Effect of Flue Supports in the Analysis of Multiflue RCC Chimney

Ms.Choppalli Kalyani R, Dr. Yogesh D Patil

Abstract—It has been observed that most of the existing studies have focused on the load considerations for design of tall chimneys. To make a further contribution to this study, this paper presents the load parameters considered for the design of RCC chimney and focuses on one of the structural parameters of RCC chimneys viz. the effects of number of supports to the flue. A brief review on the types of supports is presented in this paper and analysis is carried out for different kinds of supports to the flue. The comparison of results is plotted. The software STAAD Pro and MS Excel sheets have been used for design.

Index Terms— Analysis of chimney, Multiflue chimney, Parametric analysis, Steel flue supports, Tall RCC chimneys.

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1 INTRODUCTION

INDUSTRIAL chimneys are of great importance as they serve a useful function of disposal of a large amount of waste gases in the atmosphere at high altitudes so that it dilutes before it settles down. The construction of tall, reinforced concrete chimneys has been on the increase in the last few decades owing primarily to the increasing demand of air pollution control. Chimneys in the range of 275m have been built and there is every reason to believe that this trend toward the taller chimneys will continue.

Because of the changes in the proportions of chimneys many structural problems, such as the response to earthquake and wind forces, became more critical.

Hence, the study of the parameters affecting the construction and performance of tall chimneys has acquired importance. This paper discusses one such parameter, the number of flue supports of a 275m tall RCC multiflue Chimney

2 DESIGN OF CHIMNEY

The design of a chimney has the following stages:

Physical dimensioning
Load calculations
Analysis for wind
Analysis for earthquake
Shell design
Liner design
Accessories design

2.1. PHYSICAL DIMENSIONING:

A chimney is sized such that it can exhaust a given quantity of flue gases at a suitable elevation and with such a velocity that the ground level concentration (GLC) of the pollutants, after atmospheric dispersion is within the limits prescribed in the pollution regulatory standards while the chimney retains its structural integrity. Thus while handling a given quantity of flue gases, the major factors which influence a chimney's dimensions are

Draft requirements.
Environmental regulations.
Structural considerations.

Analysis of wind is done in accordance with IS 875 & IS 4998 (Part 1) and earthquake loads are analysed in accordance with IS 1893. Shell design is done in accordance with IS 4998-1975.

Accessories of chimney include Cap, Lightening protection aviation warning lights, Aviation warning lights, Ladder, Clean out and access doors, Breaching connection, Mounting for lifting materials, Air vents, Galleries, Soot hopper & Platforms

2.2. LOAD CONSIDERED FOR DESIGN OF CHIMNEY:

The following loads are considered for the analysis and design of the chimney:

Dead loads
Live loads
Wind loads
Seismic loads,
Temperature effects.

2.2.1. DEAD LOADS

Dead loads shall include the weight of chimney shell, liners, liner supports, other accessories and load of ash and soot as applicable.

- *Choppalli Kalyani Ramarao is currently pursuing masters degree program in structural Engineering in S.V.N.I.T,Surat, India. Email:kalyani.choppalli@gmail.com*
- *Dr. Yogesh D. Patil, Asst. Professor, Applied Mechanics Department, S.V.N.I.T. Surat, India. E-mail: chipatil@yahoo.com*

2.2.2. LIVE LOADS

Live loads shall be taken in accordance with IS 875 (Part 2):1987. The imposed loads on internal platform and hood of multi-flue chimneys shall include appropriate loads during construction.

2.2.3. WIND LOADS

The effect of wind on these tall structures can be divided into two components, known respectively as

Along-Wind Effect
Across-Wind Effect

The former is accompanied by 'gust buffeting' causing a dynamic response in the direction of the mean flow, whereas the latter is associated with the phenomenon of 'vortex shedding' which causes the chimney to oscillate in a direction perpendicular to the direction of wind flow. Estimation of wind effects therefore involves the estimation of these two types of loads.

Along Wind Effects

Along-wind loads are caused by the 'drag' component of the wind force on the chimney when the wind acts on the face of a structure. For the purpose of estimation of these loads the chimney is modeled as a cantilever, fixed to the ground. The wind is then modeled 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 modeling 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. Hence most codes use an 'equivalent static' procedure known as the gust factor method. This method is immensely popular and is currently specified in a number of building codes including the IS (IS: 4998) code. This process broadly involves the determining of the wind pressure that acts on the chimney due to the bearing on the face of the chimney, a static wind load. This is then amplified using the 'gust factor' to take care of the dynamic effects.

