Industrial Structure (MCE-367)
Unit-3
Syllabus:
Unit-3: Design of Industrial chimney

Name of Faculty: Madan Chandra Maurya
Asst. Professor, CED, MMMUT Gorakhpur.

INDUSTRIAL CHIMNEYS

Introduction

- **Steel Chimneys are also known as steel stacks. The steel chimneys are made of steel plates and supported on foundation. The steel chimneys are used to escape and disperse the flue burnt gases coming from furnaces of boilers to such a height that the gases do not contaminate surrounding atmosphere.**

- **The cross-sectional area of steel chimney is kept large enough to allow the passage of burnt gases.**

- **The cross sectional area of steel chimneys depends on the type and quantity of fuel to be used in a plant, available draft for carrying the burnt gases up the chimney and losses due to friction within the chimney.**

Introduction

Draft: The draft is defined as the difference between *absolute gas pressure* at any point in the duct or steel chimney and the *ambient atmospheric pressure* at any point on the height of steel chimney above sea-level, the type of fuel to be burnt, the type of furnace and the temperature of burnt gases.

How Gases flow ?

When the gases in a steel chimney are heated, then the gases expand. The hot gases occupy larger volume than before. The weight of gases per cubic metre becomes less. As a result of this, the unit pressure at the bottom of chimney due to weight of hot gases also becomes less than the unit pressure due to weight of cold air outside of chimney. *The difference between two pressure results in the flow of burnt gases up the chimney.*

Introduction

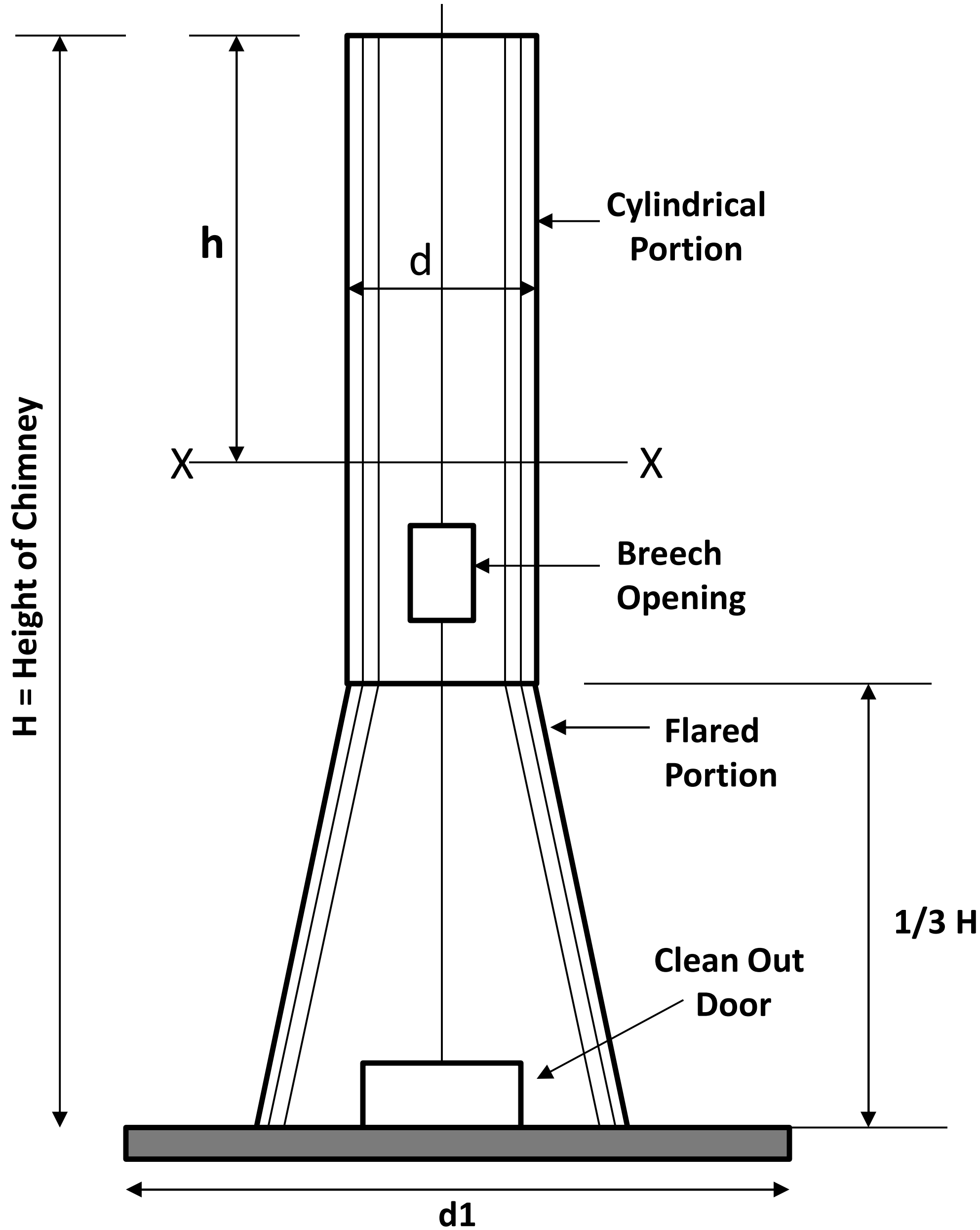
Notes:

