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Parametric Study of Self Supported Steel Chimney

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ABSTRACT

Present study deal with the investigation on parametric study on self supporting chimney considering in three different cities of India . The 65 m height and 80 m height of chimneys were selected and analyzed for wind force and seismic loadings for seismic zone III , IV and V, as per Indian standards (IS: 6533 -1989) and IS 1893(part 1) 2002. The wind loads were determined as per IS 875-1987 for the basic wind speed 47m/s, 50m/s and 55m/s. The thicknesses of the chimney were kept constant for this study. Significant increments were observed in displacement, bending moment and shear force for different seismic and wind zones. The results of self supporting steel chimney were obtained out with the above said parameters.

Introduction

The chimney is an important industrial structure for discharged waste hot flue gases or smoke or harmful gases at higher elevation in atmosphere. Steel chimney is subjected to static and dynamic loadings. Static analysis is carried out by static wind loading and dynamic analysis was carried out by considering both seismic loading as well as dynamic wind loadings. The chimney is idealized as cantilever segment with tubular cross section. In addition to the dead load, the wind loads and seismic loads were also acting on the steel chimney. Steel chimneys are ideally suited for process work where a low thermal capacity required and short heat-up period .Basic dimensions of a self-supporting steel chimney are for the most part acquired from the environmental consideration. Other essential geometrical consideration is limited by design code IS 6533 (Part 1 and 2): 1989 to obtained preferred mode of failure. B.S.K Reddy *et al.*,(2016) Study the effect of along and across wind effects on reinforced concrete chimney for I and VI wind zones of India. there results shows that, the wind zone –I^{st} across wind loads was governing and for wind zone-VI along wind loads was governing compared the across wind loads. D. Menon and P. Srinivasrao. (1997) Analyze wind and earthquake forces on tall reinforced concrete chimney on the combination of along and across wind loads of chimney as per ACI 307-98 code. They computed the governing load for designing of chimneys. R. Kumar and V. B. Patil.,(2013) carried out the parametric study of reinforced concrete chimney for different heights, diameter, earthquake zones, wind zones, types of soil and various loading conditions. They concluded that vortex induced oscillation depends upon wind speed and slenderness of chimney. The wind and earthquake oscillations have become more critical to influence on the response and design of chimney. Further they discuss the temperature and grade of concrete were also a design criteria especially near the top of chimney. The stresses induced at top of chimney due to moment due to wind and self weight is minimum and the temperature stresses were predominates. M. G. Shaikh et al.(2008), They carried out comparative study on the wind force and seismic loads for tall reinforced concrete chimney, for along wind. The wind analysis is done by peak factor method and for across wind by random response method. G. Murali et al., (2012) study the response of mild steel chimney under wind loads were compared. The results indicated that the forces and moments of C3 is higher than the C1 and C2.C1, C2, C3, chimney were located on that place having wind speed 47m/s, 50m/s and 55m. K. Sahoo, (2012) Analysis of Self Supporting Steel chimney and reported manhole increases the von mises stress resultant and top displacement in the self supported chimney. Manhole increases reduces the effective stiffness of a chimney as evident from the modal analysis results .Therefore it is important to consider manhole opening in the analysis and design of self supported chimney, K. Sahoo(2013), "Analysis of Self supporting steel chimney as per Indian Standard .It is found that the maximum moment and bending stress due to dynamic wind load in a self supported chimney are continuous function of the geometry .This study does not support the IS 6533 (Part 2) :1989 criteria for minimum top diameter of the chimney and minimum base diameter of the chimney. P. Kumar and A. Swarup (2016) the present study for the region Nashik, district of Maharashtra state in India. According to which wind load and earthquake load parameters were considered as per IS code such as IS4998(part-1):1992, IS 1893 (part-4):2005 and IS 875(part-3). The present study is carried only to study the merits and demerits of these types of chimney configuration based on the analysis, for such terrain conditions.

B. T. K Reddy, S M A M Hussain ,and R Parnati (2014) investigates the stresses, deflection and mode shapes of the chimney due to the presence of an inspection manhole. Maximum Von Mises stress, top deflection and mode shapes were calculated using finite element software ANSYS.

