DYNAMIC BEHAVIOUR OF TALL CHIMNEYS

Babu[1], B. Jose Ravindraraj[2], R. Ram Kumar[3], R. Saranya[4]

[1]PG Scholar, Structural Engineering, PRIST University Thanjavur, Tamil Nadu, India.
[2]Assistant Professor, Civil Engineering, PRIST University Thanjavur, Tamil Nadu, India.
[3]PG Scholar, Structural Engineering, PRIST University Thanjavur, Tamil Nadu, India.
[4]PG Scholar, Structural Engineering, PRIST University Thanjavur, Tamil Nadu, India.

Abstract

Chimneys are very important structures for the emission of poisonous gases in power plants. After realising the urgent need to restrict the pollution levels, chimney height is being rapidly increased. So most of the chimneys are tall slender structures which fail due to wind excitation The present study discusses the dynamic behaviour of tall chimneys. Reinforced concrete chimney of 275m high, which is located in warora, Maharastra is taken for the present study. The objective of this project is to study the change in the stress pattern due to presence of flue holes and also to carry out the influence of along wind and across wind effects on the height of chimney for different wind speed and location. The analyse of chimney is carried out by developing a three dimensional model created with plate elements using STADD Pro. The stress concentrations in the flue duct in the chimney have been studied.

Keywords: *Tall Slender, Warora, Maharastra, Flue Holes, STADD Pro, Stress Concentration.*

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1. INTRODUCTION

As large scale industrial developments are taking place all around the world, a large number of tall chimneys would be required to be constructed every year. The primary function of chimney is to discharge poisonous gases to a higher elevation such that the gases do not contaminate the surrounding atmosphere. Due to increasing demand for air pollution, height of chimney has been increasing since the last few decades, However chimneys being tall slender structures generally with circular cross sections, they have different associated structural problems and must therefore be treated separately from other forms of tower structures. Analysis and design of chimney depends on various factors such as wind force, environmental conditions, types of materials used and cross sectional area of the chimney. Chimneys over the height of 150m are considered as tall chimneys. Tall RC chimneys form an important part of major industries and power plants. Damage to the chimneys leads to shut down of the industry and power plants. A chimney achieves simultaneous reduction in concentration of number of pollutants.

1.1 Functions of Chimney

A chimney is a means by which waste gases are discharged at a high elevation so that after dilution due to atmospheric turbulence, their concentration and that of their entrained solid particles is within the acceptable limits on reaching the ground. A chimney achieves simultaneous reduction in concentration of a number of pollutants such as sulphur dioxide, fly ash etc and being highly reliable it does not require a standby. While these are the distinct merits, it is well to remember that a chimney is not the complete solution to the problem of pollution control

1.1.1 Material of Construction

The popular material for construction of chimney in the beginning were steel and brick, As chimney grew taller, a stage was reached when brick become uneconomical and was replaced by the steel chimneys and reinforced concrete chimneys. In recent years reinforced concrete is the has greater resistance against wind induced vibration and foundation settlement.

1.1.2 Height of Chimney

Chimney with a height exceeding 150m are considered as tall chimneys, However with the recent emphasis on structural dynamics, it is generally accepted that the chimney may be considered as tall when its height exceeds 150m and in addition its aspect ratio is such that it calls for evolution of the structural response to the dynamic wind loads. Thus it is not only a matter of height but also the aspect ratio when it comes to classifying a chimney as tall.

1.1.3 Number of Flues

The flue will be made of steel or brick. Often, a single chimney serves more than one boiler. In such a case, when one of the gas sources is shut down for maintenance, the gas exit velocity will be reduced because of a reduction in the total volume of the gases to be handled. This can lead to heavy pollution and in order to overcome this problem, a chimney serving more than one boiler can be provided with a separate flue for each gas source with such flue housed in a common enclosing concrete wind shield. These are popularly called multi flue chimneys. The steel flue liners can be used up to the exit velocity of 45 m/s, where as brick flue liners can be used upto 30 m/s.

1.2 Need for Study

Typically the most critical section in the chimney is the bottom portion of the chimney, where huge openings are provided for the flue duct entry. Around the openings the beam column arrangement with extensive reinforcement is provided to take care of the increase in stresses due to presence of openings. Hence extensive studies is required to suggest viable alternatives.

