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Investigations on Chimneys Using Reinforced Concrete Stacks for Effective Construction and Economy

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Abstract— **This project deals with the analysis and design of Reinforced Concrete (RC) chimney. Such chimneys are presently designed in conformity with Indian Standard code of practice (IS 4998). The main loads to be considered during the analysis of tall structures such as chimneys are wind loads, temperature loads and seismic loads in addition to the dead loads. These are designed using working stress method. A chimney is a wind structure, i.e. a structure in whose design wind loads play a dominant role. In this project as the design has been carried out analytically, it was not possible to consider the dynamic component of wind in analysis. Instead measures have been taken as per Indian Standard Code to mitigate the effects due to "vortex shedding". The seismic loads are another cause of natural loads on the chimney. These loads, caused by earthquakes are generally dynamic in nature. However, the codes provide for quasi-static methods for the evaluation of these loads. Codal provisions normally recommend amplification of the 'normalized response' of the chimney with a factor that depends on the local soil conditions and the intensity of the earthquake. The temperature load effects are also an important consideration in the analysis of loads effects on chimneys taking into consideration the fact that the chimneys are used for the venting of hot gasses. This develops a temperature gradient with respect to the ambient temperature outside and hence causes stresses in the reinforced concrete shell. The design of chimney mostly deals with the analysis of concrete shell at different sections and to find the stresses in steel as well as concrete and ensure that they are in permissible limits as per the codal provisions. This requires the assumptions of chimney's shape and size and the materials prior to approach the problem of design. The size of the chimney depends on the volume of flue gases to be emitted and the height is fixed on the environmental considerations.**

Index Terms— **Chemical Corrosion, Lining and Insulation, Response Spectrum Method, Seismic Coefficient.**

I. INTRODUCTION

Past few decades the usage of reinforced concrete chimneys in place of steel chimneys and brick masonry has become very popular due to their low economy and durability. Composite material like reinforced concrete is exceedingly suitable for chimney stacks. Brick chimneys are very heavy requiring expensive foundations. In contrast to the steel chimneys, the maintenance costs are minimum in the case of concrete stacks. The development of slip form method of constructing cylindrical stacks has resulted in rapid construction in the case of concrete chimneys. Concrete stacks with lesser maintenance costs are architecturally superior to masonry and steel chimneys.

Typical dimensions of the chimney have been assumed to formulate the problem statement.

II. DESCRIPTION OF CHIMNEYS

A. Parts of Chimney

A reinforced concrete chimney is generally circular in shape with a rigid concrete shell cast with a rich concrete mix of M-30 to M-40 grade and provided with longitudinal vertical reinforcement and horizontal hoop reinforcement. A fire brick lining 100 to 150 mm thick is provided inside the concrete shell with an air gap to reduce the temperature gradient from the interior surface of fire brick lining to the exterior surface of the concrete shell.

Reinforced concrete brackets with holes are provided at regular intervals to support the fire brick lining. At the bottom of the chimney, provision is made for a flue opening. The chimney is generally made to rest on a circular raft foundation. The various parts of the chimney are shown in Fig.1

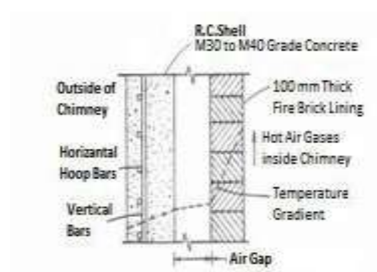


Fig.1 Typical cross section of chimney shell

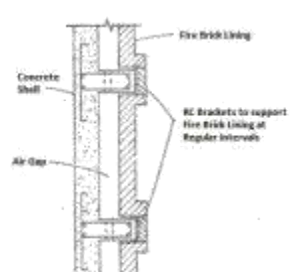


Fig.2 Parts of RCC Chimney

B. Design Factors

Reinforced concrete chimneys are designed to withstand the stresses developed due to

i. Self-weight of chimney

ii. Wind pressure

iii. Earthquake Loads

iv. Temperature stresses

III. ESTIMATION OF WIND LOAD EFFECTS

The wind load exerted at any point on a chimney can be considered as the sum of quasi-static and a dynamic-load component. The static-load component is that force which wind will exert if it blows at a mean (time-average) steady speed and which will tend to produce a steady displacement in a structure. The magnitude of force exerted by wind is dependent, among other things, on the wind speed and its fluctuations, R_e, etc. Hence to estimate wind loads, knowledge of its characteristics are important.

As per IS 4998 Part 1 "*criteria for design of reinforced concrete chimneys"* clause 4.3 says that Wind loads shall conform to IS 875 (Part 3): 1987. The procedure for estimating loads on chimneys due to wind as per *"Annex A of IS 4998"* is as follows:

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

$$F_z = P_z \times C_D \times d_z$$

Where

$\mathbf{P_z}$= design wind pressure obtained in accordance with IS 875 (Part 3): 1987

$\boldsymbol{z}$ = height of any section of the chimney in m measured from the top of foundation

C_D= drag coefficient of the chimney to be taken as 0.8

d_z=diameter of chimney at height z in m

The design wind pressure (Pz), for the along-wind response, shall be obtained in accordance with IS 875 (Part 3): 1987, taking the appropriate factor depending upon the class of the structure as defined in that standard as illustrated below:

Nature of Wind in Atmosphere: In general, wind speed in the atmospheric boundary layer increases with altitude from zero at ground level to a maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect) but this is ignored in the code. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the averaging time employed in analyzing the meteorological data and this averaging time varies from a few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust depends on the averaging time. In general, smaller the averaging interval, greater is the magnitude of the gust speed.

Basic Wind Speed (Vb): IS 875 Part III gives basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain (Category). Basic wind speeds presented in Fig. 1 have been worked out for a 50 year return period. Basic wind speed of 39 m/s (Roorkee) has been adopted in the calculations.

Design Wind Speed (Vz): The basic wind speed (V_b)obtained from above step shall be modified to include the following effects to get design wind velocity at any height (V_z) for the chosen structure:

a. Risk level.
b. Terrain roughness, height and size of structure.
c. Local topography.

It can be mathematically expressed as follows:

$$V_z = V_b K_1 K_2 K_3$$

Where

V_z = design wind speed at any height z in m/s

K_1 = Probability factor (Risk Coefficient)

K_2 = Terrain, Height and Structure Size Factor

K_3 = Topography Factor

The factors K_1, K_2, K_3 may be obtained from relevant clauses of IS 875 Part III.

Design Wind Pressure: The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$p_z = 0.6\, V_z^{\,2}$$

Where

p_z= design wind velocity in N/m^2at height z, and

V_z= design wind velocity in m/s at height z.

