimneys are of two types:

1. Self-supporting steel chimney
2. Guyed steel chimney

➢ **Self-supporting Steel Chimney**

A self-supporting steel chimney or stack is made of steel plates and supported on foundations. When the lateral forces (wind or seismic forces) are transmitted to the foundation by the cantilever action of the chimney, then the chimney is known as self-supporting. The chimney together with the foundation remains stable under all working conditions, without any additional support. The self-supporting steel chimneys are made up to10m diameter and from 50 m to 100 m in height.

➢ **Guyed Steel Chimneys**

In high steel chimneys, the mild steel wire ropes or guys are attached to transmit the lateral forces. Such steel chimneys are known as "guyed steel chimneys." In guyed steel chimneys, all the externally applied loads (wind, seismic force etc.) are not totally carried by the chimney shell. These attached guys or stays do share these applied loads. These chimneys may be provided with 1, 2, or 3 sets of guys. In each set of guys 3 or 4 m sometimes 6 wires are attached to the collars. A particular type of steel chimney is selected depending on the advantage and disadvantages with reference to economy.The Objectives of Study are

1. To study the design steel chimney for industrial structure considering wind loading.
1. To decide the single stack in number of small segment to reduce the section diameter.
2. To Develop an understanding of optimal design of Steel chimney structure.
3. To derive the various combination of segmentation of chimney and compare the performance of chimney.

➢ **Selection of steel chimney**

Factors considered for selection of steel chimney type are as follows:

1. Cost effectiveness

2. Number of units, equipment type, and fuel type to be used.
3. If chimney used for boilers, consider surface area, output efficiency, draft requirements.
4. Equipment operation mode.
5. Flue gas temperature before entering the chimney and its variation.
6. Specific weight, dust quantity, and data about flue gas aggressiveness.
7. Local statutory regulations relating to height, ash dispersion, provision for earthling aviation warning lamp, and health.
8. Erection mode
9. Select lining type based on composition of the flue gases.

2. LITERATURE REVIEW

Ali VasalloBelver, et.al, (2012) A simplified fluid–structure interaction approach is used to study the dynamic behaviour of a particular 90 m steel chimney under vortex-induced vibrations. Navier–Stokes equations for incompressible flow are solved in 2D in several transverse planes of the line-like structure. The resultant pressure field is introduced using standard FEM interpolation techniques, together with the dynamical behaviour of the structure and its boundary conditions.

Shuangping Duan, (2019)A solar chimney is an important green architectural element that aides the ventilation, heating and cooling of buildings. The proper design of a solar chimney requires a reliable model to estimate the airflow rate generated by solar radiation. Previous analytical models are based on inputs such as temperature, density or heat supply, which are difficult to predict the ventilation performance of a solar chimney at the preliminary design stage. This paper presents a new predictive model for the airflow rate in a typical solar chimney based on inputs such as incident solar radiation intensity and the emissivity of the glass cover considering both room and chimney cavity configurations.

3. METHODOLOGY

Design Manual Calculations:

- Type - Self-supporting steel chimney
- Height - 72 m
- Top Diameter - 3m
- Soil Bearing Capacity - 200kN/m2
- Thickness of Fire Brick - 100mm
- Location of terrain category - 2

STEP 1)Total Height = 72 m

$$\text{Height of Flare} = \frac{1}{3} \times \text{Total Height}$$

Diameter of flare = (1.6 × 3)

=4.8 m

STEP 2)Computation of Wind Pressure

Design of wind speed (V_Z)

$V_Z = V_b \times K_1 \times K_2 \times K_3$ [IS875 Part 3, cl. 5.3.]

V_b= Basic wind speed

K_1 = Probability factor

K_2 = Terrain Roughness & height factor

K_3 = Topography Factor

$P_Z = 0.6\, V_Z^2$

P= $P_Z \times D \times Z \times S$[IS875 Part 3, cl. 5.4.]

Where, D = Diameter of Section

z = Height of Segment

S = Shape Factor = 0.7

STEP 3) Design of Chimney Shell

1) Stresses due to self-weight (f_s) = 0.0785h

2) Stresses due to weight of lining (f_l) = $\frac{2h}{t}$

3) Stresses due to wind (f_w) = $\pm \frac{4Mw}{\pi d^2 t}$

STEP4) Computation of Actual Weight

W_s =771.806 KN

W_l = 1447.644 KN

Increase W_t by 5 % to account for lap stiffness, platforms, ladder etc.

