A COMPARATIVE STUDY ON WIND ANALYSIS OF TAPERED AND NON-TAPERED REINFORCED CONCRETE CHIMNEY

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Abstract – *Rapid industrialization due to globalization results in the raise of tall chimneys around the world. Considering the structural variations in chimney design, the present paper discusses the analysis of reinforced concrete chimneys by considering two chimney sections i.e., Tapered & Non-Tapered. The main focus is to study the wind analysis considering along wind loads with two different sections of chimneys. In the typical case of slender, tapered Reinforced Concrete Chimneys, it is the along-wind response that generally predominates and governs the design. The structures proposed in this work were analyzed using the same wind intensity which was obtained according to IS: 875 (Part 3) - 1987 and the wind loads on chimney were calculated according to 'CRITERIA FOR DESIGN OF REINFORCED CONCRETE CHIMNEY' i.e., IS: 4998-1992 chimney (part-1). The chimney structures were developed using commercial software STAAD.Pro V8i and the effect of lateral load i.e., wind loads are analyzed. Given the rapid development in the industrial sector and consideration of Ground Level Pollution, the study draws its importance by designing an efficient chimney using STAAD.Pro V8i software with respect to wind loads.*

Key Words: **Chimneys, STAAD.Pro, wind loads, Industries, pollution.**

1. INTRODUCTION

As large-scale industrial developments are taking place all around, an overwhelming number of tall chimneys would be required to be constructed every year. The primary function of a chimney is to discharge pollutants into the atmosphere at higher elevations and velocities so that the concentration of pollutants deemed harmful were avoided in the human vicinity. The control standards have led to the construction of increasingly tall reinforced concrete (RC) chimneys worldwide. Construction of tall chimneys needs a better understanding of loads acting on them and of the structural behavior, so that with the help of modern construction equipment and techniques, the most favored material for chimney construction, could be used efficiently [1]. The proper design and construction of such chimneys will create self-standing structures to resist wind load and other forces acting on them.

2. LITERATURE REVIEW

A literature review is carried out on the analysis of chimneys with a special interest in the effect of wind loads on the chimney. Vickery and Basu proposed an empirical model which is widely recognized and accepted as a model for the prediction of across-wind response on a tall circular chimney and it has been recommended in a few international Codes of Practice [2]. A salient feature of this model is the concept of negative aero-dynamic damping, using which the enhanced response due to vortex shedding in the lock-in region is computed. While this might be a useful concept, Zhou et. al. (2000) reported that this assumption oversimplifies the correlation of the across-wind forces along the height [3]. Chmielewski, et. al. (2005) studied natural frequencies and natural modes of high multi-flue industrial RC chimneys with the flexibility of soil [4]. This paper used the finite element method for analysis. Also, experimental work to investigate the free vibration response is carried out by using two geophone sensors and experimental results are compared with analytical results. The results show that the soil flexibility under the foundation influences the natural modes and natural periods of the chimney by a considerable margin. Davenport devised the gust factor method, and this method has been widely used for along wind calculation during the past three decades [5]. Following Davenport's formulation, several researchers suggested various modifications to the gust factor method [6]. Flaga and Lipecki (2010) analyzed the lateral response on concrete chimneys of circular cross-sections due to vortex excitation. A mathematical model of vortex shedding is proposed for calculating the maximum displacement of the chimney at the top due to vortex shedding [7]. Researchers also conducted several studies to determine the wind-induced vibration of a full-scale chimney. Wind tunnel testing has proved to be an efficient and practical approach towards the study of the response of tall structures, particularly chimney models, under atmospheric wind flow [8]. Kareem and Hseih (1986) carried out the reliability analysis of concrete chimneys under wind loading [9]. In this paper, safety criteria are taken into consideration. Excessive deflection at the top of the chimney and exceedance of the ultimate moment capacity of the chimney cross-section at any level were taken as failure criteria. The formulation for wind-induced load effects, in both along-wind and across-wind directions, is presented according to the probabilistic structural dynamics. Few researchers also highlighted the masonry type of construction without any experimental investigation. It is therefore appropriate herein to study these constructions since existing knowledge regarding their behavior is very limited and, in addition, in many places, these chimneys are considered the silent witnesses of the past, and they are protected by law as cultural heritage. The first work analyses the typology and structure of industrial chimneys built between 1870 and the first decades of the 20th century in the Italian regions of 'Piedmont' and 'Veneto'. The study also analyses problems associated with their restoration. The second paper studies the behavior of three significant chimneys in these areas using the finite element method with linear analysis, taking into account the self-weight of the chimney, wind, temperature differences, and earthquakes as acting forces. Pistone et al. (1996) deal with restoration problems in masonry chimneys. Recently, two more examples addressing this type of construction are (a) Pallare´s et al. (2004), where different failure criteria are compared to study the failure of a masonry chimney [10], and (b) Van et al, (2004), in which stability and preservation of these chimneys are treated [11]. Tamura and Nishimura (1990) studied the elastic model of the RC chimney in the wind tunnel and confirmed that epoxy resin material can be used to simulate the dynamic behavior of the reinforced concrete chimney in wind tunnel testing [12]. The literature review presented above shows that there are several published works on concrete chimneys. Experimental and theoretical studies are presented on the behavior of tall chimneys subjected to wind. It is found that the majority of the research papers on the chimney are concentrated on its response to wind and earthquake analysis. For the present study, we consider papers on wind effects on chimneys. The structures proposed in our work were analyzed using the same wind intensity which was obtained according to IS: 875 (Part 3) - 1987 [13] and the wind loads on chimney were calculated according to 'CRITERIA FOR DESIGN OF REINFORCED CONCRETE CHIMNEY' i.e., IS: 4998-1992 chimney (part-1) [14].