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The results show that, the due to the presence of manhole, the stresses are increased by approximately 1.5 times for the chimney and frequency is decreased by approximately 1.12 times. From the above studies its seems that the wind effect on steel chimney is most critical and unpredictable as compared to earthquake loading. For designing of steel chimney, height of chimney, base diameter, top diameter and thickness of chimney is most critical parameter. A detailed literature review is carried out as part of the present study on wind engineering, design and analysis of steel chimney as well as concrete chimney. The main objective of the present study was to explain the effect of wind loads and seismic loads with variation of height in the design of self-supported steel chimney. Estimation of wind effects (along wind and across wind), vortex shedding, vibration analysis, and gust factor were studied.

Design of a self-supporting steel chimney as per IS 6533 (Part-1 and 2): 1989 is discussed through example calculations. A study is carried out to understand the logic behind, geometrical limitations given in Indian Standard IS 6533 (Part-1 and 2): 1989. The relation between geometrical parameters and corresponding moments and shear were developed by using MathCAD software. Two parameters: (i) top-to-base diameter ratio and (ii) height-to-base diameter ratio were considered for this study. A numbers of chimneys with different dimensions analysed for dynamic wind load and seismic load. A total of 6 numbers self-supporting steel flared chimneys were analysed for dynamic wind load due to pulsation of thrust caused by wind velocity and also due to seismic load. These models are analysed by finite element software STAAD.Pro.

Description of the selected chimneys

In the present study a total of 6 numbers of chimney were selected in which 3chimneys are 65m height and 3 chimneys having 80 m height and these were located in Delhi, Bhubaneswar and Darbhanga with varying Seismic and Wind zone. The thickness and the diameter of flared base of the chimney were kept constant for all the cases in the study. The geometrical dimension and figure are shown in table 1 and figure 1 respectively.

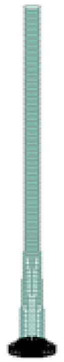


Fig 1. Geometry of steel chimney

The design of all the chimneys were according to code IS 6533 (Part 2): 1989, As per code the minimum base diameter is 1.6 times the top diameter of the chimney and minimum top diameter of the chimney should be one twentieth of the height of the cylindrical portion of the chimney. The chimney models were considered to be located at Delhi, Bhubaneswar with a basic wind speed of 47m/s,50/s,55m/s. Safe bearing capacity of the site soil at a depth 2.5m below the ground level is assumed to be 30kN/m^2. Fixity at the base of the chimney is assumed for the analysis.

These three chimneys of 65m high and 80m high were considered above ground level. In the analysis these 3 cities were classified according seismic and wind zones as listed in table 2.

Dynamic wind load as per is 6533 (part-2): 1989

The dynamic effect of wind load due to pulsation of thrust caused by wind velocity in addition to static wind load when the fundamental period of the chimney should be less than 0.25s and the fundamental period of vibration for a self-supporting chimney can be calculated as per IS-1893 Part-4:2006 as follows:

$$T = C_T \sqrt{\frac{W_t}{E_S A_{base} g}} H$$

Where, C_T Coefficient depending upon slenderness ratio, W_t= Total weight of the chimney,

H= total height of the chimney, E_S = Modulus of elasticity of the material of structural shell and A_{base}= Area of cross section at base of chimney shell. Stiffness of the flared chimney is generally approximated as two times the prismatic chimney.

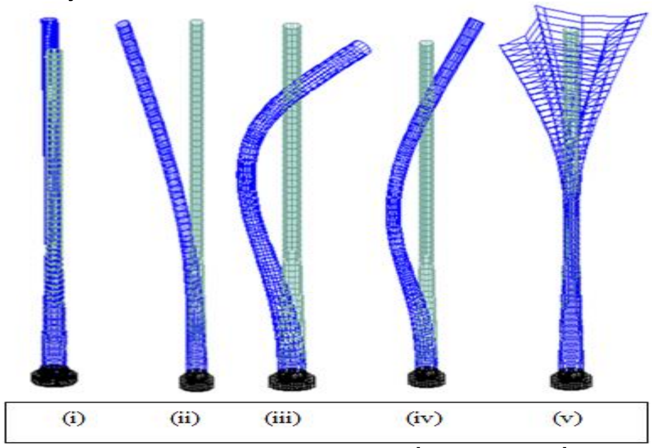


Fig 2. mode shapes (i)1st mode (ii)2nd mode (iii)3rd mode (iv)4th mode (v)5th mode.