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 modeled as a cantilever, fixed to the ground. The wind is then modeled to act on the exposed face of the chimney causing predominant moments in the chimney.

Across Wind Effects

Across-wind loads are caused by the corresponding 'lift' component of wind. In spite of considerable research the problem of accurately predicting the across-wind response has to be fully resolved. Hence the CICIND code does not take into account across-winds. For this study the codes used therefore were the IS 4998(Part 1): 1992 and the ACI 307-95.

2.2.3.1. STATIC WIND EFFECTS

Drag Force

Wind exerts a static force known as drag on a bluff body obstructing an air stream. The distribution of wind pressure around the circumference of such a body depends on its shape and direction of wind incidence.

The drag force on a single stationary bluff body can be written down as

$Fd = (1/2)\ xCdxAx\rho_{a}xU2$
Where,
Fd = drag force in N
Cd = drag coefficient
A = area of section normal to wind direction in sq. m.

Circumferential Bending

The radial distribution of wind pressure on a horizontal section of a chimney depends on Re. It is assumed that the along wind resultant of such pressures is balanced by the resultant of shear forces induced in the structure and these shear forces, in turn are assumed to vary sinusoidally along the circumference of the chimney shell. With these assumptions, bending moments in the shell can be obtained using established analytical methods.

2.2.3.2. DYNAMIC WIND EFFECTS

Gust Loading

The literal meaning of gust is a short blast of wind. 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 modeling 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. Hence, most codes use an 'equivalent static' procedure known as the gust factor method. This method is immensely popular and is currently specified in a number of building codes including the IS (IS: 4998) code. This process broadly involves the determining of the wind pressure that acts on the chimney due to the bearing on the face of the chimney, a static wind load. This is then amplified using the 'gust factor' to take care of the dynamic effects.

All along-wind loads that act on the chimney are not due to the static wing bearing on the surface of the chimney alone. There is a significant change in the applied load due to the inherent fluctuations in the strength of wind that acts on the chimney. It is not possible of feasible to take the maximum load that can ever occur due to wind loads and design the chimney for the same. At the same time it is very difficult to quantify the dynamic effect of the load that is incident on the chimney. Such a process would be very tedious and time consuming. So, most of the codes make use of the gust factor to account for this dynamic loading. To simplify the incident load due to the mean wind is calculated and the result is amplified by means of a gust factor to take care of the dynamic nature of the loading.

The gust factor is defined as the ratio of the expected maximum moment to the mean moment at the base of the chimney.

Aerodynamic Admittance

A structures response to wind load, at any frequency, depends on the spatial characteristics of wind turbulence. This aspect is taken into account by a term called "aerodynamic admittance coefficient". The calculated response of a structure to wind load has to be multiplied by this aerodynamic admittance coefficient to allow for response modification due to spatial wind turbulence characteristics.

Vortex Formation & Excitation

A vortex is a spinning, often turbulent, flow of fluid. Any spiral motion with closed streamlines is vortex flow. The motion of the fluid swirling rapidly around a center is called a vortex.

The phenomenon of alternately shedding the vortices formed in the wake region is called vortex shedding. This is the phenomenon that gives rise to the across-wind forces.

This phenomenon was reported by Strouhal, who showed that shedding from a circular cylinder in a laminar flow is describable in terms a non-dimensional number Sn called the Strouhal number.

$$S_n = \frac{shedding\_frequency \times diameter\_of\_cylinder}{mean\_flow\_velocity}$$

The phenomena of vortex shedding and hence the across-wind loads depends on a number of factors including wind velocity, taper factors etc., that are specified by the codes. Codal estimation of the across-wind loads also involves the estimation of the mode-shape of the chimney in various modes of vibration.

Wake Bufetting

Buffeting is defined as the unsteady loading of a structure by velocity fluctuations in the incoming flow and not self-induced. Buffeting vibration is the vibration produced by turbulence.

Wake buffeting is the aerodynamic effect on a downstream chimney due to vortices shed from an upstream structure. Buffeting effects in any particular case should be evaluated on a scale model tested in wind tunnel. Information on wind pressures exerted due to buffeting is limited in spite of the fact that many chimney are built in groups and in the proximity of other tall structures.