3. METHODOLOGY

WIND LOAD CALCULATIONS ON CHIMNEYS AS PER IS: 4998-1992 (PART 1)

Design wind pressure, $P_Z = 0.6\ V_Z^2$ (clause 5.4, IS 875-part-3-1987)

Design wind speed, $V_Z = V_b.K1.K2.K3$ (clause 5.3, IS 875-part-3-1987)

Basic wind speed from fig.1 page no. 9 of IS 875-part.3-1987, clause 5.2

As V_b = 50m/s (Basic wind speed in vizag)

K1 = Probability factor (Risk coefficient). From table 1

K1 = 1.08 (For important building & Power plant structures)

K2 = Terrain height and structure size factor

K2 = 1.1 (For 50m height and category 2, class C)

K3 = 1.0

V_Z = 50 x 1.08 x 1.1 x 1.0

V_Z = 59.4 m/s

Wind velocity at desired height is given by

$$V_Z = 59.4 \times (Z/10)^{0.2}$$

According to IS 4998- 1992 Part I, the drag force or along wind load per unit height of the chimney by peak factor method (or) simplified method is given by

$$F_Z = P_Z\, C_d\, d_Z$$

Where P_Z = Design wind pressure (from IS 875- Part 3)

C_d = 0.8 (Coefficient of drag as per IS 4998-1992 Part 1)

d_Z = Diameter at height Z

The velocities, pressures and respective forces were calculated and tabulated below:

S. No	Height (Z)	Diameter (d_Z)	Velocity (V_Z)	Pressure (P_Z)	Force (F_Z)
1	5	4.8	51.71	1.604	6.161
2	10	4.6	59.40	2.117	7.791
3	15	4.4	64.42	2.490	8.764
4	20	4.2	68.23	2.793	9.386
5	25	4.0	71.35	3.054	9.774
6	30	3.8	74.00	3.285	9.987
7	35	3.6	76.31	3.494	10.063
8	40	3.4	78.38	3.686	10.026
9	45	3.2	80.25	3.864	9.891
10	50	3.0	81.96	4.030	9.672

Table -1: Calculation of wind force at basic wind speed V_b = 50 m/s (Tapered)

