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Analytical study on Reinforced Concrete Chimney with manhole effect

[1]Sumit J Lalwani, [2]Bharat B Nathani

[1] PG Student, Department of Civil Engineering H.J.D Institute of Technical Education And Research Kera bhuj

[2] M.E (structural engineer), Department of Civil Engineering H.J.D Institute of Technical Education And Research Kera bhuj

Abstract — when we design high-rise structure, winds are the major lateral forces that have to deal with Chimney are tall and slender structure. Wind play important role in design of tall structure because it exerts static and dynamic load whose effects on cylindrical structure. Because of variation in dimensions of chimney along its height structural analyses such as wind oscillation have become more critical the purpose of this study analysis along and across wind effect on R.C.C unlined chimneys height 50meters for zone VIth wind zone of India. The bureaus of Indian standard design codes procedure have been used to analyze chimney. Basic wind speed of VIth zone is (55 m/s) taken into consideration. Effect of inspection manhole on the behavior of R.C.C chimneys are taken into consideration. These models are analyzed by finite element software Staad Pro. And MS excel sheet.

Keywords-; static wind load, Dynamic wind load, von mises stress, deflection, frequency, manhole

I. INTRODUCTION [8]

In the last 60 years, among various engineering structures, chimneys have been an important application in the construction industry. Romans used tubes inside the walls to draw smoke out of bakeries but chimneys only appeared in large dwellings in northern Europe in the 12th century. Chimneys are a symbol in any country. There has been demand for all tall chimneys due to setting several large plants such as power stations, nuclear power plants and industries like oil and gas refineries etc. With increase recognition to that of flue gases in order to meet the demands of air pollution control, the trend is towards constructing taller chimney. Chimneys in ordinary dwellings were first built of wood and plaster or mud. Since then chimneys have traditionally been built of brick or stone, both in small and large buildings. Early chimneys were of a simple brick construction. Later chimneys were constructed by placing the bricks around tile liners. Chimneys or stacks are very important industrial structures for emission of poisonous gases to a higher elevation such that the gases do not contaminate surrounding atmosphere. The first concrete chimney was built in Germany in 1876. Reinforced concrete chimney was introduced in UK and Europe in 1907. Chimney with heights exceeding 150m called as tall Chimney. First tall reinforced concrete chimney 165 m have been built in Japan in 1916 remained the tallest chimney in the world. Chimney are relatively tall, slender and generally with circular cross-sections. Different construction materials, such as concrete, steel or masonry, are used to build chimneys. Steel Chimneys are also known as steel stacks. They are typically almost vertical to ensure that the hot gases flow smoothly, drawing air into the combustion through the chimney effect. Tall reinforced concrete (RC) chimneys form an important component of major industries and power plants.

II. ANALYSIS OF RCC CHIMNEY

2.1 Design inputs of chimney

Details of the chimney as follows, Height of the chimney – 50m Outer diameter of chimney at bottom – 3.2m Outer diameter of chimney at top – 2.2m Thickness of shell at bottom –0.3m Thickness of shell at top – 0.3m Grade of concrete – M25 Height to base diameter ratio – 15 Top diameter to base diameter ratio – 0.68 Basic wind speed – 55m/s Drag coefficient = 0.8 Manhole location =2m ,4m, 6m	Description of loading: Density of various materials considered for design, Concrete – 25kN/m3 Structural steel – 78.5kN/m3 Live load – 5kN/m3 Wind load: The following wind parameters are followed in accessing the wind loads on the structure Basic wind speed – 55m/s Terrain category -1 Class of structure – c Risk coefficient k1 – 1.08 Topography factor k3– 1 K2 factor taken from IS 4998(part 1):1992

III. ESTIMATION OF WIND LOAD [4]

3.1 Analysis Procedure for Wind Load as per IS 4998 (Part 1) 1992

3.1.1 Along Wind Effects: Along-wind loads are caused by the 'drag' component of the wind force on the chimney. This is accompanied by 'gust buffeting' causing a dynamic response in the direction of the mean flow. Along-wind effect is due to the direct buffeting action, when the wind acts on the face of a structure. For the purpose of estimation of these loads the chimney is modelled as a cantilever fixed to the ground. The wind is then modelled to act on the exposed face of the chimney causing predominant moments in the chimney. Additional complications arise from the fact that the wind does not generally blow at a fixed rate. Wind generally blows as gusts, this requires that the corresponding loads and hence the response be taken as dynamic. True evaluation of the along-wind loads involves modelling the concerned chimney as a bluff body having incident turbulent wind flow. However, the mathematical rigor involved in such an analysis is not acceptable to practicing engineers.