Buffeting effects in any particular case should be evaluated on a scale model tested in a wind tunnel. Based on previous model tests, the following broad observations may be made

A leeward chimney experiences much larger amplitudes than a windward one

Buffeting effects on a chimney due to another similar chimney depend on spacing between them. the interference effect reaches a maximum when the centre to centre spacing between similar chimneys is about five times the diameter measured at one third the height from the top.

In a chimney, oscillations of large amplitude can be caused if the predominant frequency of vortex shedding from an upstream obstruction coincides with its natural frequency. Thus, frequency mistuning is an important tool to reduce buffeting effect.

2.2.4. SEISMIC LOAD / EFFECTS

Chimneys are particularly vulnerable to earthquakes because they are tall, slender structures. Such structures have to be carefully designed to safely withstand the forces likely to be imposed on them by ground motion.

An earthquake resistant design essentially consists of evaluating the structural response to an assumed likely ground motion and then calculation the corresponding shear forces and bending moments which the structure needs to safely resist. The characteristics of a likely ground motion depend on source mechanism, properties of the sub surface media transmitting seismic waves, reverberations in local layered geology and many such factors.

Many a times a designer often has to work with very limited information regarding the characteristic and frequency of past ground excitations and simplifying assumptions necessary in respect of soil structure interaction, structural stiffness, damping, etc,.

For analysis, a chimney is treated as a cantilever beam with predominant flexural deformation sand is analysed by one of the following methods.

Response spectrum method
Modal analysis technique
Time history response analysis

The time history response analysis is the most accurate of all the methods but still is not frequently used as compared to other methods because of lack of knowledge and availability of the actual ground motion data. In this method a structure's response history is evaluated by subjecting its mathematical model to a design earthquake. The analysis is carried out for each incremental time interval and at each stage the structural response is evaluated. For this purpose, earthquake records at the site are analyzed at the structure subjected to more than one such earthquake motion in order to even out the peaks. Alternatively a series of artificially generated accelerogram may be used.

2.2.5. TEMPERATURE EFFECTS

The concrete shell of a chimney has to withstand the effects of a thermal gradient prevailing across its thickness. As a result of such temperature gradient, vertical and circumferential stresses are developed whose values can be determined after establishing the magnitude of the thermal gradient under steady state conditions.

As per the CICIND Model code for chimneys, the effects of temperature differences between the inner and outer faces of the concrete shell should be calculated for the steady state heat flow. The characteristic value of the flue gas temperature should be determined from the given operational conditions and controls.

The characteristic value of the ambient temperature should be taken as the regional average minimum temperature for the two coolest months of the year.

Temperatures may be for simplicity be calculated as for plane walls incase of chimneys.

Loading Combinations To Be Considered For Design

Dead loads
Dead loads + wind loads
Dead loads + earthquake loads
Dead loads + temperature effects
Dead loads + wind loads + temperature effect
Circumferential effect due to wind
Circumferential effect due to temperature
Circumferential effect due to wind + temperature

3. FLUE CAN SUPPORT SYSTEM

The supporting system for the flue cans be sub classified as

Top hung
Bottom supported
Intermediate supported

With top suspended arrangement, the liner walls are normally in tension but they are subjected to large thermal expansion in downward direction. The thermal movement may be as much as 90cm for a 275m tall chimney liner. This magnitude of vertical movement cannot be tolerated at the breaching; therefore provision of expansion joint becomes a must.

In a bottom supported liner thermal expansion is upward and expansion joint is not needed. Steel liner walls are prone to buckling failure near support due to differential temperature loading. The design results in thicker flue can sections. Usually steel liners are not preferred to be supported at the bottom.

At times, support is provided at two or more locations with more expansion joints usually between support and breaching opening for a two support condition.

In all these types horizontal restraint are required to be provided at few elevations.

In this paper, we have analysed the chimney with single flue support and two flue support condition and effects of these support conditions on the concrete shell are plotted.

