Design of Self Supporting Steel Chimney for different wind zone

Ayush Sharma[1] Abhinav Singh[2]
[1]M.Tech Scholar, Department of Civil Engineering, Swami Vivekanand Subharti University, Merrut, Uttar Pradesh, India
[2]Assistant Professor, Department of Civil Engineering, Swami Vivekanand Subharti University, Merrut, Uttar Pradesh, India

Abstract— **This paper deals with the self supporting flared steel chimney of 60m height above ground level. The steel chimney is made according to IS-6533 (1989) and analysed for wind load as per IS-875 (2015). Here steel chimney is design for all six wind zone having speed 33 m/s, 39 m/s, 44 m/s, 47 m/s, 50 m/s and 55 m/s. The study parameters like static force, static moment, maximum compressive stress and maximum tensile stress are compared for all six zone. For analysis a chimney of height 60m is divided into six part or section of 10m height. In maximum cases section 6 of wind zone VI are critical. The thickness and weight of chimney is almost equal in every case and also the maximum compressive force per unit length are compared in different wind speed which is maximum for zone VI.**

Index Terms— **Maximum Compressive stress, Self supporting Steel Chimney, Static force, Static moment, Thickness of steel plate, Weight of chimney, Wind load.**

I. INTRODUCTION

The chimney is developed by using steel plates which is important structure in industry to release flue gases at appropriate height so that its effect is least in surrounding area or atmosphere. Steel chimney are made in cylindrical shape and provided with large diameter so that hot gases move up in chimney and discharge at good height.

Self supporting flared Steel chimney provided with wide lowered portion which helps to reduce the stresses at the base steel and transfer the load to the foundation. In calculation we consider the flared portion height is one-third of the height of the chimney as flared portion height should lie between one-eighth to one-fourth of height of the chimney and the bottom of flange portion is taken as 1.6 times the diameter as it should be 40% more. For the designing of steel chimney which is self supported, different Standards of India are used that is IS-6533 (1989) Part-1 and Part-2, IS-875 (2015) Part-3. There are two types of steel chimney are:

- Self supporting steel chimney
- Guyed steel chimney.

In steel chimney (self supported), horizontal forces like seismic or wind forces transferred by the cantilever action to ground but in guyed steel chimney, lateral forces transferred by the mild steel guys to foundation. Self supporting chimney are provided with lining but in some cases it is left unlimited then also it gives better result. The various lining material used are common brick, fire brick, acid resisting brick, refractory concrete, guniting with sand and cement mixture etc.

There are six wind zone in India based on wind speed which we calculate wind load. The wind intensities are 33 m/s, 39 m/s, 44 m/s, 47 m/s, 50 m/s, 55 m/s. We design chimney of fixed height for these wind speed and analyse the Difference.

1.1 Objective

The main purpose of this work is to design self supporting flared steel chimney of height 60m as per IS: 6533-1989 code manually for all six wind zone and wind load is designed as per IS: 875-2015 (Part-3). After design we scrutinized all the selected chimney of different wind zone using manual calculation so that we compare different parameters such as static moment, static force, maximum compressive and tensile stresses etc. At last on the basis of maximum moment we calculate the maximum compressive force per unit length and compare with different zone.

II. LITERATURE REVIEW

A literature review is performed on the analysis of self supporting steel chimney with main focus in different wind zone effects. A huge number of literature are available on self supporting steel chimney. This portion gives you a brief report on literature review for this project.

Tandan and Choudhari, (2023) analyse and design steel chimney in STAAD Pro (i.e. Structural analysis and design program software) as chimney independently handle wind load, seismic load, dead load and other forces acting on it. Chimney subjected to high value of wind and less risk of ground motion (eathquake), wind loads were compared to be much impactful so chimney is designed for wind forces. Also the maximum bending moment is a continuous function of the height to base ratio in self supporting steel chimney. [1]

Patidar, et al, (2021) shows interrelation among geometric ratio of chimney made up of steel and deflection due to dynamic and static analysis. The deflection is maximum in chimney with lower diameter as compared by chimney with larger diameter as dynamic force effect is maximum in less diameter chimney. When geometric ratio is constant dynamic load produce more deflection as compared to static load. In analysis it is seen that dynamic force below some level from top is lower as compared to static force. [2]