3.1.2 Across Wind Effects: Across –wind loads are caused by the corresponding 'lift' component of the wind force on the chimney. This is associated with the phenomenon of 'vortex shedding' which causes the chimney to oscillate in a direction perpendicular to the direction of wind flow. The across-wind response of tall slender structures in atmospheric turbulence involves a number of complex fluid-structure interaction phenomena. The principal source of excitation arises from vortex shedding, but if the motion induced is significant, other velocity dependent forces begin to play an important role. Further, the longitudinal and lateral fluctuations in the approaching flow give rise to across-wind buffeting forces. The shedding of vortices is fairly regular in the sub critical range when Reynolds number (Re) $<3x10^5$ and ultra-critical range ($Re>3x10^6$), whereas it is random in the super critical range ($3x10^5<Re<3x10^6$). Normally for chimneys, Re is sub critical and this permits design to be based on an assumption that the excitation is periodic. When Re is super- critical, excitation is random and the response being small, this case does not generally control design. Across wind analysis of chimney is required only if the critical wind speeds for any mode of oscillation is less than the mean design wind speed.

3.1.3 Peak Factor Method for Calculation of Wind Load

The along wind load or drag force per unit height of the chimney at any level is calculated from the equation Fz = Pz CD Dz where Pz is design wind pressure obtained in accordance with IS 875 (Part 3): 1987, Z is height of any section of the chimney in m measured from top of foundation, CD is drag coefficient of the chimney to be taken as 0.8, and Dz is diameter of chimney at Z height the lateral load due to wind at any section is calculated by suitably averaging the loads above and below it. The moments are calculated from the sectional forces treating the chimney as a free standing structure.

3.1.4 Simplified Method for Response of Chimney.

The amplitude of vortex excited oscillation, perpendicular to the direction of wind for i_{th} mode of oscillation is calculated by the formula.

$$(1): \eta oi = \left\{ \frac{\int_0^H d_z \, \emptyset_{zi} \, d_z}{\int_0^H \emptyset_{zi}^2 d_z} \right\} \times \frac{C_l}{4\pi S^2 n K_{si}}$$

Where η_{oi} = peak tip deflection due to vortex shedding in the i_{th} mode of vibration in m,
C_L = peak oscillatory lift coefficient to be taken as 0.16,
K_{si} = mass damping parameter for the i_{th} mode of vibration,
S_n = Strouhal number to be taken as 0.2,
Φ_{zi} = mode shape function normalized with respect to the dynamic amplitude at top of the chimney in the i_{th} mode of vibration.

The sectional shear force (F_{zoi}) and bending moment (M_{zoi}) at any height zo, calculated from the following equations.

$$(2): Fzoi=4\pi^2 \; f_1^2 \; \eta oi \int_{zo}^H m_z \, \emptyset_{zi} d_z$$

$$(3): Mzoi=4\pi^2 \; f_1^2 \; \eta oi \int_{zo}^H m_z \, \emptyset_{zi} (z - z_0) d_z$$

Where f_1 = natural frequency of the chimney in Hz in the i_{th} mode of vibration,
m_z = mass per unit length of the chimney at section z in kg/m.

Mass damping parameter k_{si} calculated by the formula:

$$(4):K_{si} = \frac{2m_{ei}\,\delta_s}{\sigma.d^2}$$

Where m_{ei} = equivalent mass per unit length in kg/m in the i_{th} mode of vibration as defined
δ_s = logarithmic decrement of structural damping = $2\pi\beta$
β = structural damping as a fraction of critical damping to be taken as 0.016
σ = mass density of air to be taken as 1.2 kg/m^3

The equivalent mass per unit length in i_{th} mode of vibration (m_{ei}) is calculated by the formula:

$$(5):\ m_{ei}=\frac{\int_o^H m_z \phi_{zi}^2 d_z}{\int_o^H \phi_{zi}^2 d_z}$$

IV. ANALYSIS AND RESULTS

4.1 EFFECT OF MANHOLE

Manholes are generally provided at the bottom of the chimney for maintenance and inspection purpose. These manholes are at generally located at minimum suitable distance from the base of the chimney. Two chimney models, one with the manhole and other without manhole, are analysed using finite element software STAAD PRO. Fig 1 (a&b) presents the Von-Mises stress for chimney model with manhole and without it. Fig 2(a&b) presents the displacement response of the two chimneys under static wind force. These two figures show that higher deflection is occurred at the top of the chimney with manhole as compared to chimney without manhole. Chimney without manhole is found to have higher fundamental frequency compared to the chimney with manhole.