4. PARAMETERS OF THE CHIMNEY CONSIDERED FOR BASIC DESIGN:

Total height of the chimney above grade level. : 275 m.
No. of flues : Two
No. of Boilers : Two
Volume of Gas per Boiler. : 1280 m3/sec
Mass flow of Gas : 4000 T/h
Density of gases : 0.85 kg/m3
Temperature of flue gases. : 130^o C
Top Internal shell diameter : 20 m
Top External shell diameter : 20.8m
Bottom internal shell diameter : 27.054 m
Bottom external shell diameter r : 29.045 m
Location : Malwa (Madhya Pradesh)
Steel grade : Fe 500
Flue diameter : 7.4m

Loads considered for the analysis of support platform for steel flue:

Self-weight of platform
Grating load
Live load
Weight of flue cans to be supported

Figure 1 shows the typical section of flue supporting platform & Figure 2 shows the STAAD Model for chimney analysis.

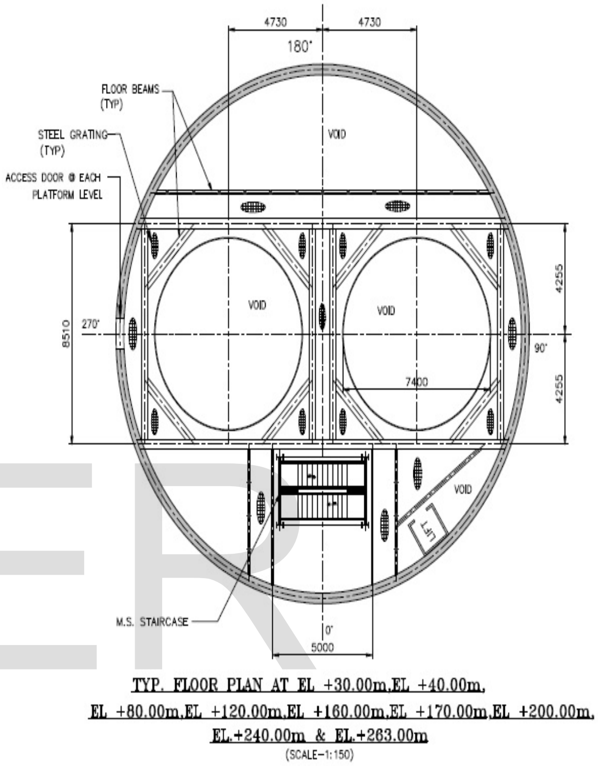
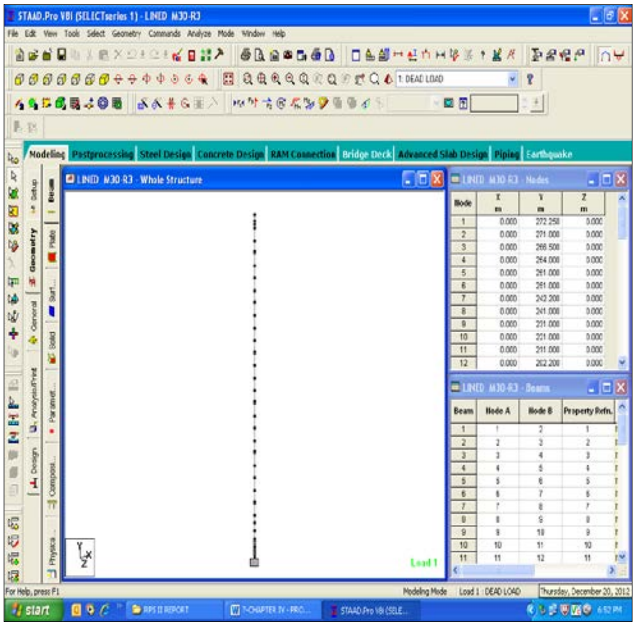


Figure 1: Typical section of flue supporting platform

Following are the steps followed for the analysis of chimney for this comparison:

1. Arriving at the geometry of the shell satisfying the flue disposal requirements.
2. Analyzing the shell in accordance with IS 4998-1992 considering the following loads and criteria:
3. Weight of chimney including accessories
4. Weight of flue liners
5. Wind loads both vertically and circumferential
6. Earthquake loads
7. Effects of temperature, both vertically and circumferentially
8. Weight of support and restraint platforms
9. Location and width of opening in the shell
10. Plotting the results in terms of Bending moments and concrete stresses & Comparison.



