Wind Analysis and Analytical Study on Vortex Shedding Effect on Steel Chimney using CFD

***T.Saran Kumar, **R.Nagavinothini**
*** PG Student, Department of Civil Engineering, SRM University, Kattankulathur Campus.**
**** Assistant Professor (O.G), Department of Civil Engineering, SRM University, Kattankulathur Campus.**

***Abstract*—The present paper deals with the study of vortex shedding effect on steel chimneys. Vortex shedding means at certain velocities air or fluid past a cylindrical body forms an oscillating flow, which depends on the size and shape of the body. Reynolds number is a dimensionless number used to predict fluid flow pattern past a body is steady or turbulent. In this study, five models of chimneys with different heights (i.e., 160m, 180m, 200m, 220m and 240m) and diameters at top and bottom, were designed as per IS 6533-1989 (Part- 2) and wind load was calculated as per IS 875 (Part – 3) – 1987. Strakes are provided at top one-third height of chimney in helical form, which increases the dead load. The chimney with and without strakes are analysed and Reynolds number was calculated from finite element software Ansys Fluent. The result shows that the presence of strakes decreases the Reynolds number.**

***Index Terms*—Ansys fluent, Reynolds number, Strakes and Vortex Shedding**

I. INTRODUCTION

A chimneyis a structure which discharge waste gases at a high enough elevation to the outside atmosphere. Chimneys are tall slender structures, which achieves simultaneous reduction in concentration of anumber of pollutants. Building materials like masonry, concrete and steel are used to construct chimneys. Steel chimneys are ideally suited for process work where a short heat-up period and low thermal capacity are required. As large scale industrial developments are taking place all around, a large number of tall chimneys would be required to be constructed every year. Due to increasing demand for air pollution, height of chimney has been increasing since the last few decades, and these are valid reasons to believe that this trend towards construction of taller chimneys will continue. Chimneys have different structural problems as they are slender structuredand must therefore be treated separately from other forms of tower structure. The proper design and construction of such chimneys will create self-standing structures to resist wind load and other forces acting on them. The effect of wind excited vibration on tall steel chimney is a matter of great concern to both structural and design engineers as this may lead to undesirable physical phenomenon called resonance. The effect is large and this will cause severe deflection and damage to the structure. Wind induced vibration of a tall steel chimney is due to vortex shedding process.

In this study, steel chimney is modelled as a cantilever structure subjected to two-degree of freedom to determine the vortex shedding effect due to wind excitation. The Reynolds number value was compared for chimney with and without strakes to investigate the type of vortex shedding flow. In this paper, the vortex shedding effect and the computational fluid dynamics theory are discussed first. Then the different chimneys models considered are analysed using ansys and the results are presented finally.

II. VORTEX SHEDDING

In fluid dynamics, a Karman vortex street (or a von Karman vortex sheet) is a repeating pattern of swirling vortices caused by the unsteady separation of flow of a fluid around blunt bodies. When air flows past a chimney of circular cross-section, vortices are shed alternately from the sides causing a pressure drop at regular intervals across the chimney section. Such pressure changes causes a lateral force perpendicular to the wind direction. There is regular shedding of vortices in the sub-critical Re range (i.e. $Re < 3 \times 10^5$) as well as in the ultra-critical Re range ($Re > 3.5 \times 10^6$). In the super-critical range ($3 \times 10^5 < Re < 3.5 \times 10^6$) the point of vortex separation oscillates causing an instability and as a result, vortex shedding becomes irregular. With increasing wind speed, as the frequency of vortex shedding approaches the chimney's natural frequency, the former jumps to lock-in with the latter. Thereafter, the chimney structure controls the frequency of vortex shedding, for a range of wind velocity close to the velocity at which vortex shedding frequency coincides with the chimney's natural frequency [10]. The different flow pattern across the cylinder is shown in figure 1.