Total = (2219.452) x 1.05

Total Weight = 2330 KN

STEP5) Check Earthquake Force

Area of c/s at Base = π × b × t
= π × 4.8 × 0.01

$= 0.241\ m^2$

$$\text{Factor} = \frac{\sqrt{2H}}{r} = \frac{\sqrt{2\times 72}}{2.4} = 42.43$$

Table CT = 78.2 CV = 1.45

$$T = CT\sqrt{\frac{WH}{EAg}}$$

T = 1.473 Sec.

$$Mx = \alpha h Wh\left(0.6\left(\frac{X}{H}\right)^{\frac{1}{2}} + 0.4\left(\frac{X}{H}\right)^{\frac{1}{2}}\right)$$

M_x= 2259.86 KN-m.

4. RESULTS AND DISCUSSION

1. Optimization for Chimney

To obtained the optimum solution for the 72 m steel chimney different cases are studied with total chimney divided into different segments. Cost optimization and cost comparison are shows following with different segment heights.

Table No 4.1. Segment Height 3 M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
3	4.8	4.725	3	8.59575	4.19	0.4	1315.66	197349
6	4.725	4.65	3	16.9089	6.58	0.4	2066.12	309918
9	4.65	4.575	3	24.93945	8.53	0.4	2678.42	401763
12	4.575	4.5	3	32.6874	10.22	0.4	3209.08	481362
15	4.5	4.425	3	40.15275	11.72	0.4	3680.08	552012
18	4.425	4.35	3	47.3355	13.08	0.4	4107.12	616068
21	4.35	4.275	3	54.23565	14.32	0.4	4496.48	674472
24	4.275	4.2	3	60.8532	15.47	0.4	4857.58	728637
27	4.2	4.125	3	67.18815	16.52	0.4	5187.28	778092
30	4.125	4.05	3	73.2405	17.5	0.4	5495	824250
33	4.05	3.975	3	79.01025	18.41	0.4	5780.74	867111
36	3.975	3.9	3	84.4974	19.25	0.4	6044.5	906675
39	3.9	3.825	3	89.70195	20.03	0.4	6289.42	943413
42	3.825	3.75	3	94.6239	20.76	0.4	6518.64	977796
45	3.75	3.675	3	99.26325	21.43	0.4	6729.02	1009353
48	3.675	3.6	3	103.62	22.06	0.4	6926.84	1039026
51	3.6	3.525	3	107.6942	22.63	0.4	7105.82	1065873
54	3.525	3.45	3	111.4857	23.16	0.4	7272.24	1090836
57	3.45	3.375	3	114.9947	23.64	0.4	7422.96	1113444
60	3.375	3.3	3	118.221	24.08	0.4	7561.12	1134168
63	3.3	3.225	3	121.1648	24.48	0.4	7686.72	1153008
66	3.225	3.15	3	123.8259	24.84	0.4	7799.76	1169964
69	3.15	3.075	3	126.2045	25.15	0.4	7897.1	1184565
72	3.075	3	3	128.3004	25.43	0.4	7985.02	1197753

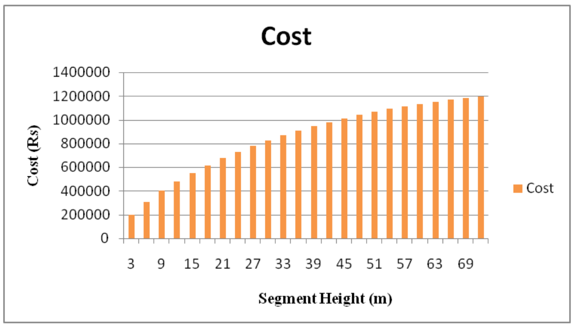

Figure No. 4.1: Segment Height 3 M

The fig.4.1 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 3m height at the bottom of the chimney cost is minimum Rs.197349and maximum cost at top of chimney is Rs.1197753.

Table No 4.2. Segment Height 4 M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
4	4.8	4.7	4	11.4296	5.07	0.4	1591.98	238797
8	4.7	4.6	4	22.3568	7.93	0.4	2490.02	373503
12	4.6	4.5	4	32.7816	10.24	0.4	3215.36	482304
16	4.5	4.4	4	42.704	12.21	0.4	3833.94	575091
20	4.4	4.3	4	52.124	13.95	0.4	4380.3	657045
24	4.3	4.2	4	61.0416	15.5	0.4	4867	730050
28	4.2	4.1	4	69.4568	16.89	0.4	5303.46	795519
32	4.1	4	4	77.3696	18.15	0.4	5699.1	854865
36	4	3.9	4	84.78	19.29	0.4	6057.06	908559
40	3.9	3.8	4	91.688	20.33	0.4	6383.62	957543
44	3.8	3.7	4	98.0936	21.26	0.4	6675.64	1001346
48	3.7	3.6	4	103.9968	22.11	0.4	6942.54	1041381
52	3.6	3.5	4	109.3976	22.87	0.4	7181.18	1077177
56	3.5	3.4	4	114.296	23.55	0.4	7394.7	1109205
60	3.4	3.3	4	118.692	24.15	0.4	7583.1	1137465
64	3.3	3.2	4	122.5856	24.67	0.4	7746.38	1161957
68	3.2	3.1	4	125.9768	25.12	0.4	7887.68	1183152
72	3.1	3	4	128.8656	25.51	0.4	8010.14	1201521