LINED M30-R3 - Nodes

Node	X m	Y m	Z m
1	0.000	272.250	0.000
2	0.000	271.000	0.000
3	0.000	266.500	0.000
4	0.000	264.000	0.000
5	0.000	261.000	0.000
6	0.000	251.000	0.000
7	0.000	242.200	0.000
8	0.000	241.000	0.000
9	0.000	231.000	0.000
10	0.000	221.000	0.000
11	0.000	211.000	0.000
12	0.000	202.200	0.000

LINED M30-R3 - Beams

Beam	Node A	Node B	Property Refn.
1	1	2	1
2	2	3	2
3	3	4	3
4	4	5	4
5	5	6	5
6	6	7	6
7	7	8	7
8	8	9	8
9	9	10	9
10	10	11	10
11	11	12	11

Figure 2: Model of the chimney shell in STAAD PRO.

11. RESULTS

Figure 3 & Figure 4 present the comparison of Bending moments and stresses from the shell analysis

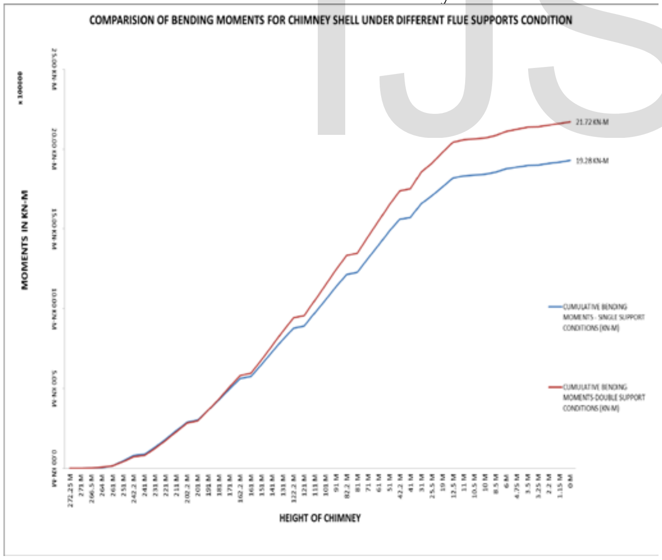


Figure 3: Comparison of Bending Moments for chimney shell for one support and two support flues.

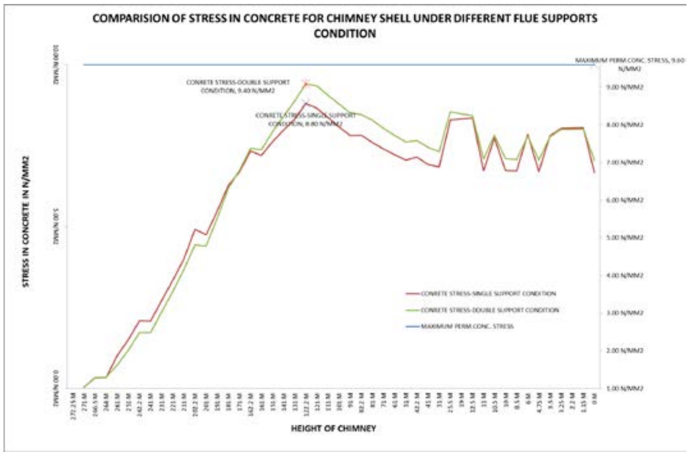


Figure 4: Comparison of Bending Stresses for chimney shell for one support and two support flues.

Material consumption for support and restraint platforms.

Elevation	Outer dia of shell	Internal dia of shell	Internal platform material consumption	
			One support	Two support
in m	in m	in m	in kN	in kN
270	20.8	20	460	460
263	20.8	20	769	560
240	20.8	20	300	300
200	20.8	20	300	300
170	21.08	20.25	590	590
160	21.37	20.5	590	590
120	22.5	21.5	590	590
80	24.68	23.35	590	590
40	26.86	25.2	590	590
30	27.41	25.67	590	590
Total			**5369**	**5160**

12. CONCLUSIONS

According to the above analysis of chimney shell for the load case Dead load + Wind load, the bending moment at the bottom of the chimney for double support system is 10.26% higher that those for the single support system.

Bending stresses in shell for one support flue analysis 6.61 % more than those for two support chimney.

Steel consumption for support and restraint platforms does not have a considerable difference.

Also, being supported at two levels, the tensile forces due to self weight of flue can reduces which in turn results in reduction of flue can thickness.

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