Note: The coefficient 0.6 (in SI units) in the above formula depends on a number of factors and mainly on the atmospheric pressure and air temperature. The value chosen corresponds to the average appropriate Indian atmospheric conditions.

This p_z obtained from IS 876 Part III calculations may be used in the calculations of forces due to wind at any section. Subsequently the moments due to wind may also be calculated. The calculations of the Chimney problem considered were done in further pages of the report.

IV. ESTIMATION OF EARTHQUAKE LOAD EFFECTS

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

A. Seismic Excitation

An earthquake-resistant design essentially consists of evaluating the structural response to an assumed likely ground motion and then calculating the corresponding shear forces and bending moments which the structure needs to resist safely. 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 other factors. Such ex-citation is random in nature which leads one to adopt design methods based on probability concepts and risk theories. However, such methods are not often used in chimney design and hence not considered in this project.

India has been divided into five seismic zones duly considering past earthquake occurrences and seismic-tectonic framework of various parts of the country. For each zone, the code stipulates a "zone factor" to adopt (taken from Table of IS 1893: 003) and a structure's response is assumed to follow an average acceleration response spectrum, as given in Fig.3 below for different degrees of damping.

Chimney vibration is essentially a dynamic problem of a transient nature. For analysis, a chimney (where the mass is nearly evenly distributed) is treated as a cantilever beam with predominant flexural deformations and is analyzed by one of the following methods:

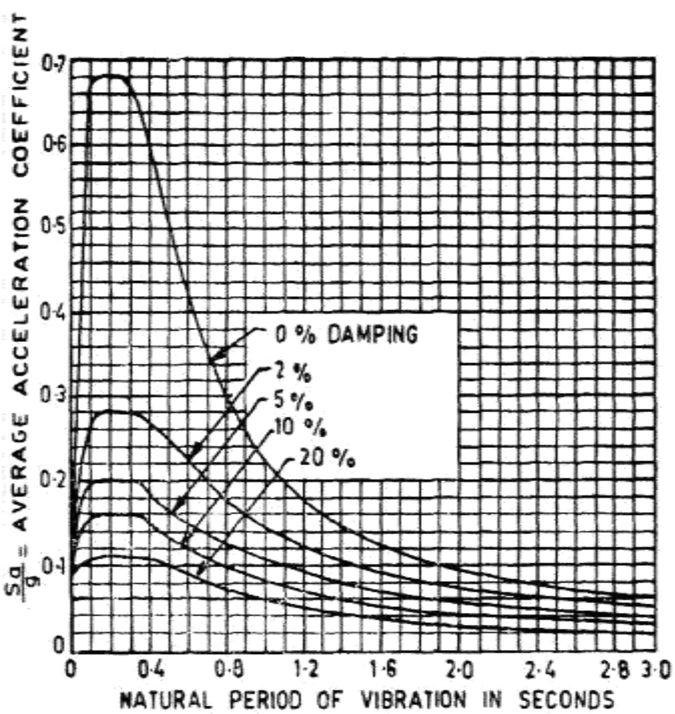


Fig.3 Average Acceleration Spectra

Source: "IS 1893 Indian Standard for Criteria for Earthquake Resistant Design of Structures"

a. Response-spectrum method (first mode)
b. Modal-analysis technique (using response spectrum)
c. Time-history response analysis.

In this project, Response Spectrum method has been used to estimate the earthquake loads coming on to the structure.

B. Response-Spectrum Method

This method involves the following steps:

i. Computation of fundamental period
ii. Calculation of horizontal seismic coefficient
iii. Determination of design shears and moment

IV. B.(i). Fundamental Period

The fundamental period of free vibration is calculated from the formula (as per IS 4998-75*"Criteria for design of reinforced concrete chimneys"*).

$$T = \frac{C_T}{3.1}\sqrt{\frac{WH}{E_e A_e}}$$

where

C_T= a coefficient depending on slenderness ratio of the structure (Table.1 below)

W = weight of the structure including lining, accessories, etc.

A_e= *area* of cross-section at the base, sq. m

T= period of vibration, s

For the value of T so obtained, the average acceleration coefficient ($\frac{S_a}{g}$) can be read from chart given above for an assumed damping factor.

Table.1 coefficient for seismic load calculation

Slenderness Ratio K=H/r_e	**C_r**	**C_v**
5	14.4	1.02
10	21.2	1.12
15	29.6	1.19
20	38.4	1.25
25	47.2	1.30
30	56.0	1.35
35	65.0	1.39
40	73.8	1.43
45	82.8	1.47

r_e= Radius of Gyration of the structural shell at the base section.

IV. B.(ii). Seismic Coefficient

The horizontal seismic coefficient (α_h) to be adopted in design is given by

$$\alpha_h = \beta \times I \times F_o \times \frac{S_a}{g}$$

Where

β = a coefficient whose value depends on the soil-foundation system (β = 1.0 except where chimneys are supported on piles through soft soil for which case β = 1.2)

I = importance factor usually taken as 1.5 for chimneys

F_0= Seismic zone factor (Table of IS 1893: 003)

$\left(\frac{Sa}{g}\right)$ = zone average acceleration

Utilizing this seismic coefficient, design shears and bending moments are calculated as given below.

IV.B.(iii) ***Shear and Moment***

For a single-degree-of-freedom system with damping factor β, the equation of motion due to ground excitation is

$$\ddot{y} + 2\beta\dot{y} + \omega^2 y = -\ddot{y}_s f(t)$$

Where,

$\ddot{y}_s$ is the maximum likely support acceleration and y the displacement relative to the support. If the system starts from rest, which is justified for earthquake motion, the general solution of this equation for the i^{th} mode is

$$y(t) = \frac{-\ddot{y}_s}{\omega_T}\int_0^t f(T)e^{-v[t-T]}\sin\omega_t(t-T)\,dT$$

Moments and shears can be obtained by differentiating y. using records of strong ground motions, Housncr *(“Vibrations of linearly tapered cantilever beams”, Trans. ASCE V 128,)*

Part1, 1963. Page 1020) has worked on that for structures with moderate damping (and using the first three modes), the above equation leads to moments and shears given by the following equations:

Bending moment, $M = \alpha_h W\bar{H}\left[0.6\left(\frac{x}{H}\right)^{1\cdot 2} + 0\cdot 4\left(\frac{x}{H}\right)^4\right]$

Shear, $V = C_v\alpha_h W\left[\frac{5x}{3H} - \frac{2}{3}\left(\frac{x}{H}\right)^2\right]$

Where

C_v= a coefficient depending on slenderness ratio (Table. 1)

$\bar{H}$ = height of e.g. of structure above the base.

x = distance from the top

The above equations have been used in the computations of earthquake loads on the structure.