S. No	Height (Z)	Diameter (d_Z)	Velocity (V_Z)	Pressure (P_Z)	Force (F_Z)
1	5	5	51.71	1.604	6.418
2	10	5	59.4	2.117	8.468
3	15	5	64.42	2.49	9.959
4	20	5	68.23	2.793	11.174
5	25	5	71.35	3.054	12.217
6	30	5	74.00	3.285	13.141
7	35	5	76.31	3.494	13.977
8	40	5	78.38	3.686	14.74
9	45	5	80.25	3.864	15.45

					5
10	50	5	81.96	4.03	16.12

Table - 2: Calculation of wind force at basic wind speed V_b = 50 m/s (Non-Tapered)

Software used- STAAD.PRO V8i

World's No. 1 Structural Analysis and Design Software Supporting Indian and major International codes. STAAD or (STAAD.Pro) is a structural analysis and design computer program originally developed by Research Engineers International in Yorba Linda, CA.

4. RESULTS AND DISCUSSIONS

The chapter presents the models developed in Staad.pro V8i, introduction to the software, loading on the chimney structures, classification of chimney, analysis results, nodal displacements, stresses, stress contours etc. in detail.

The images below show the structure of an industrial chimney in isometric view and in front view which was modeled in STAAD.Pro v8i.

MODEL FOR ANALYSIS OF RC CHIMNEY TAPERED RC CHIMNEY

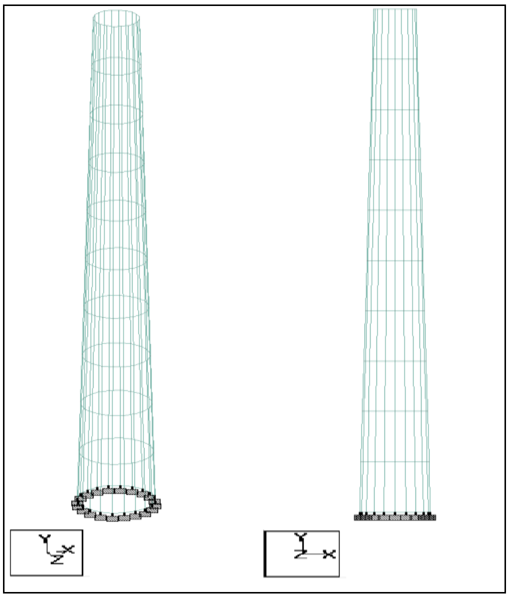

Fig -1: **Model of Tapered RC Chimney in Staad.pro V8i**

NON-TAPERED RC CHIMNEY

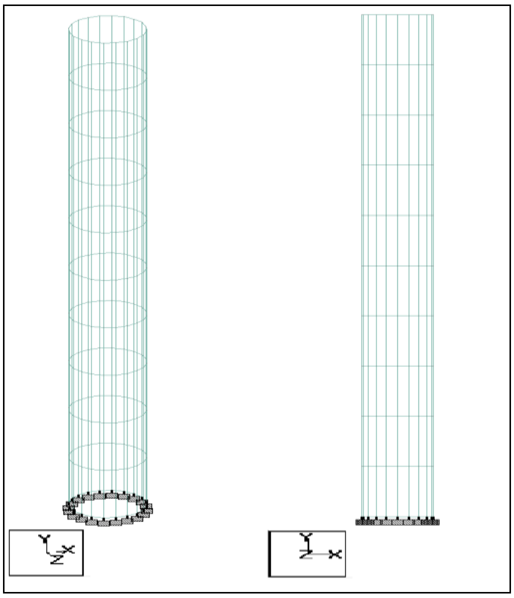

Fig -2: Model of Non-Tapered RC Chimney in Staad.pro V8i

The images below represent the wind load on the Tapered & Non-Tapered chimney considered in one direction.

WIND LOADING ON THE CHIMNEY STRUCTURE

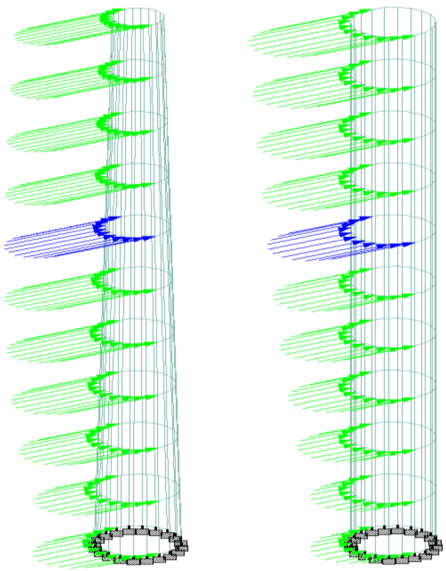

Fig -3: Loading view of the chimney structure.