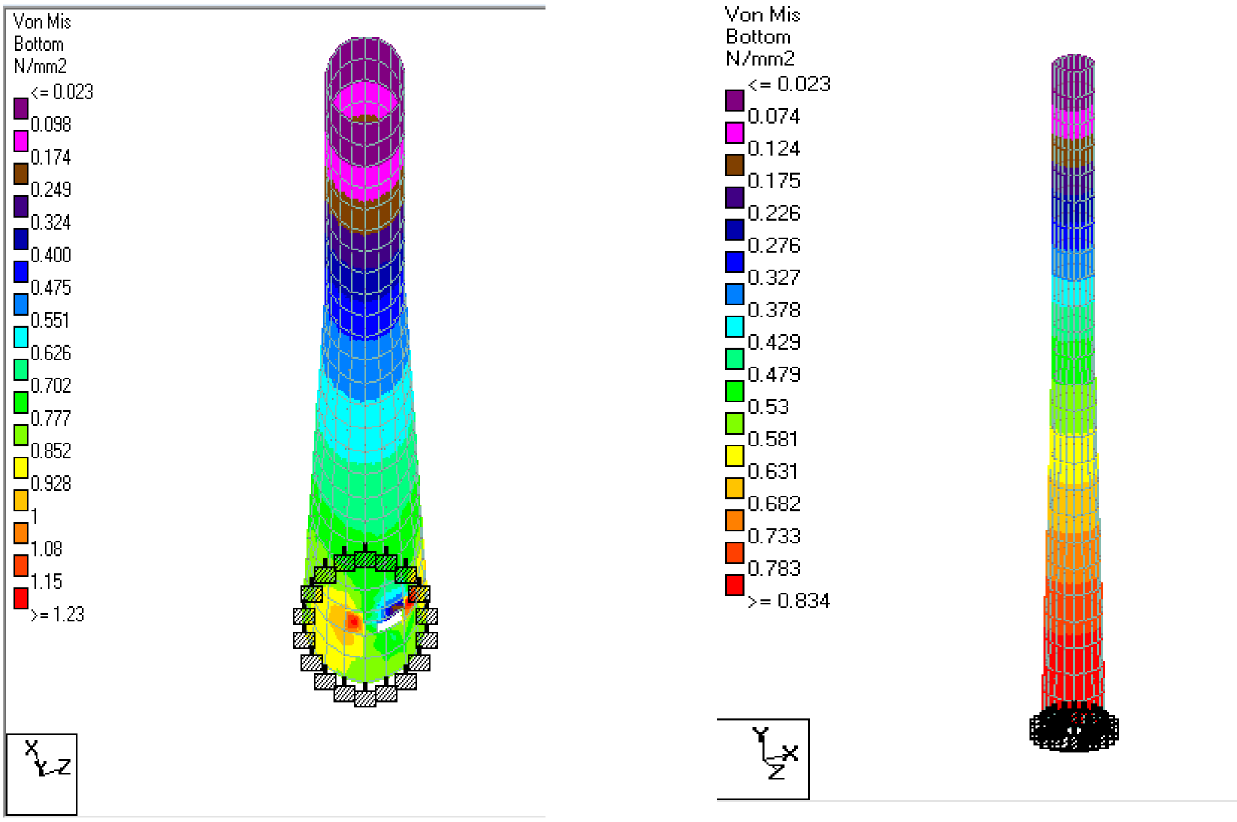
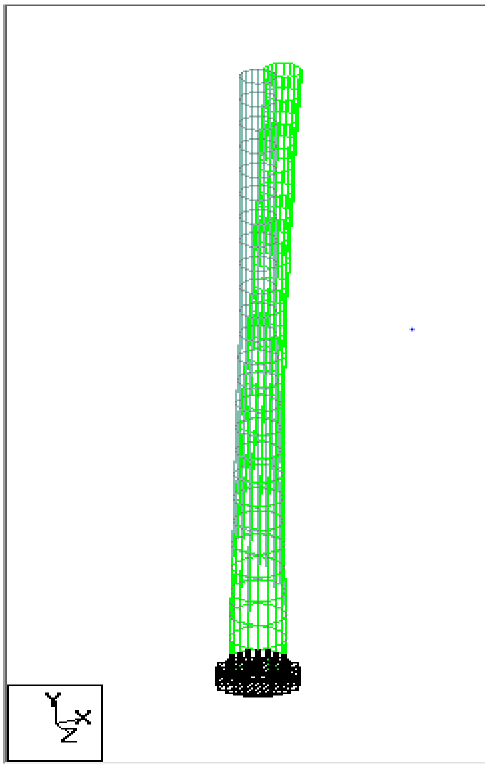