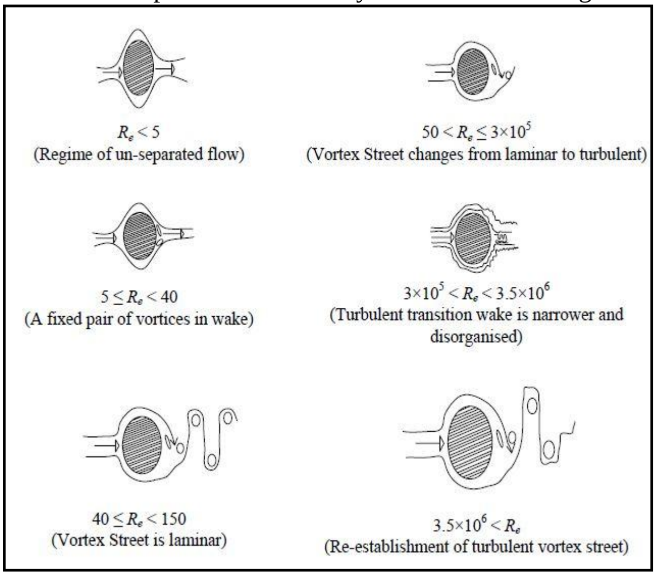


Figure 1. Flow patterns

III. COMPUTATIONAL FLUID DYNAMICS

CFD is a branch of fluid mechanics used to analyse problems that involve fluid flows by solving the numerical methods and algorithms.Navier-Stokes equation are the governing equations for Newtonian fluid dynamics. Computers are used to solve partial differential equations equations with system of algebraic equations. For the calculations of analytical solution of the differential equations various assumptions and simplifications need to be made. Most of the practical applications the analytical solutions cannot be obtained as the flow governing eqations are extremely complicated. To find the behaviour of flow at certain velocities are given in boundary conditions as inlet and outlet for the purpose of flow simulation. The experiment, which are difficult to measure the conditions practically can be tested using CFD technique.

IV. CHIMNEY MODELS FOR STUDY

In this study, five different heights of chimneys were considered for analysing the effect of vortex shedding (i.e., 160m, 180m, 200m, 220m and 240m). Each chimney model is analysed with and without the provision of strakes. The Reynolds number is identified at the top one-third height of the chimney where the strakes are provided and the values are compared. The chimney models considered are shown in figure 2.

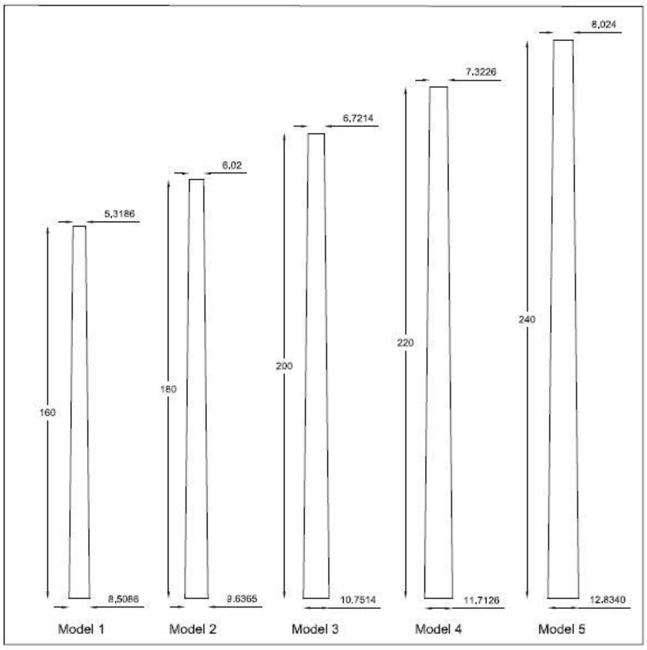


Figure 2: Dimensions of Chimney models

Strakes are discrete vertical plates attached on top portion of chimney to break the formation of vortex shedding. Provided in helical form for top one-third height.

Pitch distance = 5 D

Projection from chimney surface = 0.12 D

Where,

D = top diameter of chimney

The chimney models considered are named from 1 to 10 based on the dimensions and the provision of strakes. The models are mentioned in table 1.