Kanerkar, et al, (2020) studied on the effect of geometric parameter on unlined self supported steel chimney experience different wind intensity in particular earthquake zone with varied height to base ratio. Also the effect of providing manhole is studied. Manhole affect the stiffness of a chimney as maximum bending stress occur in chimney with manhole so account opening that is manhole in design of chimney. [3]

Dhopat, et al, (2018) study the steel chimney (self supported) behaviour with the change in ratio of top to base diameter and height to base diameter and analysed for wind load and seismic load. Effect of geometric parameter is analysed using MS Excel and STAAD Pro. Base moment is almost proportional to top to base diameter ratio. Base shear and base stress increase with increase of base diameter ratio. [4]

Singh and Parihar, (2018) analyse steel chimney according to standards of India. The impact of geometry on the steel chimney design is studied. For analysis of tubular cross-section, chimney act as cantilever column. Dimension of self supporting steel chimney is selected based on environment and the main load consider are wind and seismic load. [5]

Jadhav and Talikoti, (2017) use ANSYS software for analysis of steel chimney (self supported). The paper shows chimney model having greater thickness and larger diameter shows excellent result. This two parameter control the shear and deformation of chimney. It is concluded that deformation of chimney can be reduced if we increase the diameter and thickness of chimney. [6]

Sitara, et al, (2012) analyse the response of mild steel chimney under wind load in which three chimney of 55m height are considered subjected to three wind load 55m/s, 50m/s, 47m/s. The parameter like static force, dynamic force, dynamic moment, thickness of chimney and static moment were compared of three chimney. The thickness is found to be same for all chimney even the basic wind speed is varying. [7]

III. DESIGN METHODOLOGY

3.1 Forces acting on Steel Chimney

Steel chimney (self supported) experiences many loads such as seismic load, wind load and temperature load besides dead weight of the structure. Chimney is a tall Structure so wind load is very crucial as safety point of view. Seismic load is a natural load which is dynamic in nature. Seismic force is considered as cyclic for short period of time for calculating it. In order to create chimney as seismic tolerant we have to find the chimney behaviour with respect to the ground movement, as it is important for seismic evaluation.

3.1.1 Dead load on Chimney

The dead load of chimney acts vertically to the structure and the dead load of the access ladder, rain cap, helical strake, platform etc. are also act vertically

3.1.2 Lining Weight

The lining weight of the chimney is also act vertically to the structure. The thickness is generally taken as hundred millimeter. The brick lining unit weight is 20 KN/m^3.

Table.1 Forces acting on chimney

Forces	Formula	Abbreviation
Dead load of Chimney	Chimney weight = Weight density × Volume Chimney weight = 78.5π.d.t.h	d = Diameter of chimney (m) h = Chimney height (m) t = Thickness of steel plate (m) Weight density = 78.5 KN/m^3
Weight of Lining	W_L = 20π.d.(0.1h)	d = Diameter of chimney (m) h = Chimney height (m)
Wind Pressure	Design wind speed(V_z)= $V_b.K_1.K_2.K_3$ Wind pressure(P_z) = 0.6 V_z^2 (F_z) = K. P_z.. (D.ΔZ)	V_z = Speed of wind at Z height (m/s); K_1 = Probability risk factor; K_2 = Size factor depends on height, structure and terrain; K_3 = Factor consider for topography. P_z = Pressure of wind at Z height (N/m^2); V_z = Speed of wind at Z height (m/s), F_z = Wind force or static force at height z (KN): D = Diameter of chimney(m); ΔZ = Segment height of chimney (m); K = Shape factor.

3.1.3 Pressure of Wind

Pressure of wind acts laterally to the structure which depend on the width, height, location and shape of the structure as wind speed varies in different location. During designing steel chimney we divide chimney into number of segment and design each is design separately.