1.3 Objectives

The objective of the present study is to understand the behavior of tall RC chimneys. It is proposed

1. To study the changes in the stress pattern due to presence of flue holes.
2. To carry out the influence of along wind and across wind effects on the height of chimney for different wind speeds.

1.4 Methodology

The methodology adopted to achieve the objectives of this research work is presented in Chart-1

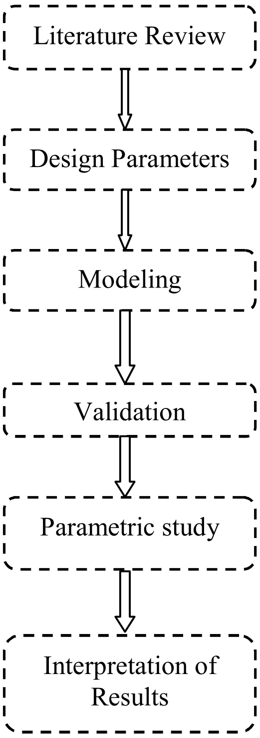


Chart -1: Methodology adopted

2. STRUCTURAL ARRANGEMENT

As an initial step a typical RC chimney of height 275m has been taken and analysed. The details of the chimney taken for the study and the details of load to be considered in the design are elaborated.

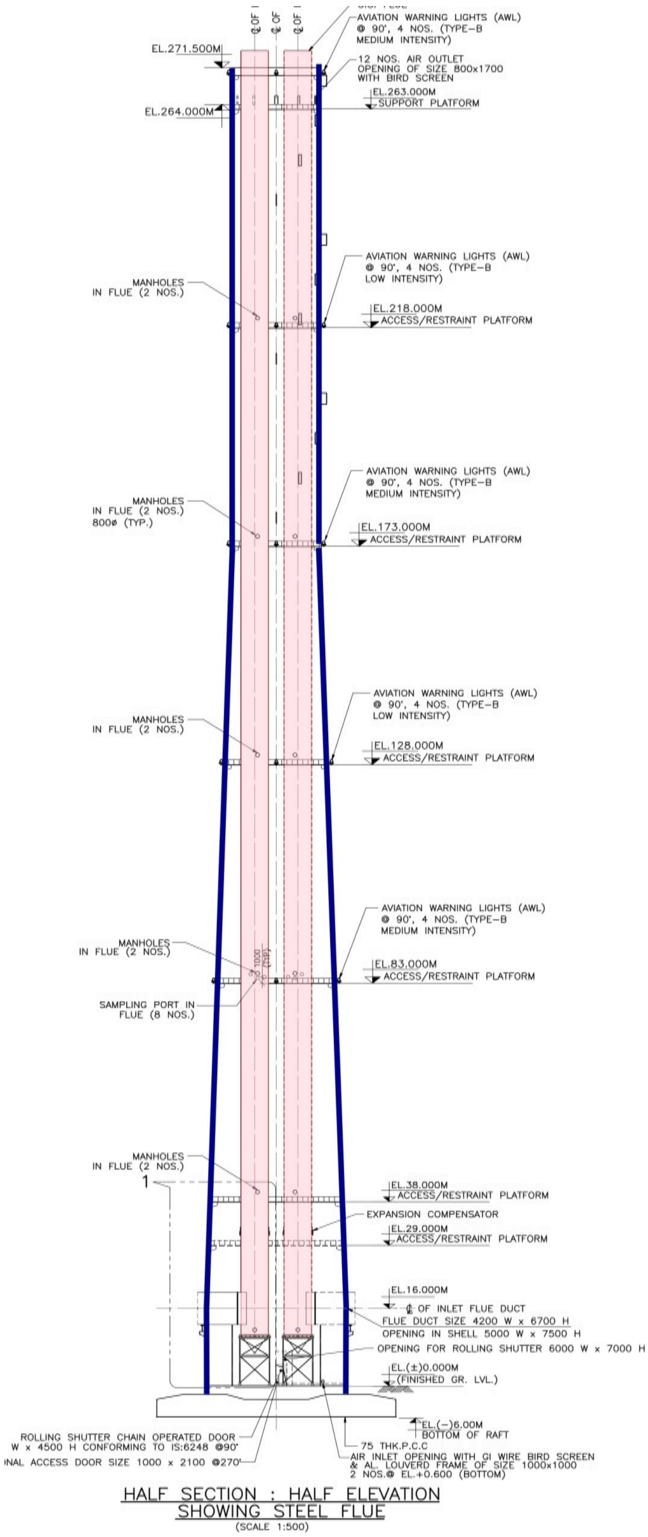


Figure -1: Elevation of chimney

2.1 Details of Chimney

The chimney consist of two main parts viz.outer shell and inner shell.The flue gases having temperature above 150˚C will have to be discharged in the atmosphere above 275m,with minimum exit velocity of 25m/s.To reduce the concentration of entrained solid particles in the waste gases, after dilution in atmospheric turbulence such that they are within acceptable limits on reaching the ground.

2.1.1 Outer Shell

Outer shell is a cylindrical cantilever structure of reinforced concrete thin structure which supports the flues and shields the flues from heavy wind.

2.1.2 Steel Flue Liner

It is a steel duct which provides a clear path for the passage of flue gases or waste gases above temperature 150˚C from zero. It protects the concrete windshield from high temperature and also protects the concrete against corrosive gases and acids.

2.1.3 Foundation

The foundation of chimney shall be annular raft or solid circular raft. The foundation is to be designed for dead load from the super structure and moment due to wind load. The main advantage of using raft foundation is higher uniform soil pressure under dead loads, it minimizes the gradual tilting of foundation laid on the cohesive soil, when the structure is subjected to lateral loads from a predominant wind direction.

2.2 Geometric Properties

The geometric properties of tall RC chimney under consideration is given below
Height of chimney- 275m
Number of flues- 2
Wind shield (material of construction)- Reinforced concrete