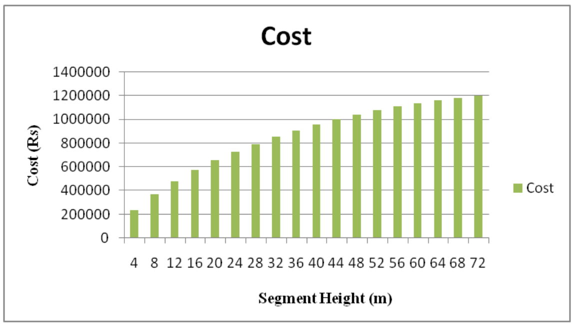

Figure No. 4.2: Segment Height 4 M

The fig.4.2 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 4m height at the bottom of the chimney cost is minimum Rs.238797and maximum cost at top of chimney is Rs.1201521.

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Table No 4.3. Segment Height 6 M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
6	4.8	4.65	6	17.0502	6.62	0.4	2078.68	311802
12	4.65	4.5	6	32.97	10.28	0.4	3227.92	484188
18	4.5	4.35	6	47.7594	13.16	0.4	4132.24	619836
24	4.35	4.2	6	61.4184	15.56	0.4	4885.84	732876
30	4.2	4.05	6	73.947	17.61	0.4	5529.54	829431
36	4.05	3.9	6	85.3452	19.38	0.4	6085.32	912798
42	3.9	3.75	6	95.613	20.9	0.4	6562.6	984390
48	3.75	3.6	6	104.7504	22.22	0.4	6977.08	1046562
54	3.6	3.45	6	112.7574	23.33	0.4	7325.62	1098843
60	3.45	3.3	6	119.634	24.57	0.4	7714.98	1157247
66	3.3	3.15	6	125.3802	25.05	0.4	7865.7	1179855
72	3.15	3	6	129.996	25.66	0.4	8057.24	1208586

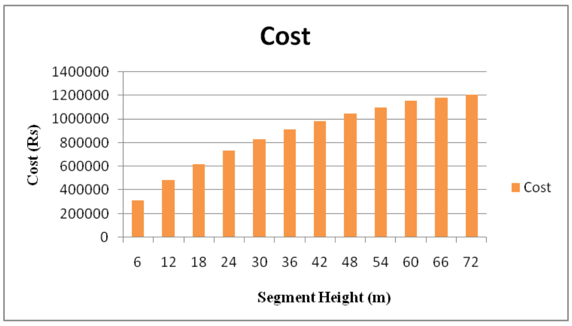

Figure No. 4.3: Segment Height 6M

The fig.4.3 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 6m height at the bottom of the chimney cost is minimum Rs. 311802and maximum cost at top of chimney is Rs. 1208586.

Table No 4.4. Segment Height 8M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
8	4.8	4.6	8	22.608	7.99	0.4	2508.86	376329
16	4.6	4.4	8	43.2064	12.31	0.4	3865.34	579801
24	4.4	4.2	8	61.7952	15.62	0.4	4904.68	735702
32	4.2	4	8	78.3744	18.31	0.4	5749.34	862401
40	4	3.8	8	92.944	20.51	0.4	6440.14	966021
48	3.8	3.6	8	105.504	22.32	0.4	7008.48	1051272
56	3.6	3.4	8	116.0544	23.79	0.4	7470.06	1120509
64	3.4	3.2	8	124.5952	24.94	0.4	7831.16	1174674
72	3.2	3	8	131.1264	25.8	0.4	8101.2	1215180

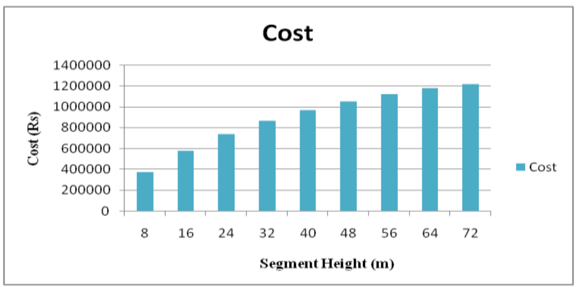

Figure No. 4.4: Segment Height 8M

The fig.4.4 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 8 m height at the bottom of the chimney cost is minimum Rs. 376329and maximum cost at top of chimney is Rs. 1215180.