3.1.4 Earthquake Forces

The Earthquake forces act laterally to the chimney. The load combination that is taken in order to calculate stresses in steel chimney are:

- Dead Load + Wind Load +Temperature Effect.
- Dead Load + Seismic Load + Temperature Effect.

Above these two combination only one is selected which is worst means having high magnitude as out of wind load and earthquake load we only considered one load.

3.2 Design Procedure

For the self supporting flared steel chimney design various steps are followed:

1) First basic dimension of chimney is found by using IS 6533 part-2 provision in which height of flared portion is taken as (1/3)H and the diameter of flared portion is taken as 1.6 times the diameter of cylindrical portion.

2) Second step is computation of wind pressure as per IS 875 Part- 3 in which we divide entire chimney into section and find the value of design wind speed and with the help of this wind pressure is calculated for different section.

3) Third step is to determine overturning moment due to wind force for each section which is determined by multiplying wind force with height of chimney from top to the point where wind force act.

4) Fourth step is to find thickness for each section as per IS 6533 Part 2:1989. According to code least shell thickness according to stability is taken as maximum of D/500 or 6mm (where D is the dia. of cylindrical portion) which is effective thickness used in design of different section. Total thickness consider corrosion which depends upon the life of chimney, type of steel material, lined and unlined internal external surface.

5) Fifth step is to design chimney shell for which stresses due to chimney weight, weight of lining and wind is considered and check for each section that it lie within the permissible stresses. Permissible stress is found by relating Diameter to thickness ratio with effective height to diameter ratio from table in Indian Standard IS 6533 (Part 2): 1989.

6) Sixth step is to calculate actual weight of chimney which is the sum of weight of steel, weight of lining and we take 5% of above two weight to account for lap, stiffness, platform, ladders etc. With the help of total weight maximum compressive force per unit length is calculated.

3.3 Problem Statement

Design a steel chimney which is self supported having height of sixty meter (60m) and the diameter of the cylindrical part of the chimney is 4m for all wind zone. The thickness of fire brick lining is 100mm. The topography at the site is almost flat and the location is of terrain category 2.

Wind zone	Speed of wind in m/sec	Height (m)	Top dia. (m)	Bottom dia. (m)	Flared height (m)
Zone I	33	60	4	6.4	20
Zone II	39	60	4	6.4	20
Zone III	44	60	4	6.4	20
Zone IV	47	60	4	6.4	20
Zone V	50	60	4	6.4	20
Zone VI	55	60	4	6.4	20

Table.2 Geometry of chimney

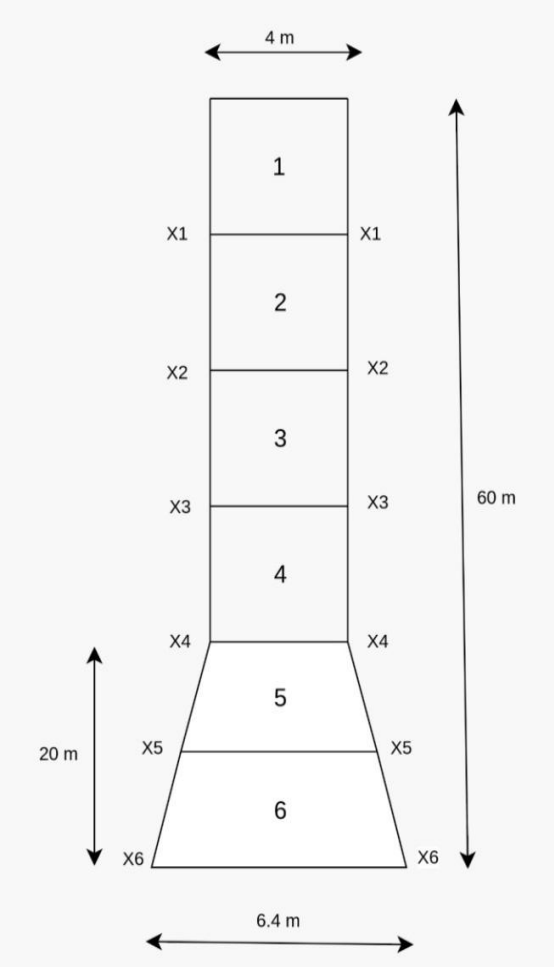

Fig. 3.1 Chimney diagram for all wind zone

IV. RESULT AND DISSCUSSION

4.1 Static Force

Static force in section (Sec.) 6 of all wind zone has maximum magnitude as compared to other section even when steel thickness is more for this section. In every particular zone (Z), it is seen that static force is reduced as we move down in chimney but after section 4 wind force increases as at that part flared portion start which increases area and wind force act on large area so large effect is seen.

