Variation in Governing Wind Loads on RC Chimney—Parametric Study

Megha Bhatt, Amey Gadkari, and Sandip A. Vasanwala

Abstract This paper deals with the study of variation in governing wind loads based on variation in dimensional parameter like H/Db ratio and tapered height of chimney. The analysis is carried out as per IS 4998: 2015. Parametric study has been carried out to study the wind force effects for total of 96 cases by varying parameters, namely basic wind speed, ratio of height to outer diameter at the bottom (H/Db), and tapered section height of the chimney. From the 96 cases, the case for basic wind speed of 47 m/s with H/Db ratios 10, 12, and 14 and tapering ratios 0, 1/3, and 1 has been discussed with the help of result tables and graphical output portraying the effects of above mentioned parameters on requirement of across wind load analysis, first mode frequency, second mode frequency, and governing wind loads on the chimney along its height. This study helps in identifying the range of dimensional parameters that are feasible for the analysis through comparison.

Keywords RC chimney · Wind load · Design parameters

1 Introduction

There is invariable co-dependency of threshold factor for dynamic analysis requirement on the dimensional parameters, i.e., as per the IS 4998: 2015 [1, 2], the across wind analysis requirements are based on the critical wind speed V_{cr} falling in to the region of 0.5 V (z_{ref}) to 1.3 V (z_{ref}), where $V(z_{ref})$ is design hourly mean wind speed at (5/6) of H in m/s, and H is total height of chimney above ground in meters. The ascertained dependency of dimensional parameters can be cited directly based on the empirical formulae provided in the code, but few secondary parameters also influence the threshold factor for dynamic analysis requirement. The objective of this paper is to carry out a parametric study considering one of the both direct and indirectly influencing dimensional parameters.

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2 Literature Review

The analytical methods depicted in the IS 4998 have been sophisticated over time, yet not to be put out of consideration; the Vickery–Basu "simplified" model has been a strong influence and has been adopted in the code after modification and simplification. The earlier revision of IS 4998 had incorporated the modified version of the Vickery–Basu "simplified" model with two separate formulae for chimney classified based on taper ratio. The ideology of taper was in congruence of slope in the elevation of the tower, i.e., it should not involve the "taper ratio" Dt/Db, but also slenderness ratio H/Db of the chimney. There were studies carried out by Vickery that denoted strong influence of tower geometry on the response. The paper by Devdas Menon and P. S. Rao [2] has discerned the influence of dimensional parameters on geometry and discussed about the disparities in codal estimates of across wind moments; this paper essentially denotes that parametric study is desideratum for understanding the analytical veracity and reliability of the proposed code.

3 Methodology

3.1 Problem Formulation

Parametric study has been carried out to study wind force effects for total of 96 cases by varying parameters, namely basic wind speed, ratio of height to outer diameter at bottom (H/Db), and tapered section height. The chimneys with tapering ratio 0, ¼, 1/3, and 1 are analyzed for H/Db ratios 10, 12, 14, 16 for all the basic wind speeds as per IS: 875 (Part 3)—2015 [3] that are 33, 39, 44, 47,50, and 55 m/s. The chimney has height of 126 m above ground and is considered to be unlined and does not have any opening in the shell. Only wind load effects are considered, i.e., the temperature stresses and earthquake forces are not considered. Table 1 shows the considered dimensional parameters for the comparative analysis, which includes outer diameter at base D_b, thickness at base t_b, outer diameter at top D_t, and thickness at top t_t. As wind force is considered to be predominant and more critical lateral load as compared to seismic force in the design of RC chimney [4, 5, 6] the parametric study is carried out only for wind forces.

Table 1 Diameter and thickness of shell for various H/D

H/D_b	D_b (m)	t_b (m)	D_t (m)	t_t (m)
10	12.6	0.63	4	0.2
12	10.5	0.525	3.3	0.17
14	9	0.45	2.8	0.14

3.2 Analytical Procedure

The analysis has been carried out as per the guidelines given in IS 4998: 2015 [1, 2]. The following steps are followed to carry out the analysis and finally the comparison.

Step 1: Carry out the static analysis using gust factor.

Step 2: Calculate critical wind speed for across wind loads for first and second mode.