Table 1: Chimney models for analysis

Sl. No	Model name	Strakes provision	Height	Top diameter	Bottom diameter
1	Model 1	No	160	5.3186	8.5086
2	Model 2	No	180	6.02	9.63
3	Model 3	No	200	6.7214	10.7514
4	Model 4	No	220	7.3226	11.7126
5	Model 5	No	240	8.024	12.834
6	Model 6	Yes	160	5.3186	8.5086
7	Model 7	Yes	180	6.02	9.63
8	Model 8	Yes	200	6.7214	10.7514
9	Model 9	Yes	220	7.3226	11.7126
10	Model 10	Yes	240	8.024	12.834

V. LOADS CALCULATION AND FLOW PATTERNS

In chimneys, along-wind loads are caused by the 'drag' component of the wind force on the chimney. Along-wind effect is due to the direct buffeting action, when the wind acts on the face of a structure. Static wind loads are calculated from IS 875 (Part 3) – 1987 i.e., Basic wind speed of Chennai 50 m/s, Design life of structure as 25 years, Terrain category 2, class C has been chosen as constant. Design wind speed calculated from the formula

$$V_z = V_b \, k_1 \, k_2 \, k_3 \quad (1)$$

Where,

k_1 = Probability factor

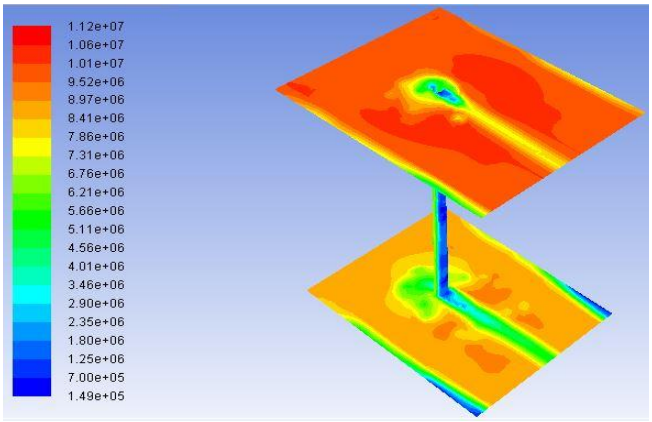
k_2 = terrain, height and structure size factor

k_3 = topography factor

CFD is a method used to find the values of the flow quantities at a large number of points in the system. The purpose of a flow simulation is to find out how the flow behaves in a given system for a given set of inlet and outlet conditions (termed boundary conditions). In this paper viscous type Laminar is chosen and air density as 1.2 kg/m^3, viscosity as 1.8 × 10^{-5} kg/ms.

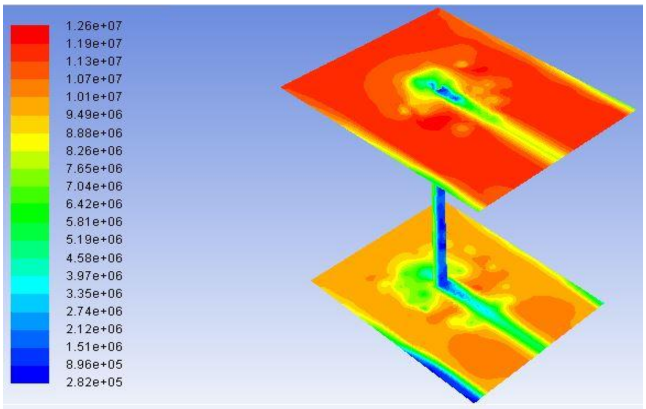
VI. RESULTS AND DISCUSSION

The Reynolds number at the top of the chimney is compared for both the cases (with and without strakes) and the values are given in table 2. The ansys fluent analysis results showing the Reynolds number throughout the height of the chimney is shown in figure 3 and figure 4.