Flue (material of construction) - Steel
Outer diameter of flue- 5.22m
Inside diameter of flue - 5.2m
Centre to centre distance between flue- 8.18m
Level of foundation - -6.0m
Shell diameter at the top of raft- 27m
Thickness of cell at top of raft - 0.70m
Shell diameter at top of chimney- 17m
Thickness of cell at top of chimney- 0.35m
Grade of concrete used- M35
Basic wind speed- 44m/s
Earth quake zone- III
Soil condition- Hard rocky strata

2.3 Material Properties

Static modulus = $5000\sqrt{fck}$
$= 5000 \times \sqrt{35}$
$= 2958040$ t/m²
Dynamic modulus = 3.5×10^{10} t/m²

2.4 Details of Platform Provided

Platforms are provided at the intermediate level to permit only longitudinal movement and lateral resistant is provided against horizontal load due to earthquake and wind. There are eight platforms provided at the intermediate levels as shown in Table 1.

Table -1: Platform provided

Platform	Platform level (m)
1	29
2	38
3	83
4	128
5	173
6	218
7	263
8	270

3. TWO DIMENSIONAL MODELLING

A preliminary investigation to assess the behavior of the tall RC chimney under consideration has been carried out. A stick model using STADD pro has been developed .The details of the model, loading considered and analysis result are elaborated

3.1 Load Calculation

The dead load acting on the chimney is due to the shell, platform and staircase.

Table -2: Total dead load acting on the chimney

Level (m)	Load due to Beam (t)	Grating Load (t)	Staircase weight (t)	Flue Load (t)	Total Dead Load (t)
270	48	90	0	0	138
263	54	5.7	22.5	900	982.2
218	19	5.7	45	0	69.7
173	19	5.7	45	0	69.7
128	26	5.7	45	0	79.5
83	34	5.7	45	0	90.7
38	42	5.7	27	0	84.2
29	44	5.7	19	0	78.9

Total live load acting on the chimney is given by

Table -3: Total Live load acting on the chimney

Level(m)	Live load (t)
270	16
263	16
218	16
173	16
128	25
83	34
38	45
29	47

The wind load on the chimney was calculated as per IS : 875 (Part 3) – 1987
Basic wind speed V_b = 44m/s
Risk co efficient K_1= 1.07

3.2 MODELLING

The chimney has been modeled in STADD Pro as beam element .The stick model has been developed for 275m tall chimney. For the preliminary study, 2D beam element is considered. The support at the base is fixed. Nodes are provided by discretization of the structure at 25m intervals