Graphs for Tapered & Non-Tapered RC Chimneys

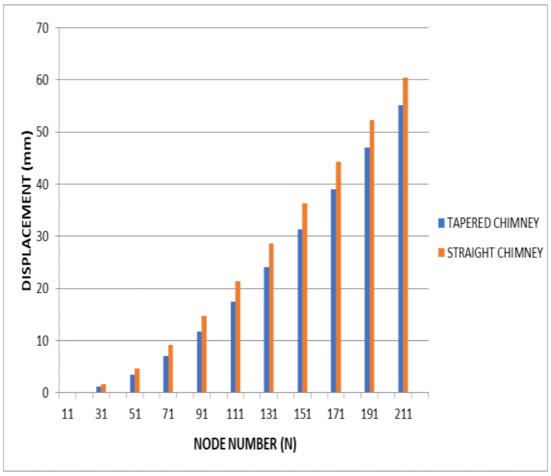

Fig -4: Nodal displacements on Tension side

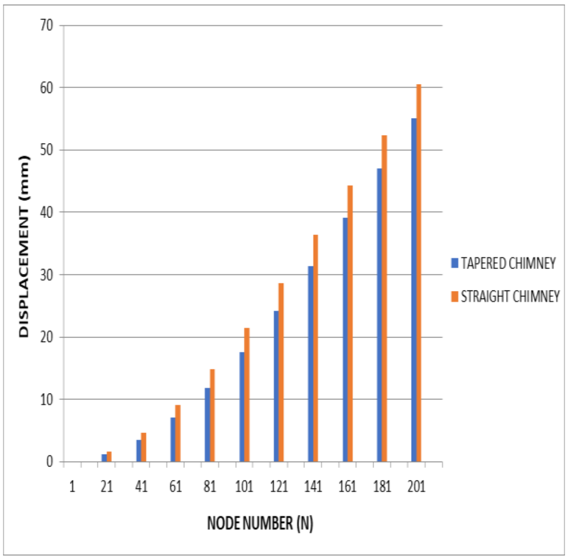

Fig -5: Nodal displacements on Compression side

Summary of Graphs (Nodal displacements)

The above graphs represent the Nodal displacements on 1) The tension side and 2) The compression side. The graphs were plotted at every 5m height of the chimney structures with respective nodes of the sides.

- **Tension Side or Windward side** In the above graphs, the displacements are plotted for Tapered & Straight RC Chimney for the same wind intensity. Both chimney sections were mentioned at the right of the section. The Straight RC Chimney had the greater displacement over the Tapered RC Chimney, at the particular node. Maximum displacement occurs at the top of the structure both in Tapered & Straight Chimneys. The displacements at the bottom of the structure are zero, as the structure is supported or affixed by a fixed support. It was clear that for both the chimney sections, the maximum displacement occurs in the tension zone only. The graphs clearly showing that the displacement at every comparative node of Straight RC chimney had a greater displacement than that of Tapered RC chimney. Here it was observed that the height of the chimney structure is directly proportional to the displacements. As the height of the structure increases, the value of the displacements also increases.

- **Compression Side-** As the chimney structure is symmetrical about its vertical axis, the variation of the displacements on the compression side to the tension side is very less. From the graphs also it is clear that, a very less difference in displacement occurs on compression side to that of the tension side, but the maximum displacement didn't occur in compression zone.