- **The self supporting steel chimney is made cylindrical in shape. The lower portion of steel chimney is widened or flared, in order to provide a large base and greater stability.**
- **The recommended height of flared portion of the chimney is equal to one-third the height of the chimney.**
- **The bottom diameter of the flared portion shall not be less than one and a quarter times the diameter of stack (i.e., d1 = 5/4.d).**
- **The steel chimneys are kept at least 5 m taller in height than the tallest building within an area of 150 m radius.**
- **Commonly the diameter of steel chimneys are kept one-twentieth to one-thirtieth of height of chimney.**
- **The steel chimenys are designed and constructed conforming to code of practice for design and construction of steel chimneys, IS: 6533-1971.**

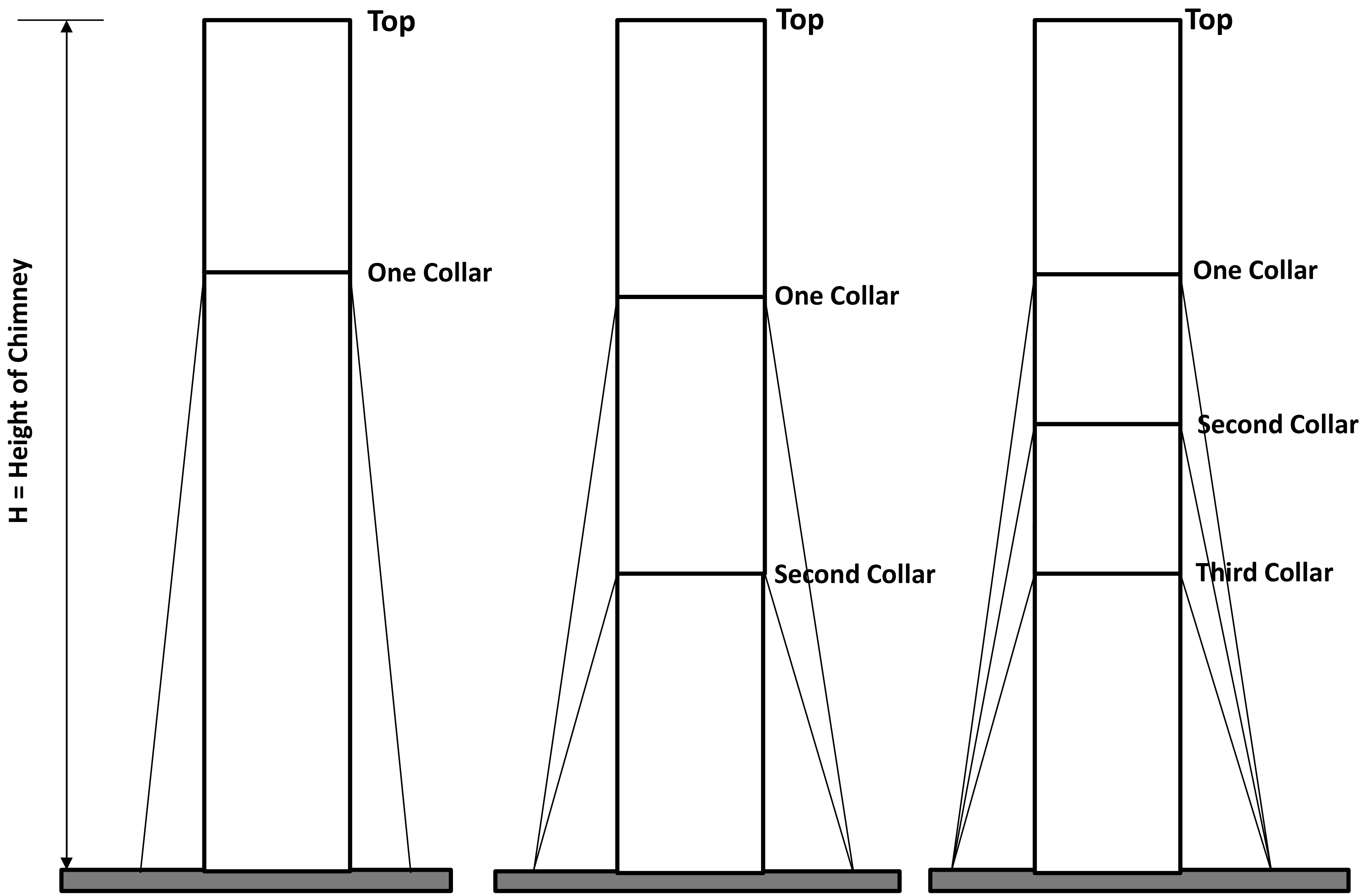
Types of Steel Chimney

1. Self supporting steel chimney,
2. Guyed steel chimneys.

Self Supporting Steel Chimney



Guyed Steel Chimney



One Set of Guy Ropes
A. With One Collar Steel Chimneys

Two Set of Guy Ropes
B. With Two Collars Steel Chimneys

Three Set of Guy Ropes
C. With Three Collar Steel Chimneys

Self-supporting Steel Chimneys

A self-supporting steel chimney or stack is made of steel plates and supported on foundations. When the lateral forces (wind or seismic forces) are transmitted to the foundation by the cantilever action of the chimney, then the chimney is known as self-supporting. The chimney together with the foundation remains stable under all working conditions, without any additional support. A self-supporting chimney is shown in Figure 14.1. The self-supporting steel chimneys are made upto 10 m diameter and from 50 m to 100 m in height.

Guyed Steel Chimneys

In high steel chimneys, the mild steel wire ropes or guys are attached to transmit the lateral forces. Such steel chimneys are known as "guyed steel chimneys." In guyed steel chimneys, all the externally applied loads (wind, seismic force etc.) are not totally carried by the chimney shell. These attached guys or stays do share these applied loads. These chimneys may be provided with 1, 2, or 3 sets of guys. In each set of guys 3 or 4 m sometimes 6 wires are attached to the collars. A particular type of steel chimney is selected depending on the advantage and disadvantages with reference to economy.