Table -4: Location of Nodes

Nodes	Height (m)
1	-6
2	0
3	7
4	25
5	50
6	75
7	100
8	125
9	150
10	175
11	200
12	225
13	250
14	275

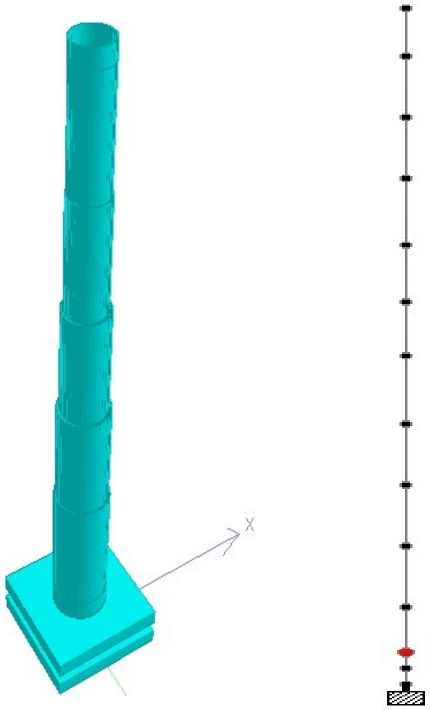
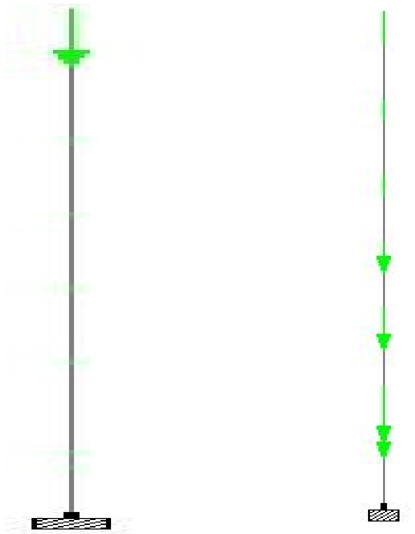
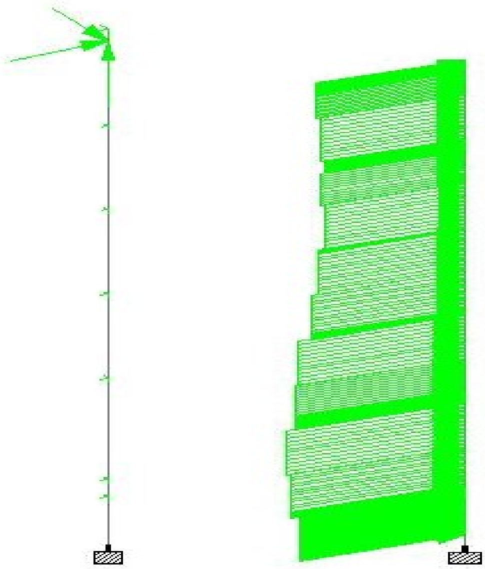


Figure -2: 2D model of RC chimney using STAAD Pro

The Dead load, Live load, Seismic load and Wind load is given as,



Dead load **Live load**



Seismic load **Windload**

Figure -3: Input loads in STADD Pro

3.3 Frequency of The Chimney

The model generated using STAAD-Pro was analysed for the various load combinations mentioned in this chapter. The frequency of the chimney obtained from the STADD Pro results are given in the Table below

Table -5: Frequency of the chimney

Mode	Frequency (Hz)	Period (sec)
1	0.252	3.966
2	1.055	0.947
3	1.059	0.370

4. THREE DIMENSIONAL MODELLING

A Three Dimensional modeling has been created using plate element. The modal analysis is performed to study the dynamic behavior.

4.1 Modeling

The chimney has been modeled in STADD Pro as plate element .The 3D model had been developed for 275m tall chimney. The support at the base is fixed.