Table No 4.5. Segment Height 12M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
12	4.8	4.5	12	33.5352	10.39	0.4	3262.46	489369
24	4.5	4.2	12	62.5488	15.75	0.4	4945.5	741825
36	4.2	3.9	12	87.0408	19.64	0.4	6166.96	925044
48	3.9	3.6	12	107.0112	22.53	0.4	7074.42	1061163
60	3.6	3.3	12	122.46	24.66	0.4	7743.24	1161486
72	3.3	3	12	133.3872	26.1	0.4	8195.4	1229310

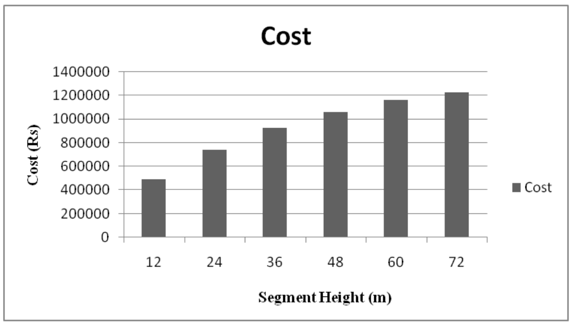

Figure No. 4.5: Segment Height 12M

The fig.4.5 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 12 m height at the bottom of the chimney cost is minimum Rs. 489369 and maximum cost at top of chimney is Rs. 1229310.

Table No 4.6. Segment Height 18M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
18	4.8	4.35	18	49.455	13.47	0.4	4229.58	634437
36	4.35	3.9	18	88.7364	19.89	0.4	6245.46	936819
54	3.9	3.45	18	117.8442	24.036	0.4	7547.304	1132096
72	3.45	3	18	136.7784	26.54	0.4	8333.56	1250034

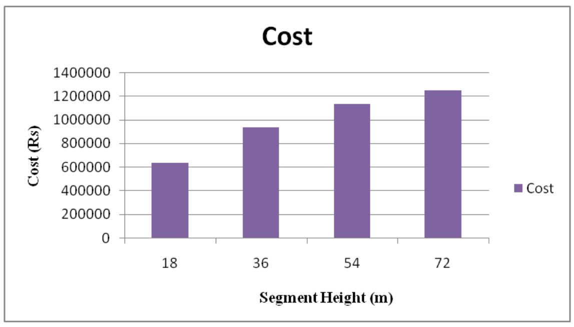

Figure No. 4.6: Segment Height 18M

The fig.4.6 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 18 m height at the bottom of the chimney cost is minimum Rs. 634437 and maximum cost at top of chimney is Rs. 1250034.

Table No 4.7. Segment Height 24M

Chimney Height	Diameter (Top)	Diameter (Bottom)	Segment Distance	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Cost
24	4.8	4.4	24	64.8096	16.8	0.4	5275.2	791280
48	4.2	3.8	24	111.5328	23.17	0.4	7275.38	1091307
72	3	2.6	24	126.6048	25.21	0.4	7915.94	1187391

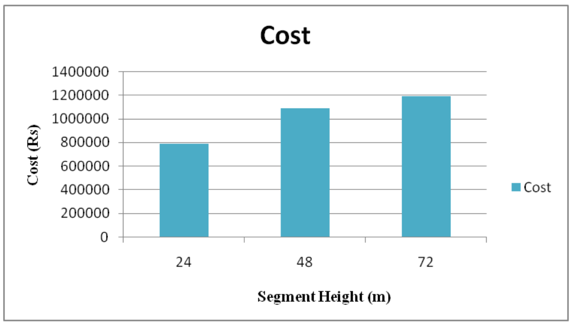

Figure No. 4.7: Segment Height 24M

The fig.4.7 shows that the variations in cost of chimney at different height. This Graph shows the cost of chimney at every 24 m height at the bottom of the chimney cost is minimum Rs. 791280 and maximum cost at top of chimney is Rs. 1187391.