V. STRESSES IN HORIZONTAL REINFORCEMENT DUE TO SHEAR FORCE:

If H= Horizontal shear force at the section d= diameter of the chimney

S = pitch of hoop bars

A_s= Area of hoop bars in one pitch length

Area of steel resisting shear in one meter height = $\left(\frac{2A_s\times 1000}{s}\right)$

If σ_s =stress in steel

Shear force resisted =$\left(\frac{2.A_t.1000\times\sigma_s}{s}\right)$

If horizontal distance between reinforcement on both sides is assumed as 0.8d,

Shear/meter =$\left(\frac{H\times 1000}{lever\ arm}\right) = \left(\frac{1000H}{0.8d}\right)$

Solving the above equation we get

$$\left(\frac{2.A_t.1000\times\sigma_s}{s}\right) = \left(\frac{1000H}{0.8d}\right)$$

$$\therefore \sigma_s = \left(\frac{Hs}{1.6A_t d}\right)$$

Where, d & s are expressed in mm and A in mm^2.

VI ESTIMATION OF TEMPERATURE LOAD EFFECTS

In walls of Reinforced Concrete chimney, stresses are developed due to the temperature difference between the inner and the outer surface of the walls. This temperature difference from inside to outside tends to expand the inner surface relative to the outer one. Due to the monolithic action of the entire wall, differential expansion is not possible and hence equal expansion takes place so that the shell is compressed on its inside surface and pulled on its outside surface. As a whole there is an average increase in length of the chimney due to the temperature gradient.

A. Equations For Evaluation Of Stresses Of Singly Reinforced Section

The following is a derivation of the equations for the temperature stresses. Let

T^o = temperature difference between inside and outside with a linear temperature gradient.

α = coefficient of expansion of steel and concrete.

e = strain difference in temperature

m = modular ratio

t_s= area of reinforcement per unit width

t_c= area of concrete per unit width

σ_{ct}= stress in concrete due to temperature

σ_{st}= stress in steel due to temperature

$$p = \left(\frac{t_s}{t_c}\right)$$

k = neutral axis depth constant

Referring to fig.4, Considering Force Equilibrium, we have

$$\frac{1}{2}\sigma_{ct}kt_c = t_s\sigma_{st} = pt_c\sigma_{st}$$

Therefore, $\sigma_{st} = \left(\frac{\sigma_{ct}k}{2p}\right) = m.\sigma_{ct} - \left(\frac{at_c - kt_c}{kt_c}\right) = m.\sigma_{ct}\left(\frac{a-k}{k}\right)$

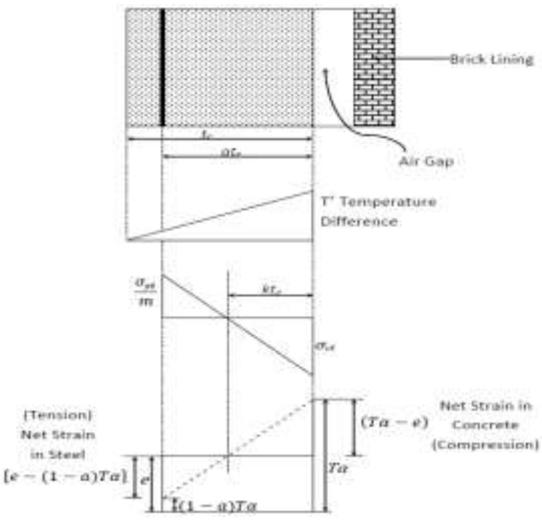


Fig.4 Temperature stresses in concrete

On Solving,

$$k^2 = 2pm(a-k)$$

Where, the value of k may be obtained as

$$k = -mp + \sqrt{2mpa + p^2m^2}$$

Rise in temperature in reinforcement $=(1-a)T$

Free Expansion in Steel $=(1-a)\alpha T$

The tensile stress in steel is due to the difference between that due to strain e and due to temperature rise$(1-a)T$. Hence the Tensile Stress in steel is

$$\sigma_{st} = E_s[e - (1-a)\alpha T]$$

At the neutral axis, there is free expansion due to strain e,

$$e = (1-k)\alpha T$$

Hence, Stress in steel is

$$\sigma_{st} = E_s[(1-k)\alpha T - (1-a)\alpha T]$$

$$\sigma_{st} = E_s\alpha T(a-k)$$

Stress in concrete,

$$\alpha_{ct} = E_c(T\alpha - e) = E_c(T\alpha - (1-k)\alpha T)$$

$$\alpha_{ct} = E_c\alpha kT$$

Stresses in horizontal reinforcement

At high temperatures, the inner surface of the chimney is prevented from expansion and therefore gets compressed. The outer surface will expand more than the natural expansion and will be in tension. Due to temperature stresses, generally the hoop tries to expand and consequently tensile stresses develop in the hoop reinforcement.

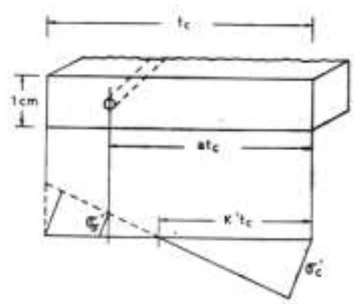


Fig.5 Stresses in Horizontal Reinforcement Due to Temperature Difference

Using the fig.4&5 and the following notation

$k't_c$ = position of the neutral axis

σ'_c = compressive strength in concrete

σ'_s = compressive strength in steel

A_s'= area of hoop reinforcement per unit height

A_s =cross sectional area of steel

s = Spacing

$$A_s' = \left(\frac{A_s}{s}\right) = p \cdot t_C$$

$$\sigma_s' = m\sigma_c'\left(\frac{a-k'}{k'}\right)$$

Consider the force equilibrium of the section, Compressive force of the concrete on the inner side = Tensile force in the horizontal reinforcement.

$$\frac{1}{2}\sigma_c' k' t_C = A_s'\sigma_s' = p\, t_C\, m\, \sigma_C\left(\frac{a-k'}{k'}\right)$$

$$k' = \sqrt{2mpa + p^2m^2} - pm$$

Using this equation, the position of the neutral axis is determined.

Stress in concrete $=\sigma_c' = (\alpha T - e)E_c$

Stress in Steel $=\sigma_s' = [e - (1-a)\alpha T]E_s$

$$\therefore [\sigma_c' + m\sigma_s'] = E_s\alpha T a$$

Knowing the value of k', using above equations stresses in steel and concrete can be found obtained.

B. Doubly Reinforced Section

Consider a concrete section with unequal reinforcement on the two faces and which is heated on one face relative to the other by T Kelvin. Temperature in steel near the hot and cold faces will be **aT** and **(1-a) T** respectively and that at the neutral axis will be **(1-n) T** where the vertical strain will be $e = \alpha T\,(1-n)$.