Fig.2 presents the comparison of the fundamental mode shapes of a typical chimney obtained from empirical equation and Eigen value analysis. The figure 2, shows that the empirical equation for fundamental mode shape is closely matching the actual mode shape. Therefore, the use of empirical equation in the present study is justified. Dynamic effect of wind is influenced by a number of factors, such as, mass and its disposition along chimney height, fundamental period and mode shape. Values of dynamic components of wind load should be determined for each mode of oscillation of the chimney as a system of inertia forces acting at 'center of mass' location.

Table 1. Geometrical dimension of self-supporting steel chimney.

Height of chimney(m)	Flared height(m)	Height of cylindrical portion (m)	Bottom diameter(m)	Top diameter(m)
65	22	43	3.2	2
80	22	58	3.2	2

Table 2.Description of selected cities with respect to seismic and wind zones.

Cities	Height of chimney above GL in m	Seismic zone	Wind zone (basic wind speed) in m/s
Bhubaneswar	65 and 80	III	50
Delhi	65 and 80	IV	47
Darbhanga	65 and 80	V	55

The chimneys are essentially slender towers with almost uniformly distributed mass. Thus, the dynamic behavior of these towers is strongly influenced by the higher mode affects. All modes with total modal mass participation of 90% or more were included in the time-history analyses (Sezen et al., 2008). Modal analyses were carried out to determine the frequencies and mode shapes of the chimney. A total of 20 frequencies of the chimney were obtained. The frequencies and time periods for different shape for height of chimney were shown in Table 3. In figure 2, the first five mode shapes and frequencies of the chimney obtained from modal analyses were illustrated. The first four modes were translational modes namely in the z and x directions, whereas the fifth mode was the torsional mode.

Results from seismic analysis

From seismic analysis of self supporting steel chimney the deflection of chimney in zone IV and 5 with respect to chimney in zone III are 49.9% and 123.9% higher respectively for 65 m high chimney. Also the Deflection is 49.9% and 124.9% increasing in zone IV and zone V respectively as compared to zone III for 80m high. The Moment is 33.1% and 82.7% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 37.3% increasing in zone IV as compared to zone V for 65m height. Moment is 31.1% and 77.7% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 35.5% increasing in zone IV as compared to zone V for 80m height. The shear stress is 27.8 % and 69.5% increasing in zone IV and zone V respectively as compared to zone III.

Also deflection is 32.6% increasing in zone IV as compared to zone V for 65m height. Shear stress is 25.3 % and 63.4% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 30.3% increasing in zone IV as compared to zone V for 80m height.

Results from wind analysis

Comparing the different result obtained the deflection is 13.1% and36.9% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 20.9% increasing in zone IV as compared to zone V for 65m height. Deflection is 20.25% and 36.94% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 13.8% increasing in zone IV as compared to zone V for 80m height. Moment is 13.17% and 36.9% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 21% increasing in zone IV as compared to zone V for 65m height. Moment is 27% and 36.9% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 7.77% increasing in zone IV as compared to zone V for 80m height. Shear stress is 13.17%and 36.9% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 21% increasing in zone IV as compared to zone V for 65m height. Shear stress is 27.11%and 36.9% increasing in zone IV and zone V respectively as compared to zone III. Also deflection is 7.73% increasing in zone IV as compared to zone V for 80 m height.

The graphical representation of different result obtained for deflection, bending moments and shear force are also shown in figure 3(a, b), 4 (a, b)and 5 (a, b) respectively for wind forces and seismic forces.

Table 3. Frequencies and Time period for Mode Shapes65m and 80m high chimney.