INDUSTRIAL CHIMNEYS

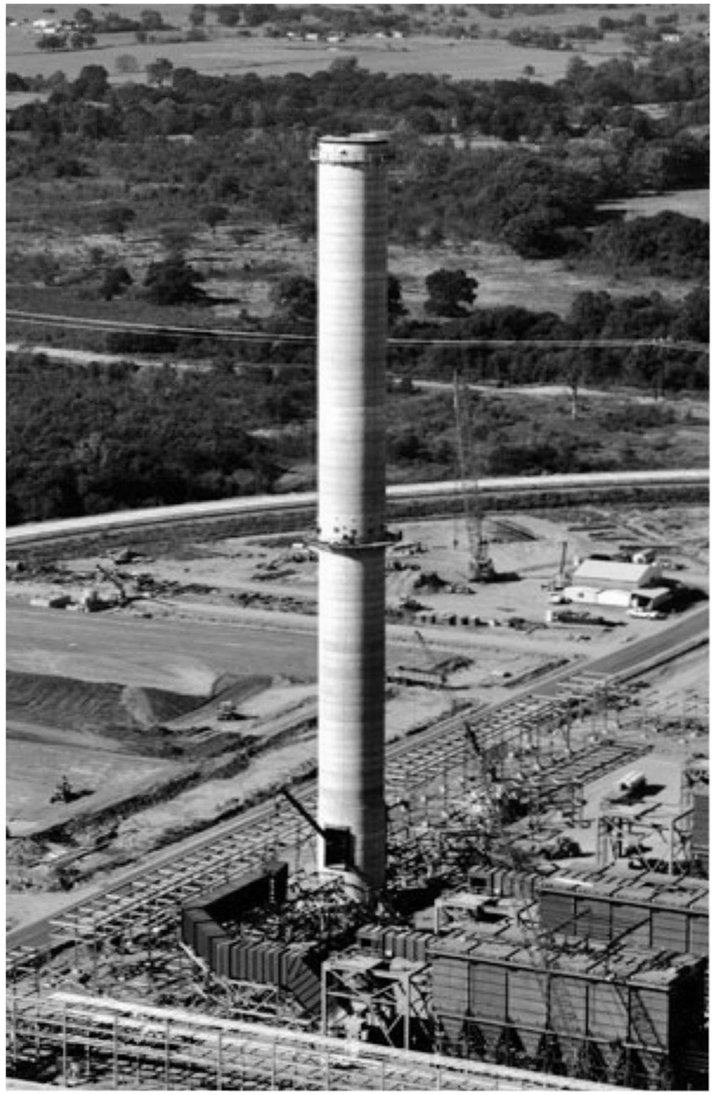
INDUSTRIAL CHIMNEYS

CHIMNEYS AT
RAICHUR
THERMAL POWER STATION

220m tall

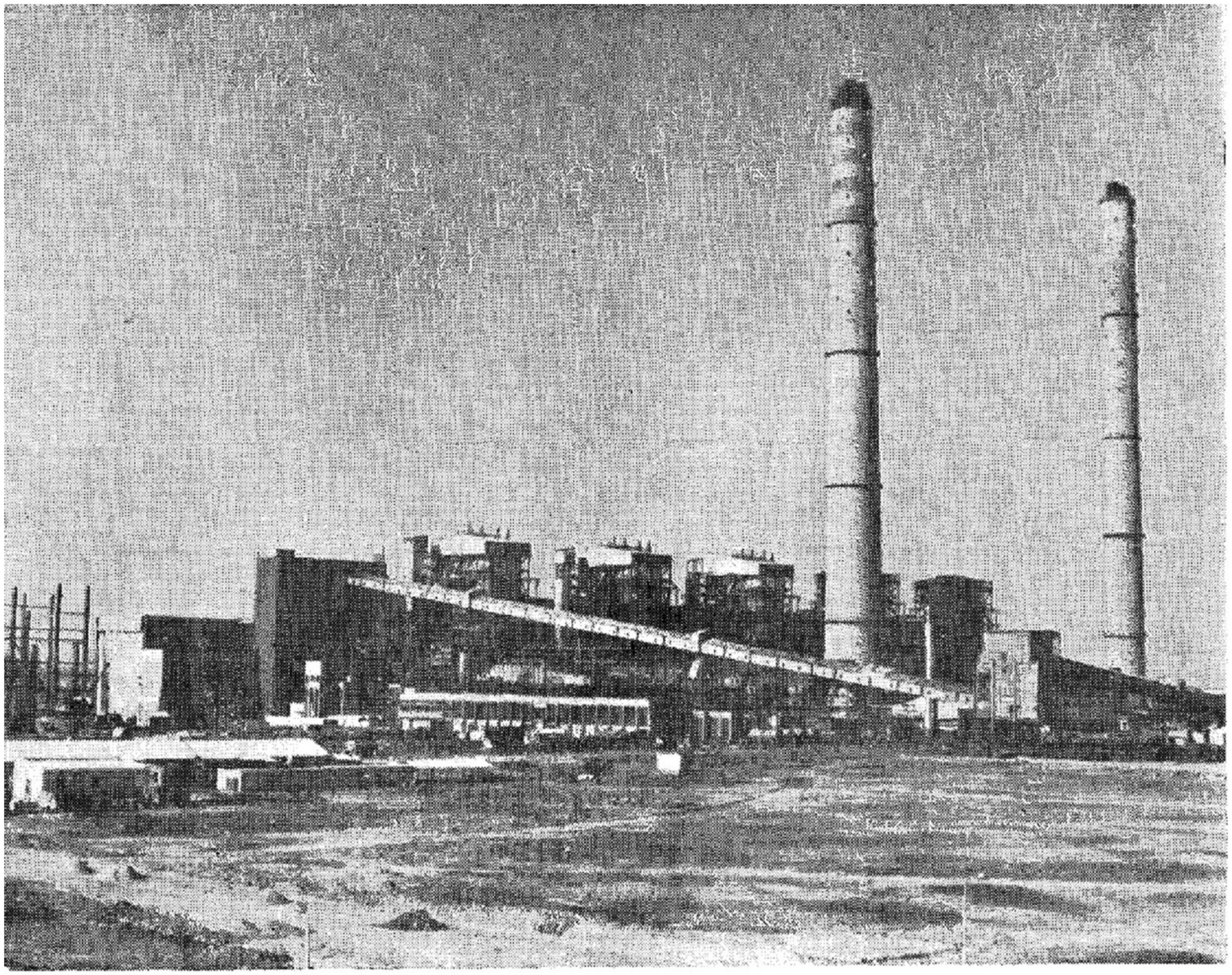
NOTE AVIATION PAINTING FOR THE TOP PORTION OF CHIMNEY

INDUSTRIAL CHIMNEYS



CHIMNEY
READY TO
RECEIVE
THE FLUE
DUCT FROM
BOILER
HOUSE

INDUSTRIAL CHIMNEYS



Chimneys dominate (*Courtesy:* NTPC)

POWER PLANT VIEW SHOWING CHIMNEY CONVEYOR JUNCTION TOWERS, etc

INDUSTRIAL CHIMNEYS

1. DEFINITION OF CHIMNEY

Chimneys are tall and slender structures which are used to discharge waste/flue gases at higher elevation with sufficient exit velocity such that the gases and suspended solids (ash) are dispersed into the atmosphere over a defined spread such that their concentration, on reaching the ground is with in acceptable limits specified by Pollution Control Regulatory Authorities.

In a coal based power plant, flue gases from each boiler are fed to a chimney, for dispersion into atmosphere.