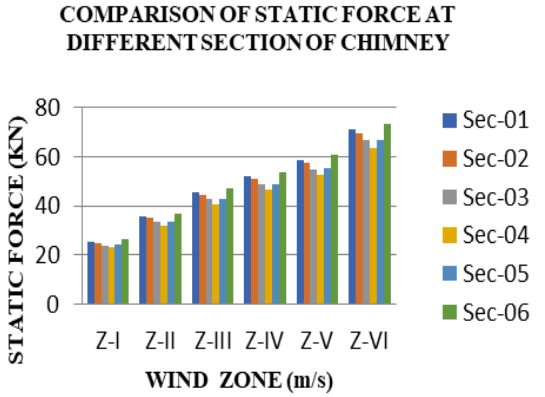

Fig. 4.1 Comparison between Static force and Wind zone

	Sec-01	Sec-02	Sec-03	Sec-04	Sec-05	Sec-06
Zone I	25.64	25.04	23.98	22.94	24.08	26.52
Zone II	35.82	34.97	33.5	32.05	33.64	37.05
Zone III	45.58	44.5	42.63	40.79	42.82	47.16
Zone IV	52.02	50.8	48.62	46.55	48.86	53.81
Zone V	58.87	57.49	55.06	52.68	55.29	60.9
Zone VI	71.23	69.55	66.62	63.747	66.90	73.68

Table.3 Static force value

4.2 Static Moment

In every zone the section 6 experience maximum moment as all section wind forces are considered in it with respect to base of chimney which show section 6 is critical for overturning moment. Wind speed plays a very crucial role here as Zone VI having very high wind speed i.e. 55m/s because of which every section of this zone experience greater magnitude compared to all other wind zone.

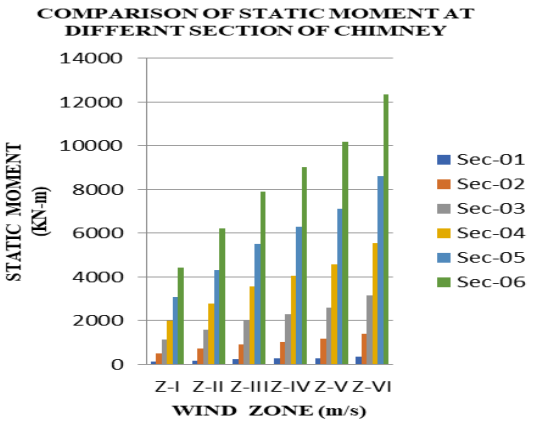

Fig. 4.2 Comparison between Static moment and Wind zone

	Sec-01	Sec-02	Sec-03	Sec-04	Sec-05	Sec-06
Zone I	128.2	509.8	1136.6	1998.1	3094.6	4444.3
Zone II	179.1	712.2	1587.7	2790.9	4322.7	6207.9
Zone III	227.9	906.36	2020.5	3552	5501.5	7900.9
Zone IV	260.1	1034.3	2305.8	4053.3	6277.9	9015.8
Zone V	294.3	1170.5	2609.5	4587.2	7104.8	10203.4
Zone VI	356.1	1416.2	3157.2	5550.0	8596.1	12345.2

Table.4 Static moment value

4.3 Maximum Compressive Stress

Maximum compressive stress occur in section 4 as from section 1 to section 4 less thickness of chimney shell is provided as compared to other section as it is safe within permissible stress but for section 5 and 6 different thickness is taken which automatically reduces the stress. Here it is seen more the thickness of steel plate, less the compressive stress.