Graphs for Principal Major Top & Bottom Stresses of Tapered & Non-Tapered Chimneys

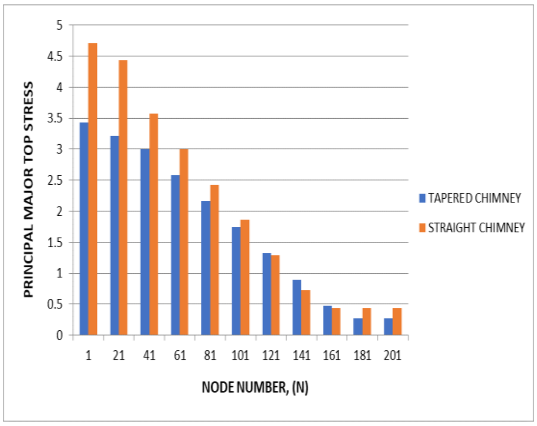

Fig -6: Principal Major Top Stress on Tension Side

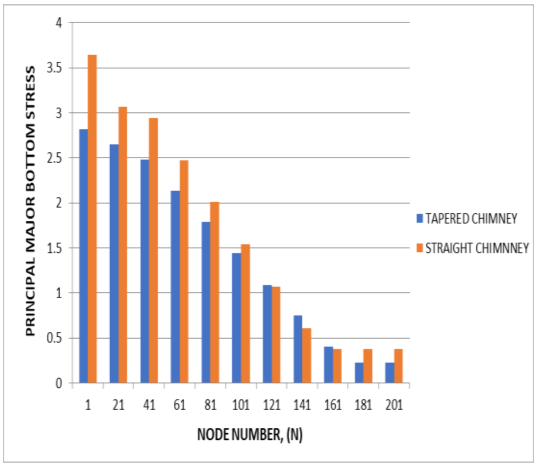

Fig -7: Principal Major Bottom Stress on Tension Side

The graphs showed a clear vision that the stresses were more in the Straight RC Chimney than the Tapered RC Chimney at the particular node. It was clear from the graphs that the stresses vary linearly along the structure. Here it was observed that the height of the chimney structure is inversely proportional to the Principal Major Top & Principal Major Bottom stresses. As the height of the structure increases, the value of the stresses decreases. Then it was clear that the maximum stresses occur at the base of the chimney structure. Hence the stresses are maximum at the base, and minimum at the top of the chimney structure.

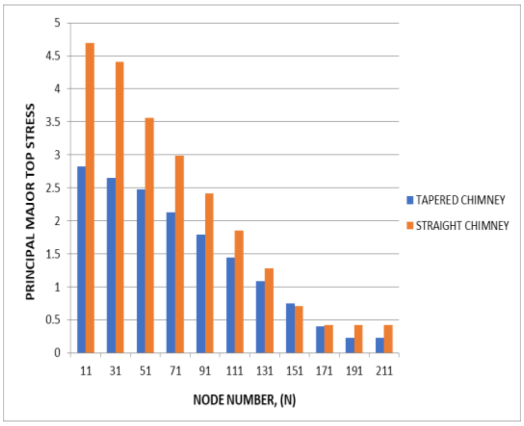

Fig -8: Principal Major Top Stress on Compression Side

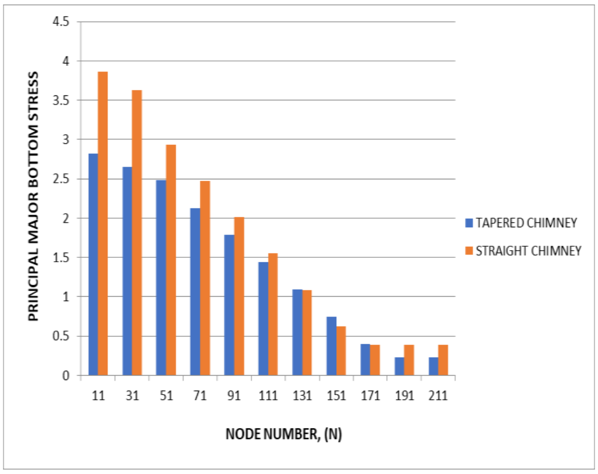

Fig -9: Principal Major Bottom Stress on Compression Side

From the graphs it is clear that the stress behavior on the compression side is almost having the same behavior as that on the tension side.