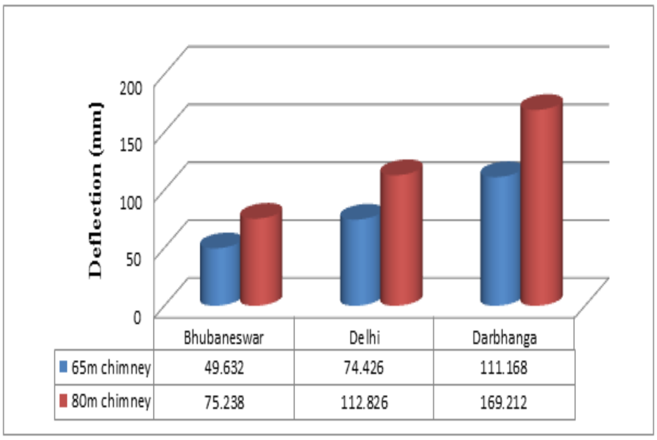
Mode	Frequency(CYCLES/SEC)		Time period(SEC)	
	65m high chimney	80m high chimney	65m high chimney	80 m high chimney
1	0.70	0.43	1.44	2.32
2	0.70	0.43	1.43	2.32
3	3.42	2.23	0.29	0.45
4	3.42	2.23	0.29	0.45
5	7.48	5.71	0.13	0.18
6	7.48	5.71	0.13	0.18
7	8.15	7.46	0.12	0.13
8	8.15	7.46	0.12	0.13
9	8.61	7.64	0.12	0.13
10	8.61	7.64	0.12	0.13
11	9.05	8.58	0.11	0.12
12	9.05	8.58	0.11	0.12
13	10.33	9.05	0.10	0.11
14	10.33	9.05	0.10	0.11
15	11.96	10.34	0.08	0.10
16	11.96	10.34	0.08	0.10
17	14.58	10.64	0.07	0.09
18	14.97	10.64	0.07	0.09
19	14.97	11.32	0.07	0.09
20	16.06	11.71	0.06	0.09

Table 4. Deflection , moment and shear force due to seismic effect.

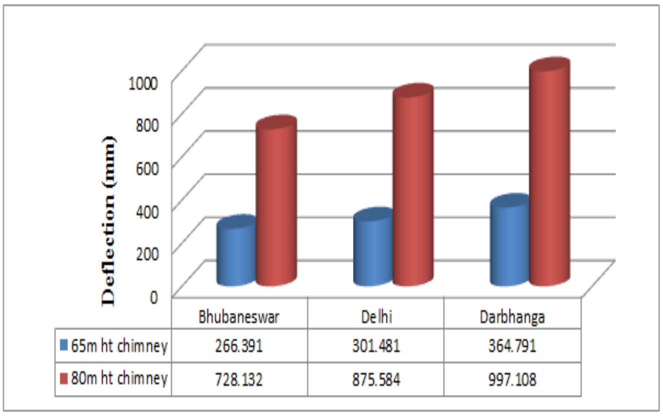
Cities	Height of chimney					
	65(m)	80(m)	65(m)	80(m)	65(m)	80(m)
	Deflection		Moment		Shear	
Bhubaneswar	49.63	75.24	79.86	83.14	0.07	0.07
Delhi	74.43	112.83	106.30	109.01	0.08	0.09
Darbhanga	111.17	169.21	145.96	147.80	0.11	0.12

Table 5: Deflection , moment and shear force due to wind effect

Cities	Height of chimney					
	65(m)	80(m)	65(m)	80(m)	65(m)	80(m)
	Deflection		Moment		Shear	
Bhubaneswar	301.48	875.58	7030.30	8623.9	3.91	4.64
Delhi	266.39	728.13	6211.98	6786.95	3.45	3.65
Darbhanga	364.79	997.10	8506.75	9294.23	4.73	5.00

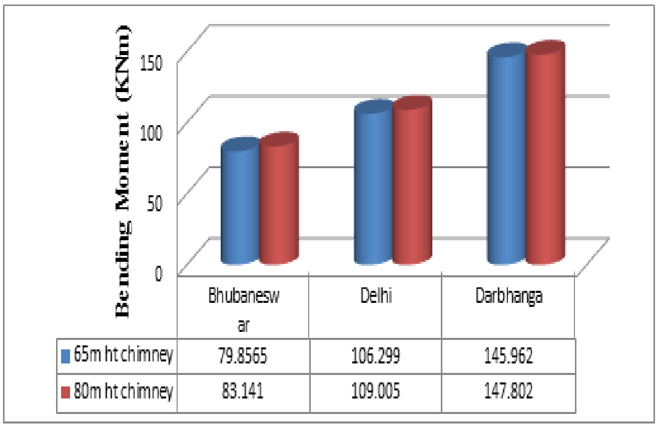


(a)