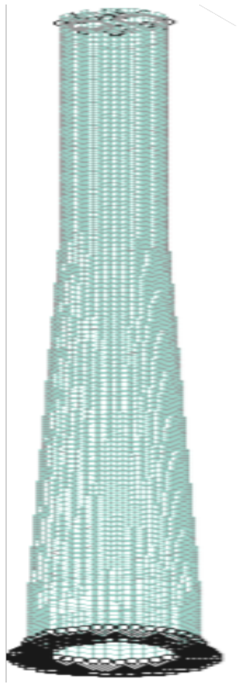


Figure -4: 3D Plate model

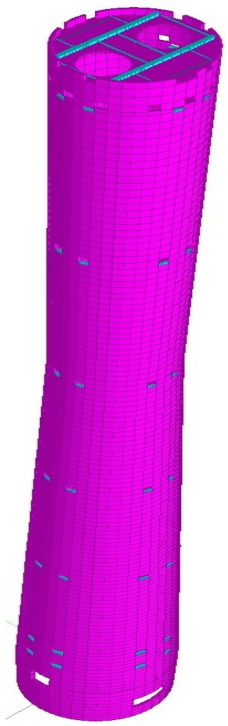


Figure -5: Rendered view of chimney

4.2 Openings Provided For Modeled Chimney

The openings have to be provided in the wind shields to accommodate the beam supports .The openings are deducted for the flue duct, vehicular flue erection, and platforms provided at the intermediate levels.

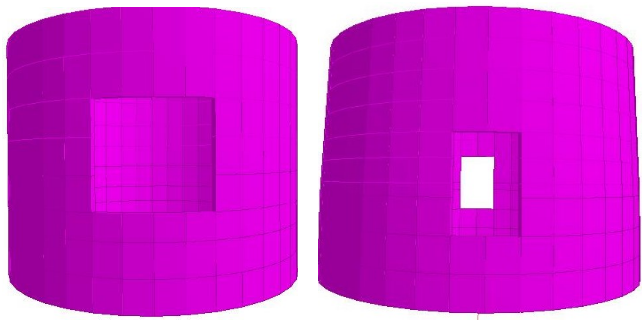


Figure -6: Shows the opening for vehicular flue erection and opening for flue duct

4.3 Providing Platform

The platforms rest on the shell. So openings have to be provided in the wind shield to accommodate the beam supports. The platforms are provided to support the flue and also to access the flue area for maintenance and inspection. There are eight platforms provided at the intermediate level to permit only the longitudinal movement and lateral restraint is provided against horizontal load due to earthquake and wind load

Table -6: Details of platform provided

Platform	Platform level (m)
1	29
2	38
3	83
4	128
5	173
6	218
7	263
8	270

5. RESULTS AND DISSCUSION

Wind is essentially the large scale movement of free air due to thermal currents. It plays an important role in chimney design because of its capacity to transport and disperse pollutants and also because it exerts dynamic loads whose effect on a slender structure such a chimney is significant.

5.1 WIND LOAD CALULATION

Dynamic wind load induces along wind and across wind load on a RC chimney. Hence to estimate wind loads knowledge of its characteristics is important
The two methods of estimation of along and across wind loads are

1. Simplified Method
2. Random Response Method

5.2 Along Wind Effect

The along wind effects 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 effects are due to the direct buffeting action, when the wind acts on the face of the structure. The chimney should be modeled as a cantilever structure for the calculation of loads.

5.2.1 Simplified Method

The along wind load or drag force per unit height of chimney at any level shall be calculated from the equation

$F_z = P_Z \, . \, C_d . \, d_z$

Where

P_Z- Design wind pressure obtained in accordance with the IS 875(Part 3)1987.

Z- Height of any section of the chimney in m, measured from the top of foundation

C_d- Drag co-efficient of the chimney

d_z - Diameter of chimney at height z in m

Height of the chimney H=275m

Basic wind speed V_b=44 m/sec

Probability factor K_1=1.07

Terrain category is taken 2 with well scattered obstructions over a height of 1.5m to 10m.

Structure classification- Class A components having maximum dimension of 20m

Topography factor K_3=1

Drag Coefficient of Chimney C_d = 0.8 upto 175m and C_d = 0.927 from 175m to 275m.

5.2.2 Random Response Method

The along wind response of the chimney is calculated by the gust factor method .The gust factor is defined as the ratio of the expected peak load to the mean load.

The along wind load per unit height on the chimney

$F_z = F_{zm} + F_{zf}$

where F_{zm} is the wind load in N/m height due to hourly wind speed

$F_{zm} = P_Z \, . \, C_d \, . \, D_z$

Where

F_{zf} is the wind load in N/m height due to the fluctuating component of wind

Basic wind speed V_b=44 m/sec

Background factor indicating the slowly varying the component of wind load fluctuation B=0.53

Turbulence Frequency r = 0.187.