Step 3: Compute moments corresponding to the specific case of wind speed and dimensional parameters.

Step 4: Calculate combined moments for cases where across wind load analysis is required.

Step 5: Plot and compare the analysis outcomes in order to draw inferences.

3.3 Comparison

A comparative study is carried out to justify the dependency of across wind load analysis requirement on dimensional parameters under study and clearly define thresholds based on these dimensional parameters. Another purpose of comparative study is to clearly outline the feasible range of dimensional parameters that can be utilized while trying to gage the behavior with the preliminary calculations.

4 Results and Discussion

The selective results for the case of basic wind speed $Vb = 47$ m/s, H/Db ratios 10, 12, and 14 and tapering ratios 0, 1/3, and 1 have been depicted in Tables 2, 3 and 4.

Tables 3 and 4 have the computed values of natural frequency of the chimney for first mode and second mode, respectively, which are used for determining the critical wind speed and then verifying with the threshold range for across wind analysis specified in the IS 4998: 2015 [1, 2].

Table 4 depicts the requirement for the across wind load analysis based on the criteria specified in the code.

Table 2 Natural frequencies for first mode

H/D_b	Un-tapered height		
	0H (m)	1/3H (m)	1H (m)
10	0.817	0.822	0.573
12	0.677	0.68	0.477
14	0.587	0.59	0.429

Table 3 Natural frequencies for second mode

H/D_b	Un-tapered height		
	0H (m)	1/3H (m)	1H (m)
10	3.078	3.084	3.441
12	2.554	2.559	2.861
14	2.194	2.198	2.496
H/D_b	Un-tapered height		
	0H (m)	1/3H (m)	1H (m)
10	3.078	3.084	3.441
12	2.554	2.559	2.861
14	2.194	2.198	2.496

Table 4 Across wind load analysis requirement comparison

H/D_b	Un-tapered height		
	0H (m)	1/3H (m)	1H (m)
10	1st mode	Not required	1st mode
12	Not required	2nd mode	1st mode
14	2nd mode	2nd mode	Not required

The dependency of natural frequency for both first mode (f_1) and second mode (f_2) on the dimensional parameters in study, i.e., D_t and D_b indicate the interdependency of critical wind speed (V_{cr}) on them too which governs the possibility of critical wind speed (V_{cr}) falling into the range of 0.5 V (z_{ref}) to 1.3 V (z_{ref}) and thus demonstrating the requirement for dynamic or across wind load analysis (Fig. 1).

The graph illustrates that for the case of fully tapered shell the along wind load governs throughout the height of the chimney (Fig. 2).