Free expansion of steel on the hot and cold faces will be **aαT**and**(1 - a) αT** respectively. Restrain of this free expansion on the hot face gives rise to the following forces:

Tensile force in steel on the cold face

$$= [e-(1-a)\alpha T](1-k)mpA_cE_c$$

Compressive force in Steel:

$$=(a\alpha T-e)kmpA_cE_c$$

Compressive force in Concrete

$$=\frac{1}{2}n(\alpha T-e)A_cE_c$$

Where 'a_t' is the distance of the reinforcement from the concrete far dace and 'n' is the distance of neutral axis from the hot face. Since there is no net force due to temperature rise, the sum of compressive forces must be equal to tensile forces.

Thus, we get the following solution

$$n=-mp\pm\sqrt{m^2p^2-2mp(2ka-k-a)}$$

Stresses in steel and concrete will be as under

Tensile stresses in steel on cold face $=\alpha TE_s(a-n)$

Compressive stresses in steel on hot face $=\alpha TE_s(a+n-1)$

Maximum compressive stresses in steel on Concrete $= n\alpha TE_C$

These stresses occur in the vertical as well as in the circumferential direction and appropriate reinforcement should be provided in each direction. Near the top of a chimney, the dead and wind loads can be low and the temperature stress can be relatively large. Hence in this region the permissible stress under the combined effect of dead and wind loads with temperature should be restricted to that normally permitted without allowing for an increase due to temperature effects.

C. Combining Vertical Stresses

As mentioned earlier, vertical temperature stresses need to be combined with those due to dead weight and moment from wind or earthquake effects. This can be achieved without evaluating temperature stresses initially on the cracked-section theory.

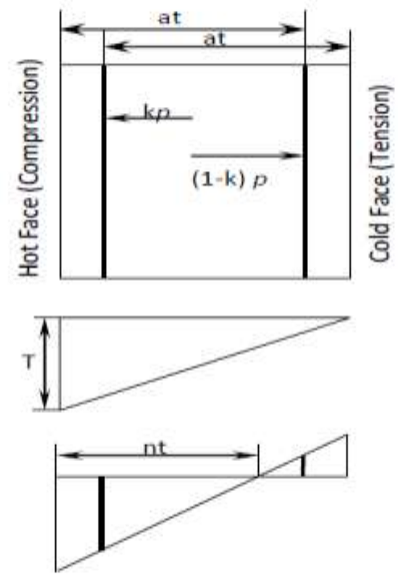


Fig.6 Temperature Stresses
Doubly Reinforced Section

Consider that a thermal gradient of ***T*** Kelvin gives rise to a fictitious stress

$$f_t' = \frac{\alpha E_c T}{2}$$

This is compressive on the hot face and tensile on the cold face. Under the action of dead weight and moment from wind or earthquake effects, an element of a shell in the compressive zone on the leeward side of a chimney will be under uniform compression for its full width. Similarly, a section on the windward side will be under uniform tension provided, of course, that the moment is high enough to cause tensile stress.

It is shown elsewhere how this fictitious temperature stress can be combined with the existing uniform compressive or tensile stresses (on leeward and windward sides respectively) due to other loads. The method is summarized below and it is extended to reflect the effect of neutral axis location on resulting stresses. The final stresses and location of the neutral axis are true values, although ′ is fictitious.

VI. C.(i). Leeward Side

i. Neutral Axis within Section ($(f_t' > f_e)$)

From the stress diagram shown in Fig.7a, it can be seen that $n = \frac{f_{comb}}{2f_t'}$.

Due to the combined effect of a thermal gradient and existing compression (due to an axial load and a moment), the forces will be

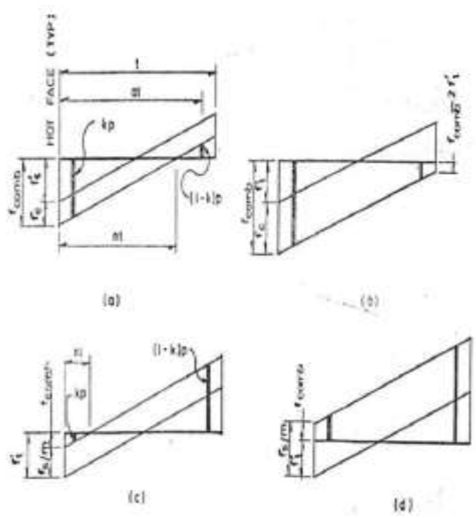


Fig.7 Combining Vertical Stresses with Temperature Stresses

Compression in concrete

$$= \frac{1}{2} n A_e f_{comb}$$

Compression in steel on the hot face

$$\{f_{comb} - 2f_t^{'}(1-a)\} kmpA_c$$

Tension in steel on cold face

$$\{2af_t^{'} - f_{comb}\}(1-k) mpA_c$$

Due to an axial load and bending moment acting on the section, the existing concrete compressive stress is f_c. Hence,

Existing compressive force on the section

$$f_c(1+mp)A_c$$

Since a thermal gradient does not alter the total force on a section, we can equate the algebraic sum of the resulting forces to the existing compressive force and we get

$$f_{comb} = 2f_t^{'}\left[-mp + \sqrt{(mp)^2 + 2mp\{k(1-a) + a(1-k)\} + \frac{f_c}{f_t^{'}}(1+mp)}\right]$$

ii. Neutral Axis within Section $(f_t^{'} > f_e)$

In this case (Fig. 7b) the extreme fiber stress on the cold face will be $(f_{comb} - 2f_t^{'})$ and the following forces can be written down:

Compression in concrete = $(f_{comb} - f_t^{'})A_c$

Compression in steel on the hot face $= (f_{comb} - 2f_t^{'}(1-a)) mpkA_c$

Compression in steel on the cold face $= (f_{comb} - 2af_t^{'})(1-k) mpkA_c$

Proceeding as in earlier case, we get

$$f_{comb} = f_c + \frac{f_t[1 + 2mp\{k(1-a) + a(1-k)\}]}{1+mp}$$

VI.C.(ii). Windward Side

i. Neutral Axis within Section $(f_s < mf_t^{'})$

Due to the other loads, the existing tensile force in steel will be pf_sA_s. Expressions for forces in steel and concrete due to temperature effects will be identical to those given in (i) above. Proceeding as in the earlier case, we get

$$f_{comb} = 2f_t^{'}\left[-mp + \sqrt{(mp)^2 + 2mp\{k(1-a) + a(1-k)\} - \frac{pf_s}{f_t^{'}}}\right]$$

Tensile stress in steel,

$$f_{sT} = m(2af_t^{'} - f_{comb})$$

$$= 2mf_t^{'}\left[(a+mp) - \sqrt{(mp)^2 + 2mp\{k(1-a) + a(1-k)\} - \frac{pf_s}{f_t^{'}}}\right]$$

ii. Neutral Axis within Section $(f_s > mf_t^{'})$

Proceeding as in previous cases, we get (Fig. 7d)

Maximum Tensile stress in steel $f_{sT} = f_s + 2kmf_t^{'}(2a-1)$

Thus, the combined stress in concrete and steel can be obtained.