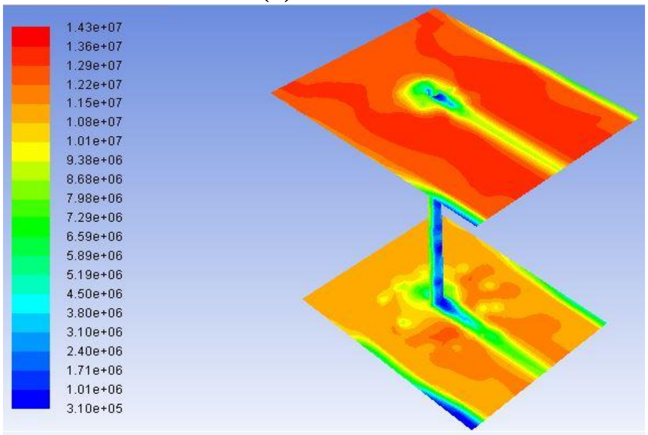


(i) Model 1

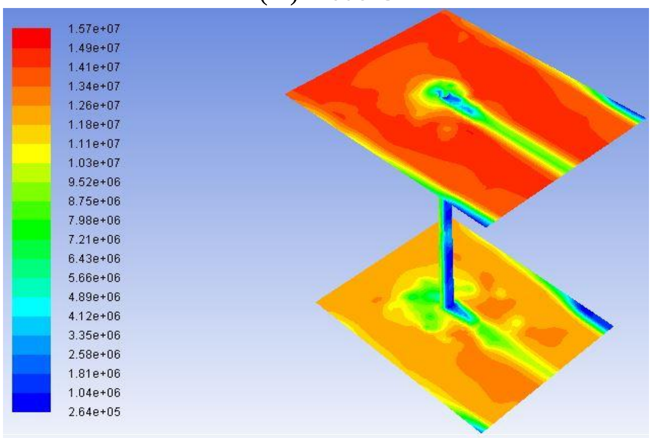
ISSN:2278 – 7798



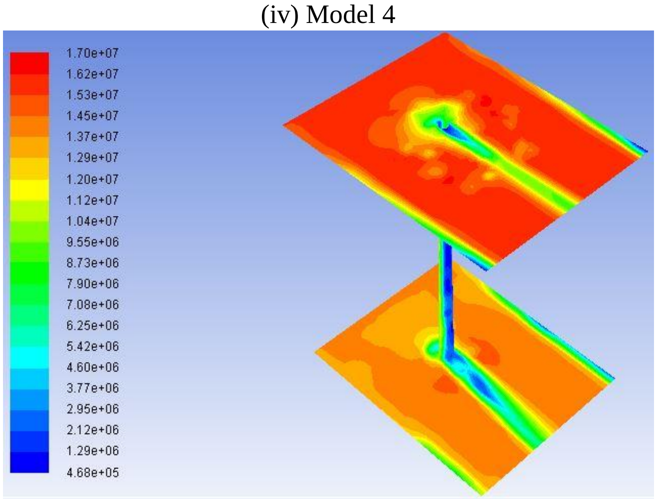
(ii) Model 2



(iii) Model 3

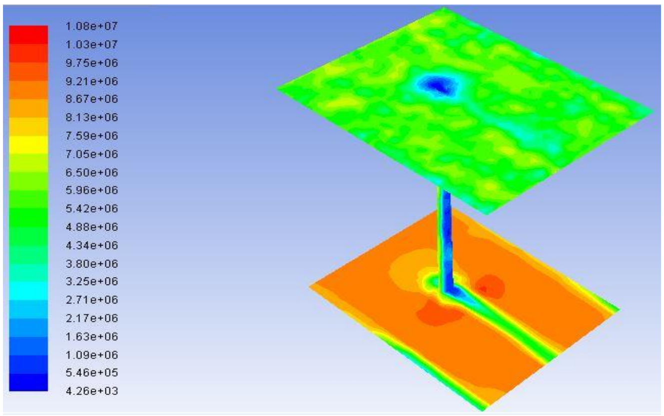


(iv) Model 4

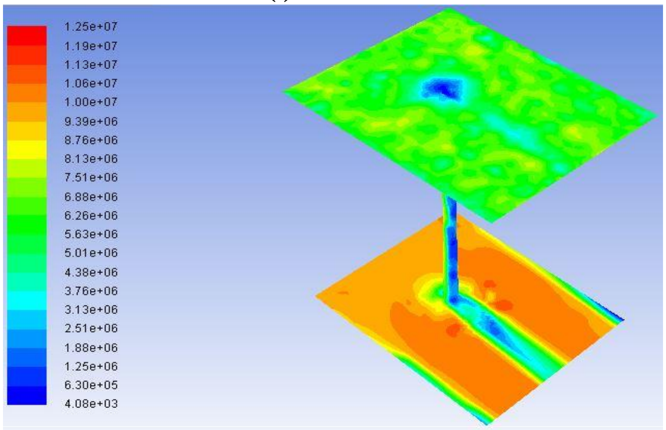


(v) Model 5

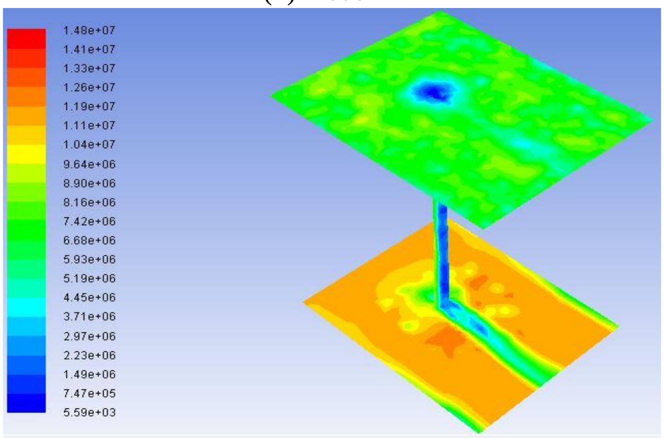
Figure 3: ANSYS fluent result for chimney models without Strakes



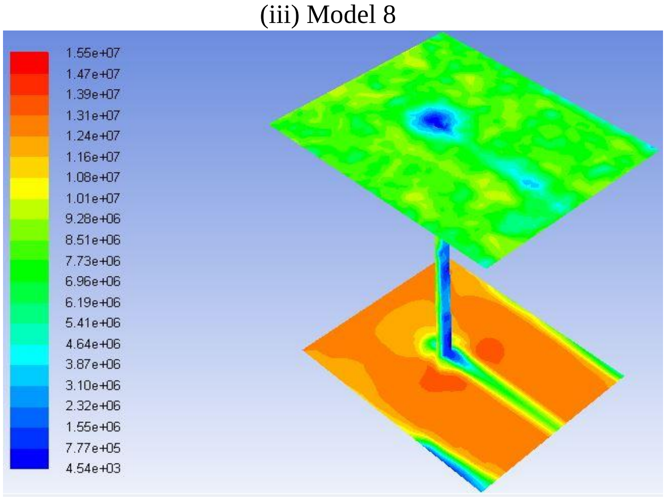
(i) Model 6



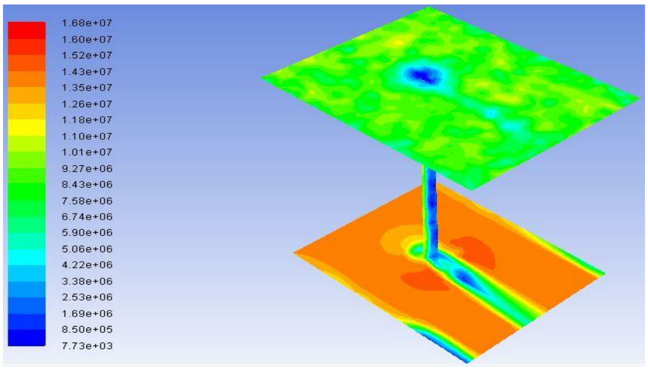
(ii) Model 7



(iii) Model 8



(iv) Model 9



(v) Model 10

Figure 4: ANSYS fluent result for chimney models with Strakes