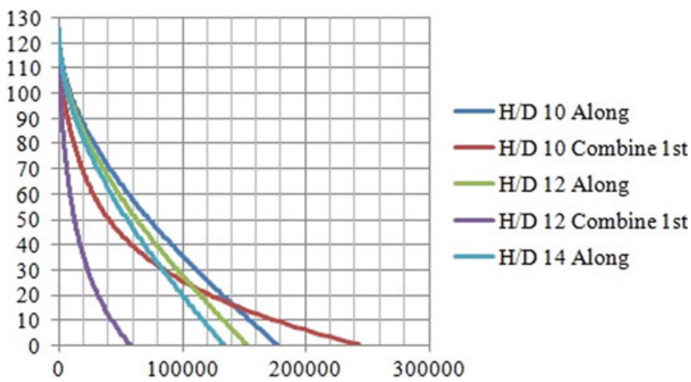

Fig. 1 Height of RC chimney (m) versus moments (kN.m) for fully tapered

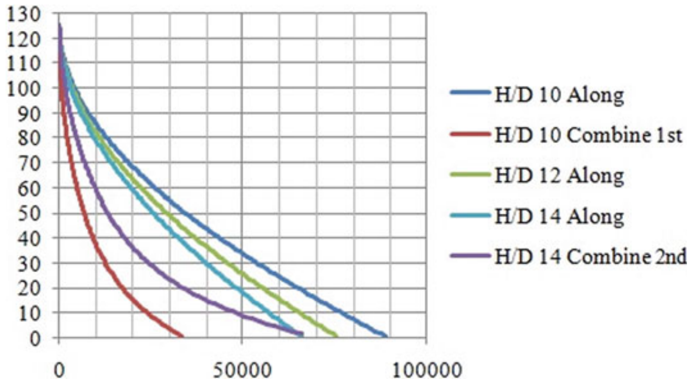

Fig. 2 Height of RC chimney (m) versus moments (kN.m) for 1/3 tapered

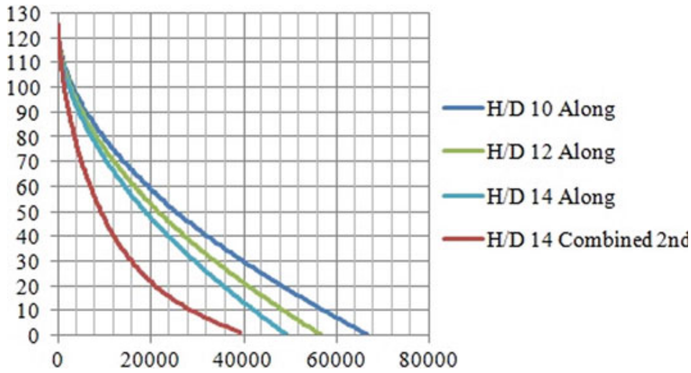

Fig. 3 Height of RC chimney (m) versus moments (kN.m) for fully un-tapered case

The graph illustrates that for the case of 1/3 tapered shell the along wind load governs throughout the height of the chimney (Fig. 3).

The graph illustrates that for the case of fully un-tapered shell the along wind load governs for nearly top 5/6H of the height of the chimney, while for the remaining height, first mode combined effect is significant. For H/D 12 and 14, the along wind load governs for the total height of chimney above the ground.

5 Ambiguities in the Code

In the code IS 4998: 2015 [1, 2], there are three parametric coefficients whose range have been mentioned, but the condition to be considered in a case when the value falls out of the required range has not been specified.

The three parametric coefficients identified are as follows:

F_{1A} = Strouhal number parameter;	F_{1B} shall be between 0.2 and 1;
F_{1A} shall be between 0.6 and 1;	β_s = Structural damping as a fraction of critical damping for across wind load;
F_{1B} = Lift coefficient parameter;	β_s shall be between 0.01 and 0.04;

According to the code IS 4998: 2015 [1, 2], clause 5.5.7-page no. 6 V* is to be varied between 0.8 V_{cr} and 1.2 V_{cr} (at least 10 intervals shall be considered). The maximum value of V* shall be limited to 1.3 V (Z_{ref}). Considering, if we take 10 intervals, we will have 10 values of $\overline{V}_*$ which value has to be taken for $F_{al}(z)$ computation has not been specified.

6 Conclusions

i. The tapered height variation for same H/Db does not affect the calculated natural frequency significantly and thus does not change Vcr.
ii. The un-tapered chimney has reduced frequency compared to other tapering cases due to elimination of (t_b/t_t) and second mode frequency becomes six times f_1.
iii. The H/D_b ratio variation has significant effect on natural frequency.
iv. First mode across wind load analysis requirement arises as the H/Db ratio, and basic wind speed is decreased, i.e., as the chimney becomes slender, at lower basic wind speed frequency for first mode decreases, and thus, V_{cr} falls into range of 0.5 V(z_{ref}) to 1.3 V(z_{ref}).
v. The case of fully un-tapered shell showed significant deviation in the qualitative response observations than the other three tapering cases. The straight cylindrical geometry, with decrease in H/Db ratio along with subsequent decrease in basic wind speed had combined moments governing over the bottom sections.

The exclusion of taper ratio from the expression based on empirical information has made this dimensional parameter almost insignificant. The earlier depiction of strong influence of aspect ratio by Vickery throughout the model experiments, and simplification has been standing contradictory to the current analytical approach. The inferences by Devdas Menon and P. S. Rao are discordant to current observations, thus portraying the significant variation in the incorporation of dimensional parameters in the recent revision of the IS 4998: 2015 [1, 2]. The effect of taper obtained from analytical computation has to be in conformity to practical response; this gives a scope to study and adopt semi-empirical method developed by Vickery.

References

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