D. Circumferential Stresses

The circumferential stresses in a chimney due to a thermal gradient can be calculated as shown above for vertical stresses. It should be noted that while using above equations, the quantity of circumferential steel provided should be used while evaluating ***k*** and ***p*** values.

These Circumferential stresses are algebraically added to that which induced in the shell due to axial forces and moments caused by wind and these stresses can be calculated in the usual manner.

VII LINING AND INSULATION

Concrete chimneys are invariably lined, primarily to concrete and reinforcement against thermal and chemical attack from exhaust gases. Secondly, the thermal-insulating property of a liner reduces heat loss from flue gases and thereby they remain buoyant and aid plume rise. Finally, a high temperature at the chimney outlet diminishes the likelihood of acid condensation.

Mainly four characteristics of a flue gas influence a liner's choice, viz. chemical composition, temperature, velocity and pressure. Gases flowing at a high velocity can cause liner abrasion, whereas a low velocity can lead to high pollution levels and possible cold-air ingress causing acid condensation at the chimney top. A positive gas pressure should be avoided since it aids penetration of flue gases into masonry liners, exposing shell concrete to possible chemical corrosion.

The use of present-day high-efficiency boilers has led to lower flue-gas temperatures, which has sharply increased the chances of acid formation and chemical corrosion. However, a lower temperature must be tolerated since a small gain in thermal efficiency can save considerable annual revenue, thereby readily justifying the use of a more expensive chemical-resistant liner.

A. Chemical Corrosion

Acid attack, which is of primary concern in chimneys, depends on the flue-gas constituents and liner surface temperature. On burning sulphur-containing fuels(such as coal, oil, etc.), Sulphur is released which oxidizes to SO2 (S + O2 →SO2) and a small portion of SO3.this latter reacts with water vapour to form concentrated H_2SO_4 at a temperature called the sulphuric acid dew point which is 115° - 150°C .at a lower temperatures, corrosive acids, such as HCl, begin to condense and at 45° - 55°C the water dew-point is reached .

Acid attack, which is of primary concern in chimneys, depend
Thus, acid and water dew-point temperatures play a significant role in the degree of corrosive attack and a designer should aim at maintaining the liner temperature away from them.

B. Mortars

A wide range of mortars are available and selection of the most suitable mortars depends on many factors including temperature conditions, type of chemicals present in flue gases, etc. The success of brickwork depends as much on its workmanship and mortar quality as it depends on the brick itself.

Cement:

Ordinary Portland cement can be used up to a skin temperature below 150°C and where chemical attack is not envisaged. High alumina cement is used to impart moderate chemical resistance but is not suited if continuous exposure to free acids is anticipated.

Sodium-silicate cements have superior resistance to both free acids and intermittent operations. Such cements have a service temperature limit of about 400°C. This mortar should not be wetted prior to putting a chimney into service, otherwise it will soften. This cement is destroyed by sulphation if the liner is exposed to a mist of H_2SO_4.

Potassium-silicate cement has superior chemical resistance as compared to sodium-silicate cement, but it is generally more expensive. It does not weaken due to sulphation and can be used for service temperatures up to 1000°*C.*

Aggregates:

Ordinary sand can be used for low temperatures and where chemical attack is not envisaged. For higher temperatures, crushed firebricks are often used.

VIII ACCESSORIES

A chimney has certain fixtures, fittings and features which are termed "accessories". These are described below.

A. Cap

At the top of a chimney a cap is provided to prevent gas-entrained matter from falling into the space between the liner and the shell and also to protect the chimney top from chemical attack. This cap is often made of sectional grey cast iron of minimum 12 mm thickness laid over 5 mm thick asbestos However, cast iron may not be suitable for certain ceramic processes and for such cases, materials such as alloys have to be used.

A cap must absorb the relative movement between a liner and a shell caused by wind, temperature or other effects. A cap is often composed of interconnected segments, but up-stands for connecting these segments together should be avoided since they become the focus of corrosion. As a further protective measure, a cap should be painted with an anti-corrosive paint. A typical detail of a cast iron cap for a single-flue brick lined chimney is shown in Fig. 8.

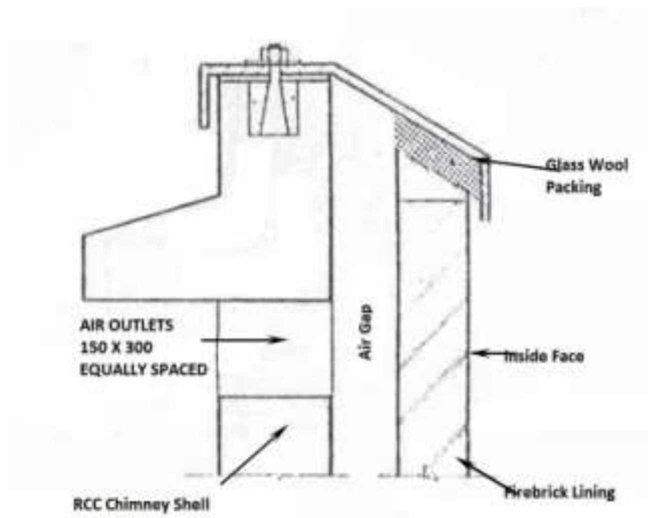


Fig.8 Typical Cap details for a Chimney

B. Lightning Protection

Lightning protection is provided by creating a path of minimum electrical impedance from the chimney top to an earthling strip in the ground. At about 1500 mm from the chimney top, a circumferential conductor (coronal band) is provided which is lead-covered, stranded and of tinned copper. This is connected to air-terminal rods (which protect about ***750*** mm above the top of a chimney) and to tinned copper down conductors. These conductors (which are embedded in concrete) should not have an intermediate splice, they should be free from sharp bends, and should be connected to an earthling strip. During construction, temporary lightning protection must be provided and this could be in the form of a single conductor connected to a temporary air-terminal rod at the top and an earthling system in the ground.

Vertical reinforcing bars near the chimney base should be electrically connected to a circumferential bar, which in turn must be electrically connected to a down conductor. Similarly, all steel pans and footing reinforcement should he connected to a down conductor. In the top reaches of a chimney, lightning protection conductors should be adequately protected from chemical corrosion by applying a lead coating or by other suitable means.