Table 2: Comparison of Reynolds Number

Sl.No	Model Number	Reynolds number
1	Model 1	5.9×10^6
2	Model 2	6.8×10^6
3	Model 3	7.5×10^6
4	Model 4	8.7×10^6
5	Model 5	9×10^6
6	Model 6	2.2×10^6
7	Model 7	2.8×10^6
8	Model 8	3×10^6
9	Model 9	3.2×10^6
10	Model 10	3.8×10^6

The comparison of values of Reynolds number for different chimneys without strakes under study is shown in figure 5.

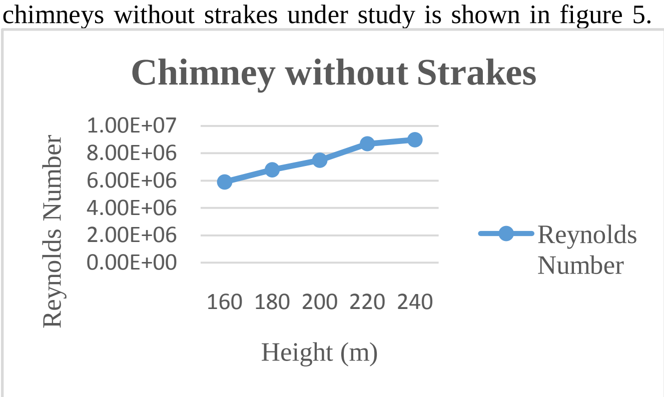


Figure 5: Reynolds number comparison for chimney models without Strakes

The values of Reynolds number for different chimneys with strakes under study is shown in figure 6.