Size reduction factor S = 0.151

Structural damping as the friction of critical dampingβ=0.016

Energy Response Spectrum E= 0.0602

Gust factor G=1.54

Natural Frequency of the chimney in the first mode of vibration f_1=0.3

Hourly Mean Wind speed V_{10} =29.48 m/s

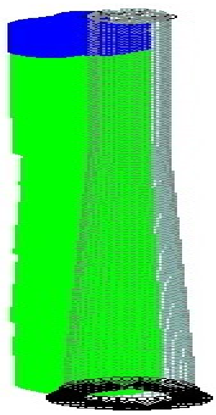
Peak Factor g=2.65

5.3 Analysis Of Chimney Using Staad Pro

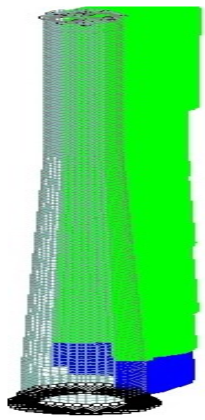
After calculating the load, the chimney should be analysed for following loads

1. Dead load including the selfweight , grating load , staircase load, hand rail load
2. Live load including flue load
3. Seismic load in X and Z direction
4. Wind load includes

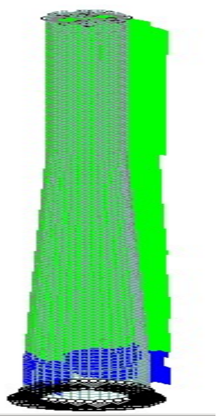
a) Along wind load in simplified method in both X and Z direction
b) Along wind load in Random Response method in both X and Z direction
c) Across wind load in both X and Z direction
d) The load combinations are taken as per IS456-2000
e) 1.5x(Dead Load + Wind load)
f) 1.2x(Dead Load +Live load + Wind load)
g) 0.9 x(Dead load + 1.5 x Wind load)
h) 1.5 x (Dead load + Seismic Load)
i) 0.9 x (Dead load + 1.5 x Seismic load)
j) 1.2 x (Dead Load +Live load + Seismic load)



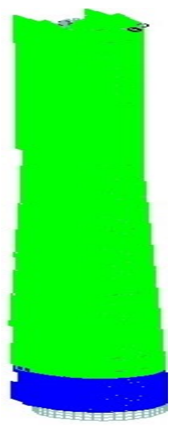
Wind load in +X direction



Wind load in -Xdirection



Wind load in +Z direction



Wind load in +Z direction

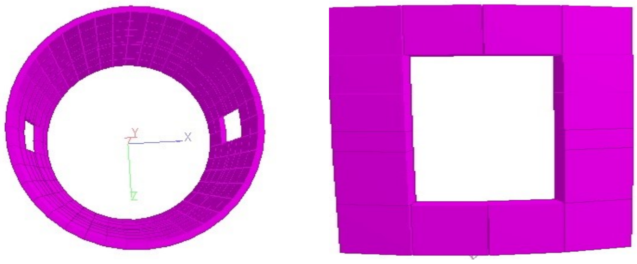
Figure -7: Wind loads as given in STADD Pro

5.4 STRESS PATTERN IN FLUE HOLES

The model generated has been analysed for the different combinations . There are two openings provided at the chimney for the flue duct. The openings are in rectangular and semi circular shape.

5.4.1 Flue Duct with Rectangular Opening

The flue holes with the rectangular opening had a maximum compressive stress compared to the circumferential hoop stress



Plan view **Rectangular opening**

Figure -8: Rectangular opening in flue

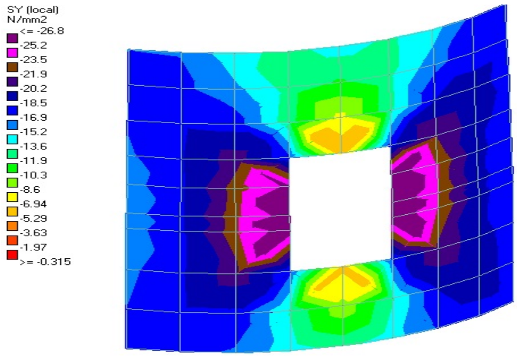


Figure -9: Stress Pattern in rectangular duct

Table -7: Maximum stress in rectangular flue duct

Openings	Hoop Stress (σ_x) (N/mm^2)	Compressive Stress (σ_y) (N/mm^2)
Rectangular opening	5.19	26.8

5.4.2 Flue Duct with Semicircular Opening

When the flue duct is provided with the semicircular opening, compressive stress is maximum compared to the circumferential hoop stress.