Stress Contours due to self weight of the chimeys

The following images i.e., Fig 10 and 11 represents the actual stress behavior for the loading condition (either self-weight or wind load) given on the chimney. Each color defines the unique stress range which helps to know the structural behavior of the chimney under specific loading condition. The actual stresses to be limited within allowable stresses to ensure the structure safety. The end value (bottom) in the above image signifies critical stresses.

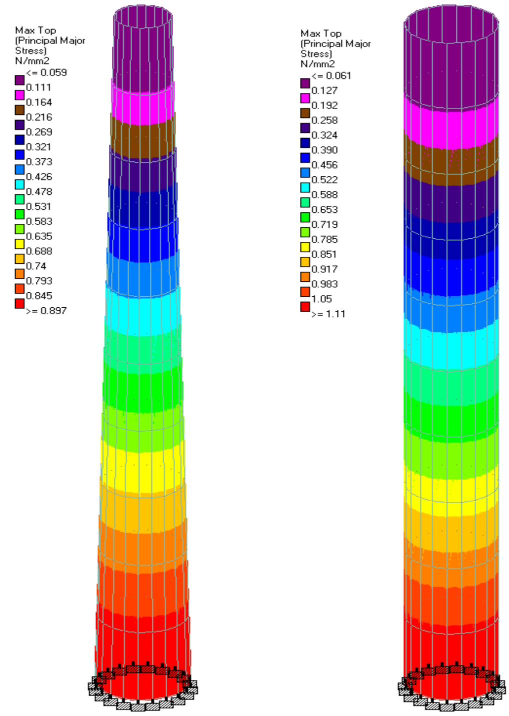

Fig -10: Stress Contours due to self weight of chimneys

Stress Contours due to Wind load on the chimeys

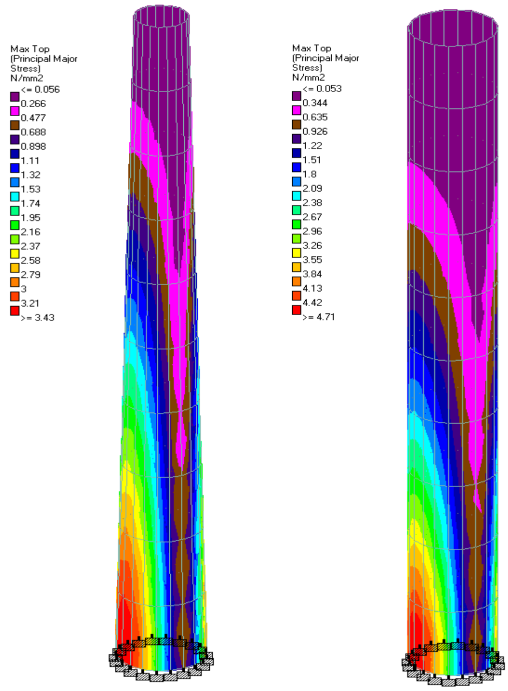

Fig -11: Stress Contours due to wind load on chimneys

The above figure represents the stress contour of Tapered chimney & Non-Tapered Chimney due to wind load on the structure.

6. CONCLUSION

Maximum displacement occurs at the top of the structure, whereas the displacements at the bottom of the structure are zero, as the structure is supported or affixed by a fixed support. Here it is observed that the height of the chimney structure is directly proportional to the displacements. As the height of the structure increases, the value of the displacements also increases. Incremental in wind intensity leads to the increment of the displacement in that direction. As the structure of chimney is fixed at its bottom, it acts like a cantilever beam, and the maximum displacement occurred at the peak of the structure. It was observed that The Non-Tapered RC Chimney had the greater displacement over the Tapered RC Chimney, at the particular node. And the maximum displacement occurs in the tension zone only, whereas the compression zone displacements are utmost similar to that of tension side due to symmetry of the structure. Here it is observed that the height of the chimney structure is inversely proportional to the Principal Major Top & Principal Major Bottom stresses. As the height of the structure increases, the value of the stresses decreases. It was observed that the stresses developed in the chimney structure are maximum at the base of the structure and minimum at the top of the structure. It was observed that the stresses were high in Non-Tapered RC chimney than the Tapered RC chimney.

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