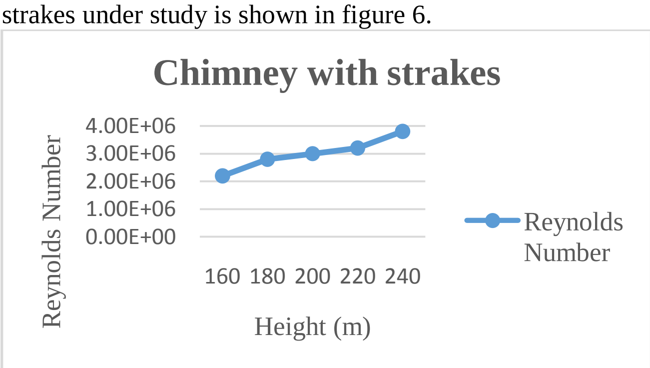


Figure 6: Reynolds number comparison for chimney models with Strakes

Comparing the above flow patterns with the regimes of fluid flow across the cylinders, the flow pattern for the chimneys without strakes is turbulent vortex with Reynolds number above 3.5 x 10^6 and the flow patterns shifts to narrow turbulent transition for the chimneys with strakes with Reynolds number less than 3.5 x 10^6.

VII. CONCLUSION

The study on the vortex shedding effect on different chimney models reveals that the wind induced vibration in the tall chimneys varies with respect to height. It is also found that the provision of strakes reduces the across wind effect on the chimneys. The analytical results shows that the Reynolds number increases with the increase in height which indicates the increase in the turbulent flow and the provision of the strakes reduces the Reynolds number on the same models which further indicates that the flow effect is controlled.

ACKNOWLEDGMENT

We express our heartfelt gratitude and sincere thanks to **Prof.G.AUGUSTINE MANIRAJ PANDIAN**, Professor, Department of Civil Engineering, SRM University for his consistent encouragement valuable suggestions during the project work.

REFERENCES

[1] N. Lokeshwaran and G. Augustine Maniraj Pandian, "Effect of dynamic loads on tall RCC chimneys of different height with elliptical and circular cross sections," IOSR Journal of Mechanical and Civil Engineering Vol. 11, Issue 4 ver. I, PP 63-67, July – Augest 2014.J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices*, vol. ED-11, pp. 34-39, Jan. 1959.

[2] S. Sule and T. C. Nwofor, "Wind induced vibration of a tall steel chimney," Canadian Journal on Environmental, Construction and Civil Engineering Vol. 3, No. 2, February 2012.

[3] B. Siva Konda Reddy, V. Rohini Padmavathi and Ch. Srikanth, "Study of wind load effect on tall RC chimney," IJAET. Vol.III, Issue II, pp 92-97, April-June 2012.

[4] Alok David John, Ajay Gairola, Eshan Ganju and Anant Gupta, "Design wind loads on RC chimney – An exoerimental case study," Procedia Engineering Vol.14 (2011) 1252-1257.

[5] G. Murali, B. Mohan, P. Sitara and P. Jayasree, "Response of mild steel chimney under wind loads," IJERA Vol. 2, Issue 2, Mar-Apr 2012, pp. 490-498.

[6] C. Yoganantham and M. Helen Santhi, "Modal analysis of R.C.C chimney," International Journal of Research in Civil Engineering Vol. 1, Issue 2, Oct-Dec 2013, pp. 20-23.

[7] IS 6533(Part 2) – 1989, "Indian Standard Code of practice for Design and Construction of Steel Chimney", BIS (New Delhi).

[8] IS 800 – 2007, "Indian Standard Code of Practice for use of Structural Steel in General Building Construction", BIS (New Delhi).

[9] IS 875(Part 3) – 1987, "Indian Standard Code of Practice for Design Loads for Buildings and Structures", BIS (New Delhi).

[10] S. N. Manohar, "Tall Chimneys – Design and Construction", 1985, TATA McGraw – Hill Publishing Company Limited.