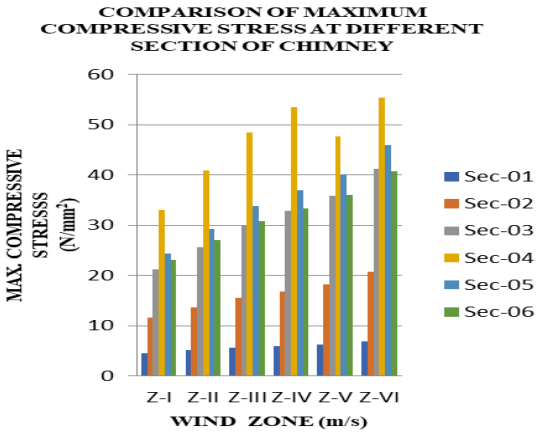

Fig. 4.3 Comparison between Maximum compressive stress and Wind zone

	Sec-01	Sec-02	Sec-03	Sec-04	Sec-05	Sec-06
Zone I	4.56	11.64	21.16	33.01	24.39	23.14
Zone II	5.06	13.65	25.64	40.90	29.21	27.06
Zone III	5.55	15.58	29.95	48.47	33.84	30.82
Zone IV	5.87	16.85	32.79	53.45	36.88	33.29
Zone V	6.21	18.21	35.81	47.64	40.13	35.93
Zone VI	6.82	20.65	41.26	55.30	45.98	40.69

Table.5 Maximum compressive stress value

4.4 Maximum Tensile Stress

Maximum tensile stresses is seen in section 4 of all zone and shows an increasing trend from section 1 to section 4. Comparable stresses is seen in section 3 and section 5 with different thickness.

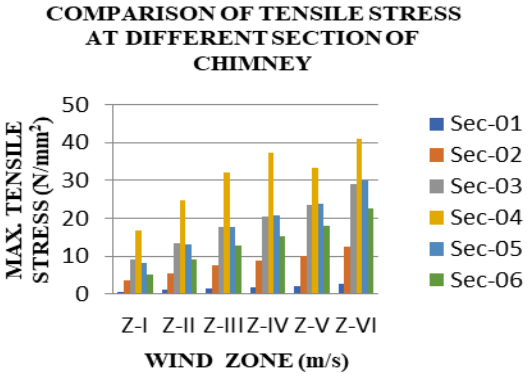

Fig. 4.4 Comparison between Maximum tensile stress and Wind zone

Table.6 Maximum tensile stress value

	Sec-01	Sec-02	Sec-03	Sec-04	Sec-05	Sec-06
Zone I	0.49	3.50	8.95	16.73	8.21	5.15
Zone II	0.99	5.51	13.43	24.62	13.03	9.07
Zone III	1.48	7.44	17.74	32.19	17.66	12.83
Zone IV	1.80	8.71	20.58	37.17	20.70	15.30
Zone V	2.14	10.07	23.60	33.36	23.95	17.94
Zone VI	2.75	12.51	29.05	41.02	29.80	22.7

4.5 Thickness of Chimney

For 60m height of chimney, 18mm thickness of steel plate is safe in every zone. As with 18mm thickness

maximum compressible and tensile stresses of all section lies within the permissible value of stresses. Upto section 3 of all wind zone 12mm thickness is safe but section 4, 5 and 6 fail for 12 mm steel plate in Zone V and Zone VI. Section 5 and section 6 is safe in all wind zone for 16mm and 18mm thickness respectively.

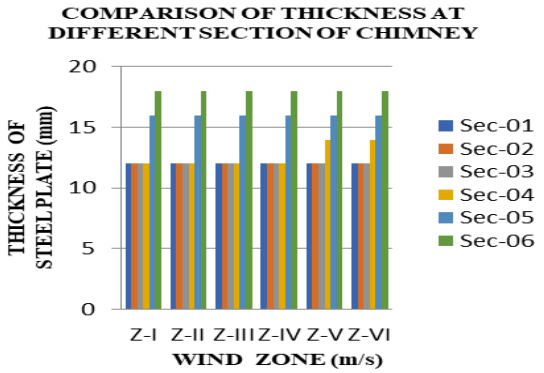

Fig. 4.5 Comparison between Thickness of steel plate and Wind zone

Table.7 Thickness of steel plate

	Sec-01	Sec-02	Sec-03	Sec-04	Sec-05	Sec-06
Zone I	12	12	12	12	16	18
Zone II	12	12	12	12	16	18
Zone III	12	12	12	12	16	18
Zone IV	12	12	12	12	16	18
Zone V	12	12	12	14	16	18
Zone VI	12	12	12	14	16	18