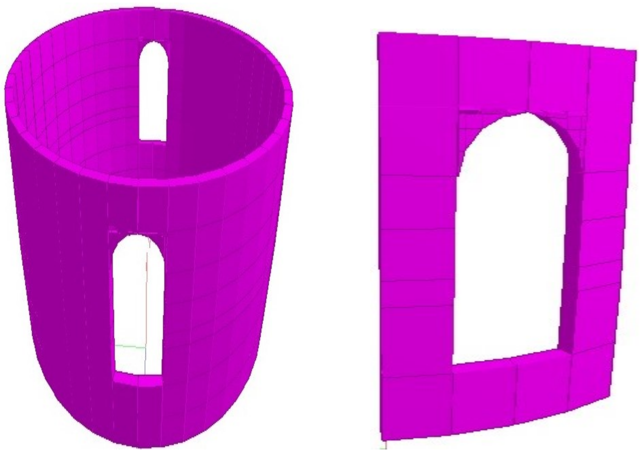


Figure -9: Semi circular opening in flue

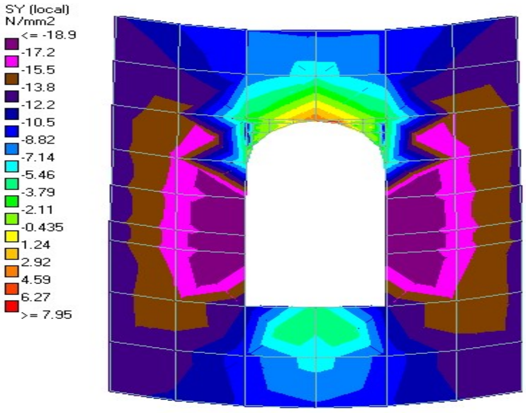


Figure -10: Stress Pattern in Semicircular duct

Table -8: Maximum stress in semicircular flue duct

Openings	Hoop Stress (σ_x) (N/mm^2)	Compressive Stress (σ_y) (N/mm^2)
Semi circular opening	4.45	18.9

When comparing the results of both rectangular and semicircular openings, it is seen that there is a reduction of stresses of the order of 30 percent around the corners. It is necessary to provide the extensive reinforcement for the rectangular opening around the openings because the stresses are maximum. But for the semicircular opening, the stresses around the corners are significantly reduced.

6. CONCLUSIONS

The main objective of the present study was to explain change in the stress pattern due to presence of flue duct and also to study the effect of along wind and across wind effects for different wind speeds. A detailed literature review is carried out as part of the present study on wind engineering, design and analysis of reinforced concrete chimney. Estimation of wind effects such as along wind and across wind methods are studied. There is no literature published on the effect of stress due to the presence of the flue duct. A typical reinforced concrete chimney of 275m height is taken for the present study. The chimney is modeled as a two dimensional beam element and three dimensional plate elements. Both the models are analysed for wind load .After analyzing the chimney, stress around the corners of flue duct are studied for two different openings such as rectangular opening and semi circular opening . It is seen that the compressive stresses around the corners are significantly reduced by about 30% and also seen that as the wind speed increases, the along wind load also increases.

The following conclusions are drawn from the following analysis

1. The wind load always governs factor the design of reinforced concrete chimney.
2. The along wind effect has a major primary effect on chimney and governs the design, when compared to the across wind effect.

3. The semicircular flue duct has a minimum compressive stress around the corners , when compared to the flue duct with rectangular opening
4. The stresses around the opening are reduced by 30% for the semicircular flue duct.
5. The along wind increases with the increasing wind speed.
6. Irrespective of the wind speed, the across wind speed increases linearly only with increase in the weight of the chimney, frequency and its mode shape.

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