C. Aviation Warning Lights

Aviation warning lights are provided even during construction once the chimney reaches a height of about 45m above grade. Both temporary as well as permanent provisions should meet the stipulations of the Civil Aviation Department. These lights should be ***RED*** in color and be either of filament or neon type, the latter being generally more reliable. They should be of sufficient intensity (about 100 lux) so that they are conspicuous considering the back-ground illumination level against which they will he viewed. Such lights can have a flasher unit and it is preferable to incorporate an automatic alarm system which will be actuated when these lights are on spare. Cables and conduits leading to these lights should safely withstand continuous exposure to the temperature experienced by concrete in which they are embedded.

Day markings are provided by painting the chimney in contrasting color bands for at least the top one-third of its height. Such bands should neither be too narrow nor too broad and could range from 0.75 to 3 m with the outer bands in the darker color. The paint used for such bands should be acid-resistant and should safely withstand the temperature expected at the chimney top.

Fig.9 Showing Aviation Warning Lights

D. Ladder

A ladder is provided for access up to the top of a chimney. It should be of sturdy construction, preferably with non-slip type rungs, and have a safety cage. A tower ladder safety device in the form of a galvanized rail carrier is also recommended and the ladder should be connected to the concrete shell by non-corrosive inserts and bolts.

E. Clean-out and Access Door

A suitable access door should be provided at the bottom of a chimney. When a metal liner is used, the opening meant for an access door is initially made large enough to serve as an access for liner cans which have to be transported to the chimney centre for erection.

Two pairs of clean-out doors are provided in the shell and lining for access into a chimney and to clean the soot hopper. These doors should be suitably treated in order to be heat and acid resistant and should be of gas-tight construction. Such doors should be provided with a latch and should normally be kept locked.

IX. CONSTRUCTION

A. General Aspects

During the construction of a tall chimney, special attention should be paid to project planning and supervision to ensure that the work is completed to specified technical standards and is executed efficiently to meet desired time and cost objectives. It is not the intention here to describe basic construction details but rather to focus attention on the important areas of planning and execution which have a bearing either on quality or economy. While discussing construction aspects, it is assumed that slip form technique is used.

It is necessary to draw up a detailed construction schedule dovetailing the various activities. Schedules can then be established for delivery of off-site materials, such as aggregates, pre-mixed concrete, prefabricated steel liner cans, etc. The sequential and timely delivery of these materials is very important to a builder since holdups due to erratic delivery can result in serious cost penalties. Secondly, since economy of the slip form technique is largely dependent on the uninterrupted progress of work, a builder must assess the economic advantage of providing standby equipment and diesel power.

During slip forming, day and night supervision is called for and a telephone link should be installed for efficient communication from a ground station to the working platform. A hoist must be provided for vertical transport of supervisory personnel. Good illumination is required both at the location of concreting and below the form shutters where finishing work would be simultaneously in progress. Since large quantities of materials have to be transported quickly to the working platform, there should be ample preplanned openings in the tubular staging within a chimney or else a crane should be positioned at the working level to lift materials externally. These materials clutter up the storage deck where good house-keeping is called for, otherwise pieces of stray materials will find their way into the forms.

Sound construction to a true profile and verticality is important. Deviation from the true vertical axis will cause dead loads to induce additional bending moments which the shell concrete will have to withstand. The following constructional tolerances are recommended as reasonable:

- Deviation from true vertical axis = 50 mm
- Deviation in wall thickness = ±5 mm
- Deviation in circularity = 10 mm

Verticality should be checked at frequent intervals during construction using accurate instruments. For tall chimneys, a plumb-bob technique to define verticality is not accurate enough and normally theodolites positioned at four ground stations are used sight targets fixed to the yoke which supports the slip form. A series of readings are generally taken to compensate for effects due to optical refraction, shimmering caused by vapor, etc. Frequent readings should be taken early-on to establish the behavioral pattern and later readings can be taken at say 300-mm intervals.

Laser-aligning instruments are gaining in popularity. These instruments commonly use a helium-neon laser operating in the fundamental mode which provides a beam of red light with very low divergence. This beam is visible in the dark, does not sag, can provide both vertical and horizontal scan and it does not obstruct the movement of men or materials. This technique thus provides an accurate means of checking the alignment and it generates a reference line for use during day or night.

Concrete and Reinforcement Work

IX.A.(i). concreting

The entire concreting operation including mixing, transporting and placing needs to be meticulously planned. Concrete, in adequate quantity to suit the rate of slip forming, must be mixed, transported, raised and placed at the desired elevation well within the initial setting time of cement. To achieve this, belt conveyors are usually adopted to convey concrete from a mixer to the base of a chimney from where it is raised to the desired elevation by winch-operated material conveying platforms or alternatively it is pumped. Concrete is poured in about 00-mm layers, and it should be placed either in an irregular pattern or clockwise and anticlockwise alternately to avoid possible spiraling of forms.

***IX.A.(ii).* Reinforcement Laying**

Reinforcement for the shaft should be in lengths not exceeding 4.5m for vertical bars and 6m for horizontal bars for ease of handling. Vertical bars are positioned with the help of

templates fixed to the forms and they should not project too far above the level at which concrete is being placed. For easy placing, horizontal bars are usually positioned outside the vertical steel and it is advantageous lo use preheat horizontal bars for circular chimneys. Hooks in reinforcement bars should be avoided and laps must be staggered

B. Formwork

Formwork is an activity, other than concreting, which requires inmost attention to ensure smooth and efficient progress of work. The need for its proper planning and execution can-not be over-emphasized. Either timber or steel forms may be used. While the former gene-rally works out to be cheaper and is easier to handle, the latter yields a superior finish and offers less frictional drag. For construction of tall chimneys, two types of form techniques are in general use in this country, viz., jump form and slip form with the latter rapidly replacing the former. These two types arc discussed below.

IX.B.(i). Jump Form

In this type of construction, jacking bars are either cast in concrete or else are carried in tubes which are cast in concrete. After casting a lift, concrete is allowed to set and then the forms are raised by jacks and the next lift is cast.

IX.B.(ii). Slip Form

Slip forms are continuously moving forms. Compared to a jump form, a slip form yields a monolithic concrete stem and enables speedier construction. On the other hand, it has a higher initial cost, requires more equipment and calls for arrangements to be made for round-the-clock concreting and supervision. On the whole, a slip form generally works out to be more economical as compared to a jump form, but this saving can be readily lost either due to poor construction planning or faulty material-delivery scheduling.