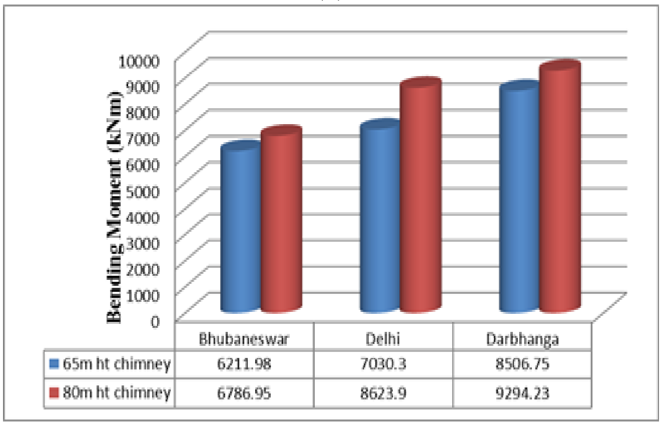


(b)

Fig3(a,b). Deflection for 65m and 80m high steel chimney (a) Seismic Load (b)Wind Load.

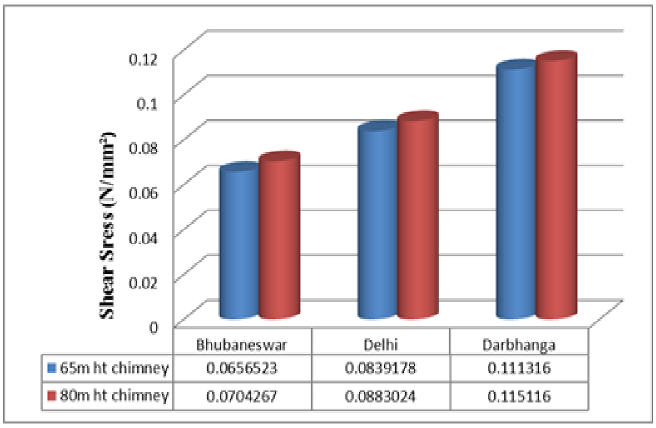


(a)

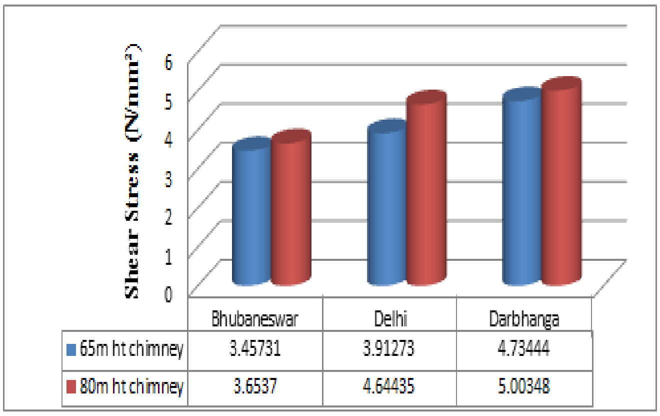


(b)

Fig 4(a,b). Bending moment for 65m and 80m high steel chimney (a) Seismic Load (b) Wind Load.



(a)



(b)

Fig 5(a,b). Shear stress for 65m and 80m high steel chimney (a) Seismic Load (b) Wind Load.

Conclusions

Based on the results obtained from this study the following conclusions are drawn

i. On studying the result the values of deflection, moments and shear force increasing with increasing in seismic zone further as the basic wind speed increases the value of deflection ,moments and shear stress were also increases

ii. It is observed from the analysis that the variation in the values of deflection, moment and shear stress are more pronounced on wind forces as compared to the variation in the values of above parameters in case of seismic. Therefore, the wind load is the governing factor for the design of self-supported steel chimney.

iii. It is found from these analyses that maximum moment and the maximum shear stress due to dynamic wind load in a self-supporting steel chimney are continuous function of the geometry (top-to-base diameter ratio and height-to-base diameter ratio). This study does not support the IS 6533 (Part-2):1989 criteria for minimum top diameter to the height ratio of the chimney and minimum base diameter to the top diameter of the chimney. This effect is caused because when chimney is designed as IS 6533 (Part-2): 1989 criteria the deflection was not within limit.

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