Table No 4.8. Cost Comparison

Segments	Segments Distance	Diameter (Top)	Diameter (Bottom)	Volume (m3)	Area (m2)	Thickness	Weight of Steel (Kg)	Optimal Cost	Conventional Cost
24	3	3.07	3	128.3	25.43	0.4	7985.0	1197753	1215180
18	4	3.1	3	128.8	25.51	0.4	8010.1	1201521	1215180
12	6	3.15	3	129.9	25.66	0.4	8057.2	1208586	1215180
6	12	3.3	3	133.3	26.1	0.4	8195.4	1229310	1215180
4	18	3.45	3	136.7	26.54	0.4	8333.5	1250034	1215180
3	24	3	2.6	126.6	25.21	0.4	7915.9	1187391	1215180

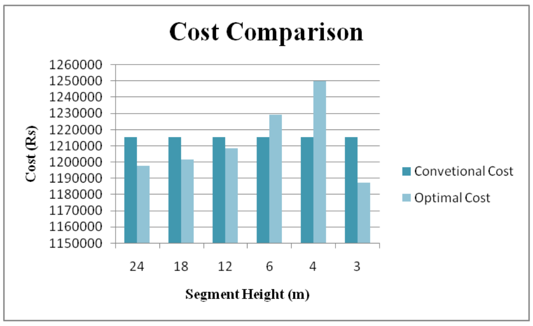

Figure No. 4.8: Cost Comparison

The fig.4.8 shows that the cost comparisonof different segment of chimney. This Graph details with cost comparison in the convectional cost with the optimal cost of chimney height at 72 m. This shows that optimization is more cost effective as number of segments goes on increases.

5. CONCLUSIONS

1. The designed steel chimney height of 72 meter was aiming to investigate its performance of optimization of chimney in increasing segmentation and reducing the section diameter. Steel chimneys are exposed to various harmful mechanical – chemical – thermal actions. Complex loads can cause various types of damage influencing the structure integrity. Based on the visual inspection and past literature study, it is clear that failure initiation of windshield was brought about by cumulative influence of the factors that have affected the local distribution of stresses such as:
   - ➢ Influence of the significant reduction of moment of inertia at the root section of the chimney structure.
   - ➢ Absence of the flue duct opening edge reinforcements.
   - ➢ Influence of prompt incursion of the stiffening rib in the chimney structure.
   - ➢ Negative influence of the welding seams ending at the flue duct opening upper edges.
2. Influence of corrosion in the corners of flue duct entries in windshield Influence of the proximity of stiffening rib top and the flue duct opening upper corners.
3. The work is presented for optimal design of 72m steel chimney structure. While doing optimization cases are considered, divided total 72m chimney into seven cases. The optimum values for cost steel are then compared with the design conventional values. This results shows that optimization is more cost effective as number of segments go on increases.

6. REFERENCES

1. Ahmed Abdeen, Ahmed A. Serageldin, Mona G.E. Ibrahim, Abbas El-Zafarany, Shinichi Ookawara and Ryo Murata, "Solar chimney optimization for enhancing thermal comfort in Egypt: An experimental and numerical study" Solar Energy, Vol No - 180, Pp. No - 524–536, 2019.
2. Ali VasalloBelver, Antolın LorenzanaIba and CarlosE.Lavın Martın, "Coupling between structural and fluid dynamic problems applied to vortex shedding in a 90 m steel chimney" J. Wind Eng. Ind. Aerodyn, Vol - 100, Pp. No - 30–37, 2012.
3. Hussain H. Al-Kayeim, Mohammed A. Aurybi and Syed I.U. Gilani, "Influence of canopy condensate film on the performance of solar chimney power plant" Renewable Energy, Vol. No -136, Pp. No - 1012 - 1021, 2019.
4. Hussain H. Al-Kayiem, Mohammed A. Aurybi, Syed I. U. Gilani, Ali A. Ismaeel and Sanan T. Mohammad, "Performance Evaluation of Hybrid Solar Chimney for Uninterrupted Power Generation" Energy, 2018.
5. José Carlos Frutos Dordellya, Mohamed El Mankibi, Letizia Roccamena, Gabriel Remion, and Jesus Arce Landa, "Experimental analysis of a PCM integrated solar chimney

under laboratory conditions" Solar Energy, Vol. No - 188, Pp. No - 1332–1348, 2019.
6. IS 6533 Part 1; 1989, "Design and Construction of Steel Chimney", Bureau of Indian Standards, New Delhi (2002).
7. IS 6533 Part 2; 1989, "Design and Construction of Steel Chimney", Bureau of Indian Standards, New Delhi (2005).
8. IS800-2007, Code of practice Steel structures, Bureau of Indian standard, New Delhi.
9. IS:875 (Part 3) – 1987 Wind Loads on Building and Structures.