The rate of slip commonly adopted for chimney construction is 150 - 50mm/h, though higher slip rates have been used. The rate of slip is extremely important and it depends, among other things, on the type of cement used, ambient temperature, etc. A slip rate slower than the optimum will invariably result in excessive drag on the forms and damage to concrete. Too high a slip rate will result in weak concrete being exposed at the bottom of forms. Hence the formwork has to be designed carefully for the likely loads.

X. LOAD CALCULATIONS AND RESULTS

A. Preliminary Dimensions

The preliminary dimensions of the chimney are taken on basis of functional requirements of chimney and a typical chimney of 70m height was chosen as a problem statement for the project. The dimensions of chimney are decided on the basis of

Table.2 Chimney parameters

Name of parameter	**Practical range**	**Typical value**
Slenderness ratio h/D_o	7-17	11
Taper ratio D_t/D_o	0.3-1.0	0.6
Base diameter to thickness ratio Db/tb	0-50	35
Mean, base thickness ratio t_m/t_b	0.3-0.8	0.55
Top mean thickness ratio $t_{t/tm}$	0.7-1.0	0.85

On this basis, the dimensions of chimney are decided as follows

- Height = 70m
- Base Diameter = 5m
- Top Diameter = 15m
- Base Thickness = 1250mm
- Top Thickness = 60mm
- Lining Thickness = 100mm fire brick lining
- Air gap between lining and shell = 300mm
- Place: Roorkee, Seismic Zone: IV (IS 1893), Basic Wind Speed: 39m/s (IS: 875 part 3)

Based on above dimensions and the estimation methods as explained above, the following calculations were made.

B. Dead Load Calculations:

Diameter at any depth y from top may be found as $15+\frac{y}{27}$

Thickness of concrete shell at any depth y from top = $\frac{0.99}{270}y+0.26$m.

Self-weight may be estimated by finding the volume of concrete above section which is done here using cylindrical coordinate system.

$$V=\int_0^y \int_{\left(7.5+\frac{y}{54}\right)-\left(\frac{0.99}{270}y+0.26\right)}^{\left(7.5+\frac{y}{54}\right)} \int_0^{2\pi} rd\,drdy$$

$$=2\pi\int_0^y \left[\frac{r^2}{2}\right]_{\left(7.5+\frac{y}{54}\right)-\left(\frac{0.99}{270}y+0.26\right)}^{\left(7.5+\frac{y}{54}\right)}$$

$$=\pi\left[3.869y+\frac{13.05y^2}{540}+\frac{2.967y^2}{270^2}\right]$$

From the above equation, overburden weight may be calculated by multiplying with $\gamma_{concrete}$. For taking care of additional load due to stakes provided to prevent vortex shedding, we have considered 1% additional weight in load calculations. Load from lining has been calculated accordingly with varying diameter of chimney assuming that the lining is supported at every 2.5m and the loads at different sections are as follows:

Table.3 Dead Load Calculations

Section	Depth from top y (in m)	Self Wt (in KN)	Lining Load	Total F_{axial}
1	45	17987.70615	4078.982211	22066.688
2	90	45504.87762	8582.659428	54087.537
3	135	84316.75904	13511.03165	97827.791
4	180	136188.5951	18864.09888	155052.69
5	225	202885.6304	24641.86112	227527.49
6	270	286173.1096	30844.31836	317017.43

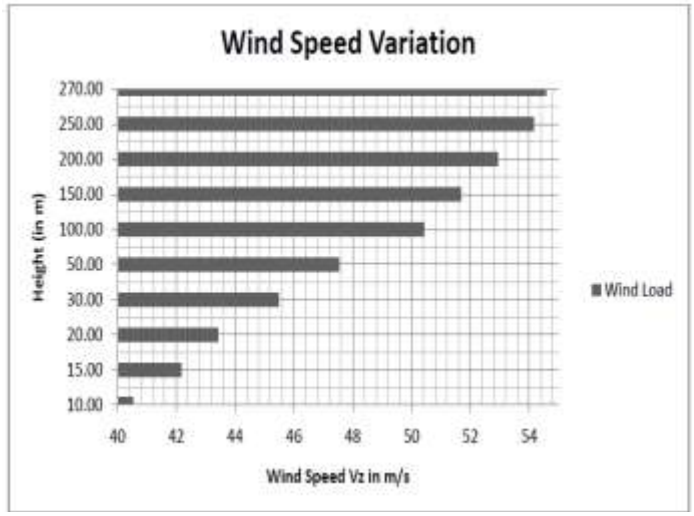
Table.4 Wind Speed Calculations

Depth of section from top (y)	K_1	K_2	K_3	V_z (in m/s)	$Pz(N/m^2) = 0.6\ Vz^2$
0	1.06	1.32	1	54.5688	1786.65236
20	1.06	1.31	1	54.1554	1759.684409
70	1.06	1.28	1	52.9152	1680.011035
120	1.06	1.25	1	51.675	1602.183375
170	1.06	1.22	1	50.4348	1526.201431
220	1.06	1.15	1	47.541	1356.088009
240	1.06	1.1	1	45.474	1240.730806
250	1.06	1.05	1	43.407	1130.500589
255	1.06	1.02	1	42.1668	1066.823413
260	1.06	0.98	1	40.5132	984.7916245
270	1.06	0	1	0	0

Wind Load Calculations

- The wind loads were calculated as per IS 4998 (Part 1): 1992 as described in estimation of wind loads.
- Corresponding to Roorkee, Basic Wind Speed = 39m/s (From Appendix **A**, IS: 875 (Part 3) 1987)
- Corresponding to power plant structures, Design life is 100 Years and hence, k_1=1.06
  (From Table.1 of IS: 875 (Part 3) - 1987).
- Assuming an upward slope < 3˚, k_3= 1.0 (Clause 5.3.3, IS: 875 (Part 3) - 1987)

Chart.01 Wind Speed variation



The wind load forces and moments due to the same at different sections are found as follows

Table.5 Wind Load - Forces and Moments

Section	Depth	F (in kN)	M (in kN.m)
1	45	1009.65	23245.8413
2	90	2095.35	93949.1466
3	135	3236.14	214309.172
4	180	4424.72	389369.899
5	225	5645.13	618478.258
6	270	6224.86	932011.054

C. Earthquake Load Calculations

The earthquake loads on the structures are estimated as described as above using the following equations

Bending Moment, $M = \alpha_h W\bar{H}\left[0.6\left(\frac{x}{H}\right)^{1.2} + 0.4\left(\frac{x}{H}\right)^{4}\right]$

Shear, $V = C_v\alpha_h W\left(\frac{5x}{3H} - \frac{2}{3}\left(\frac{x}{H}\right)^{2}\right)$

Table.6 Earthquake Load Calculations

Section	x	x/H	M (kN.m)	V (kN)
1	45	0.166667	21786.59	1113.218
2	90	0.333333	51365.14	2067.404
3	135	0.5	88822.39	2862.56
4	180	0.666667	139009.2	3498.684
5	225	0.833333	209511.5	3975.778
6	270	1	310388.6	4293.84

It can be clearly observed that the wind loads are far greater than Earthquake Loads and hence wind load moments are taken into consideration along with the dead loads to find the stresses as

$$Stress = \frac{P}{A} \pm \frac{My}{I}$$

Table.7(a) Stresses due to dead load and wind loads.