FIG:1 a) with manhole b) without manhole



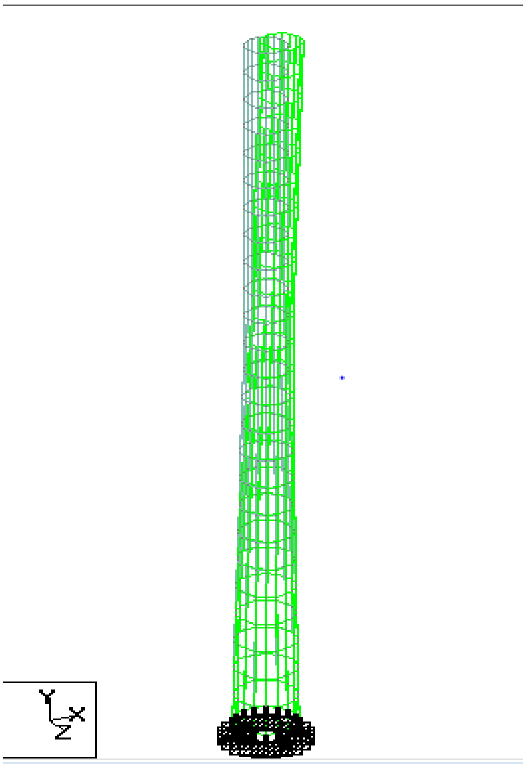
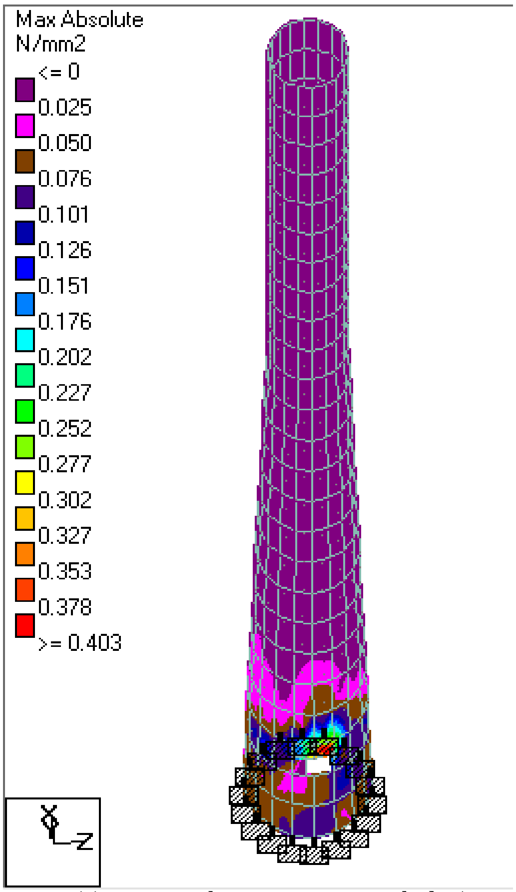


FIG: 2 a) with manhole b) without manhole

Stress diagrams of RCC chimney



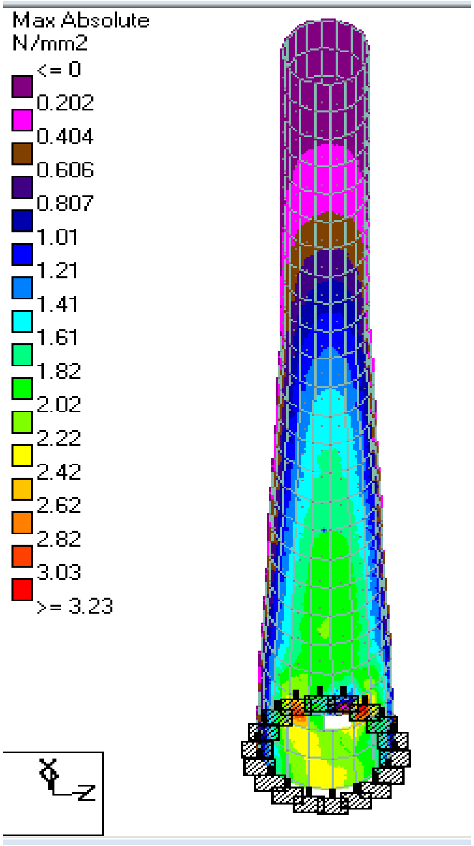


Fig: 3 (a) stress at the inspection manhole (DL and LL condition) (b) stress at the inspection manhole (wl condition)

V. CONCLUSION AND RESULTS

The purpose of this paper to analysis the effect of inspection manhole behavior at different height the basic dimensions of a simply supported unlined tapered RCC chimney. The results show that the maximum stress in the chimney with manhole is increased by 62% as compared to the maximum stress in the chimney without manhole. Chimney with manhole is found to have higher fundamental frequency compare to the chimney with manhole. This is because manhole reduced effective stiffness of a chimney as observed from model analysis

TABLE: 1

COMPARISION OF DESIGN PARAMETERS

	WITH MANHOLE			WITHOUT MANHOLE	DIFFERENCE
HEIGHT	2m	4m	6m		
TOP DISPLACEMENT (MM)	69.075	69.3	68.972	66	5%
MAX-VON MIESES STRESS(N/MM^2)	3.102	3.146	2.958	1.195	62%
TIME PERIOD (SEC)	.451	.452	.45	0.443	2%

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