4.6 Weight of Chimney

Total weight of chimney is comparable in all zone as only 0.75% increase in Zone V and Zone VI so we can say that weight of chimney is similar for all six wind zone.

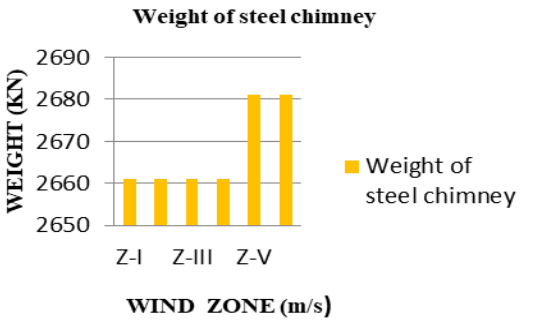

Fig. 4.6 Comparison between Weight of steel chimney and Wind zone

Table.8 Weight of steel chimney

	Total Weight of Chimney (KN)
Zone I	2661
Zone II	2661
Zone III	2661
Zone IV	2661
Zone V	2681
Zone VI	2681

4.7 Maximum compressive force per unit length

Maximum compressive force per unit length is a function of maximum moment occur in chimney and it is calculated with the help of weight of steel, lining and the base diameter of chimney. As wind VI has more wind speed as compared to other wind zone so maximum moment act in chimney which increases the compressive force per unit length, we can say that Zone VI is critical compared to other. As compared to Zone I maximum compressive force per unit length is 91% increased.

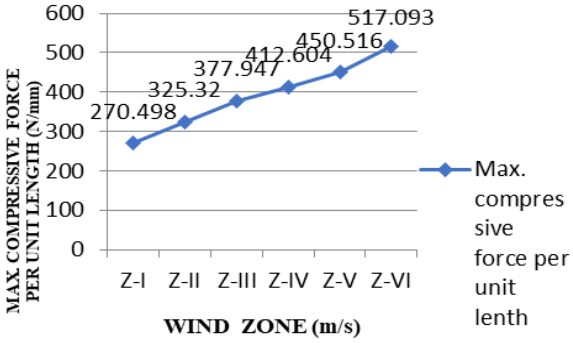

Fig. 4.7 Comparison between Maximum compressive force per unit length and Wind zone

Table.9 Maximum compressive force per unit length value

	Max. Compressive force per unit length (N/mm)
Zone I	270.498
Zone II	325.32
Zone III	377.947
Zone IV	412.604
Zone V	450.516
Zone VI	517.093

V. CONCLUSION

Based on the result obtained from the design of Steel Chimney (Self Supported) following conclusions are drawn

- The static force decreases from section 1 to section 4 but increases from section 5 to section 6 for all wind zone and the maximum static force developed in wind zone VI. The section 6 of all wind zone has maximum static force compared to other section.
- The maximum static moment developed in section 6 of all wind zone and the chimney in wind zone VI has maximum value of static moment in section compared to other wind zone.
- The maximum compressive and tensile stresses developed in chimney subjected to 55 m/s wind speed and in particular wind zone it is maximum in section 4 as after this thickness increased.
- The thickness is same upto section 3 for every wind zone but after that thickness increased for section 4, 5 and 6 to be safe from wind load.
- The total weight of chimney is same for Zone I to Zone IV but increases 0.75% for Zone V and Zone VI so there is not much change we can say that weight of chimney is similar for all six wind zone.
- Static moment increases the maximum compressive force per unit length which is maximum in section 6 of chimney subjected to 55m/s wind sp
- eed.

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