Faxial (kN)	Mwind (kN.m)	e (in m)	P (%)	teq	Area
22067	23246	1.05	1.6	0.47	23.83
54088	93949	1.74	1.6	0.65	36.14
97828	214309	2.19	1.6	0.83	50.16
155053	389370	2.51	1.6	1.01	65.89
227527	618478	2.72	1.6	1.19	83.33
317017	932011	2.94	1.8	1.39	103.6

Table.7(b) Stresses due to dead load and wind loads.

I (in m^4)	P/A	MY/I	f_c (MPa) Leeward	f_c (MPa) Windward
785.8	926.03	246.5355	1.17256	0.679
1422	1496.6	605.54	2.10218	0.891
2322	1950.3	922.8609	2.87317	1.027
3545	2353.1	1189.838	3.54299	1.163
5156	2730.3	1399.411	4.12973	1.331
7307	3058.9	1594.298	4.65315	1.465

XI. AERODYNAMIC REMEDIAL MEASURES FOR SUPPRESSING OR ALLEVIATING VORTEX EXCITED OSCILLATION

The vortex excited oscillations can be suppressed or substantially alleviated by incorporating discrete strakes on the chimney as shown in Fig. 11. The stakes are to be mounted along three helices with the strakes along each helix being displaced in azimuth by 30° and spaced vertically centre to centre by a distance of *5d/12*. The stakes are to be provided over the top 1/3 height of the chimney if the magnification given by Fig. 10 is less than 6 and over the top half of the chimney if the magnification given by Fig. 10 is greater than 6.

The following table gives the minimum area of each strake A_s to be used depending on the magnification as given by Fig. 10

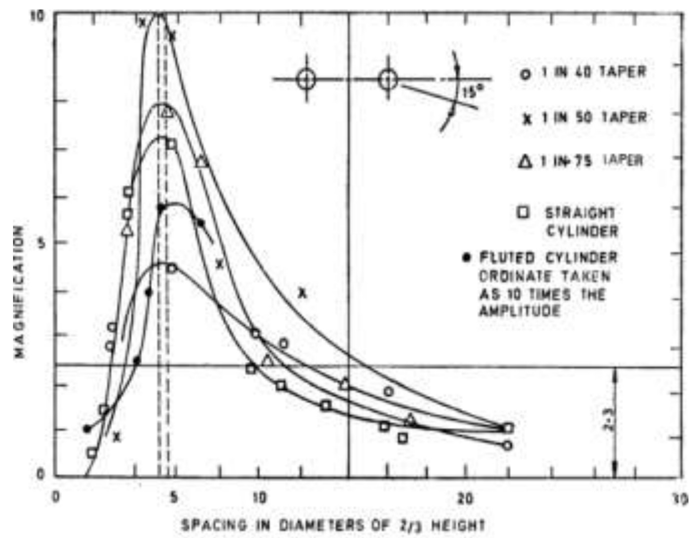


Fig. 10 Magnification Factor as a Function of Spacing in Terms of Representative Diameter at /3 Height

Table .8 Minimum area of Stake As

Magnification	$A_s = (\frac{\pi d}{4})$	Additional Equivalent Drag Coefficient Over the Region of Strakes
1.1-1.5	0.005	0.05
1.5-2.5	0.010	0.10
2.5-5.0	0.020	0.20
5.0-7.5	0.025	0.25

Continuous strakes may be used if feasible and economical. Figure 10 shows a sketch of this arrangement. The continuous strake should also be mounted over either the top one-third or

top half height of the chimney, as indicated for discrete strakes. The radial depth of the rib shall be at least *0.1d (i.e., 1.5m in our case).*

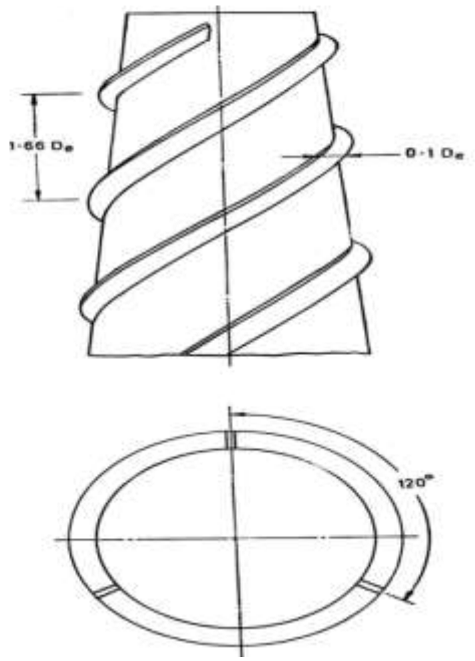


Fig.11 Continuous Stack

12 CONCLUSIONS

All the criteria involved in the analysis and design of Reinforced Concrete Chimneys were considered and analyzed. All the loads that are to be considered during the analysis phase of the chimney were taken into account. Out of all the loads considered the most important were found to be the wind loads. The earthquake loads and seismic loads were not found to be critical for design.

The methods suggested by the IS code were studied. Calculation were however done using the response spectrum method. The moment profile was calculated and plotted. The loads due to seismic action were found to be far less than that from the wind velocities, and hence it would not be a major consideration in design.

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2. REFERENCES

[1] IS 4998 (Part 1): 1992 "Criteria for design of reinforced concrete chimneys", part-1, Assessment of loads (Second Revision)' Bureau of Indian standards, New Delhi, 1992

[2] IS 875 (Part 3): 1987 "Code of practice for design loads (Other than earthquake) for buildings and structures. Part 3 Wind loads (Second Revision)" Bureau of Indian standards, New Delhi, 1987

[3] IS 1893: 2005 "Criteria for earthquake resistant Design of structures– code of practice (second revision)"

[4] "Advanced Reinforced Concrete Design" Dr. N.Krishna Raju, CBS Publishers, Delhi

[5] "Limit State Reinforced Concrete Design" Dr. Ashok K Jain, Nem Chand & Bro Publications, Roorkee

[6] "Design of concrete Structures Volume 1 &2 " O.P.Jain and Jai Krishna, Nem Chand & Bro Publications, Roorkee

[7] "Tall Chimney: Design and Construction" S.N.Manohar, Tata McGraw Hill Publications.

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