INDUSTRIAL CHIMNEYS

2. DESIGN CODES

Main Codes:

IS: 4998 – Criteria for Design of Reinforced Concrete Chimneys IS: 6533 - Code of Practice for Design and Construction of Steel Chimneys

Supplementary Codes:

IS: 456 – Code of Practice for Plain and Reinforced Concrete IS: 800 – Code of Practice for use of Structural Steel in General Building Construction

IS:875 – Code of Practice for Design Loads for Buildings and Structures (Part-3 : Wind Loads)

IS:1893 – Criteria for Earthquake Resistant Design of Structures

INDUSTRIAL CHIMNEYS

3. CLASSIFICATION OF CHIMNEYS

a) Based on number of flues

- **Single flue (each boiler will have an independent chimney)**
- **Multi flue (Single chimney serves more than one boiler; more flues are housed inside a common concrete windshield)**

b) Based on material of construction

- **Concrete (Chimney); Reinforced/Pre-stressed**
- **Steel (stack)**

c) Based on structural support

- **Guyed stacks (used in steel stacks for deflection control)**
- **Self supporting (cantilever structures)**

d) Based on lining

- **With Lining : Lined chimneys/stacks**
- **Without lining :Unlined chimneys/stacks**

INDUSTRIAL CHIMNEYS

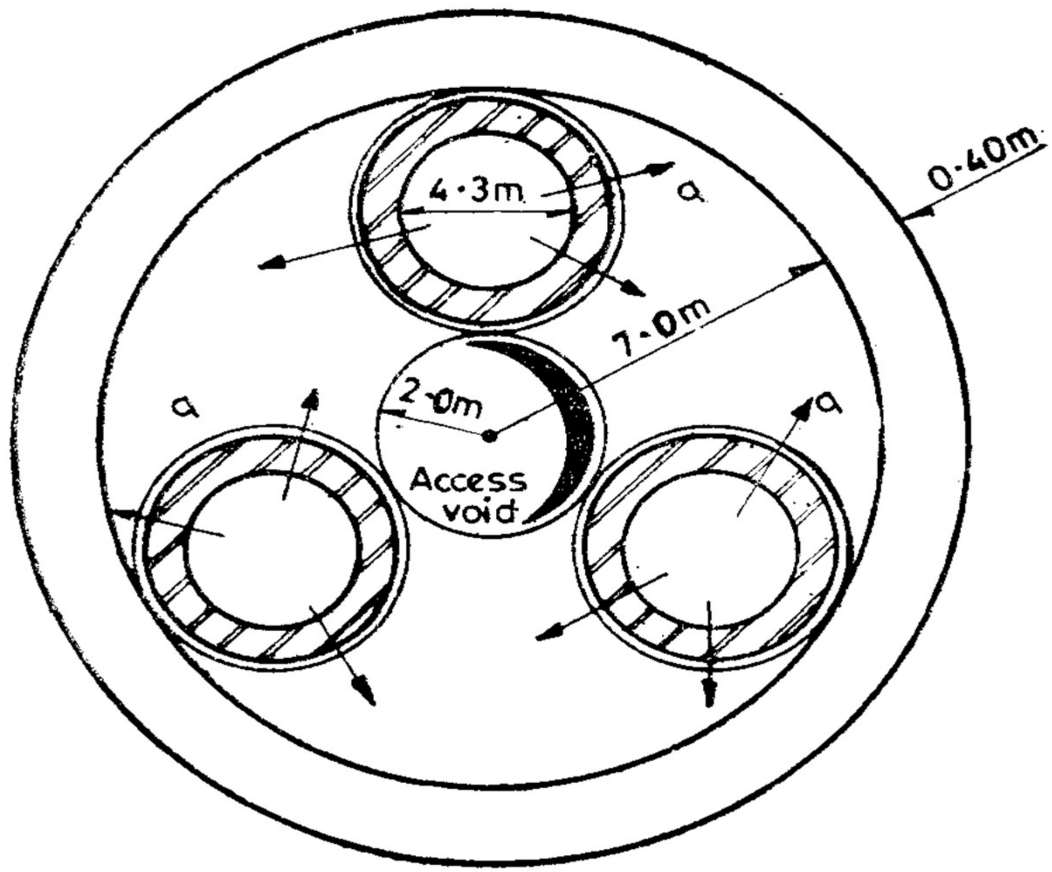
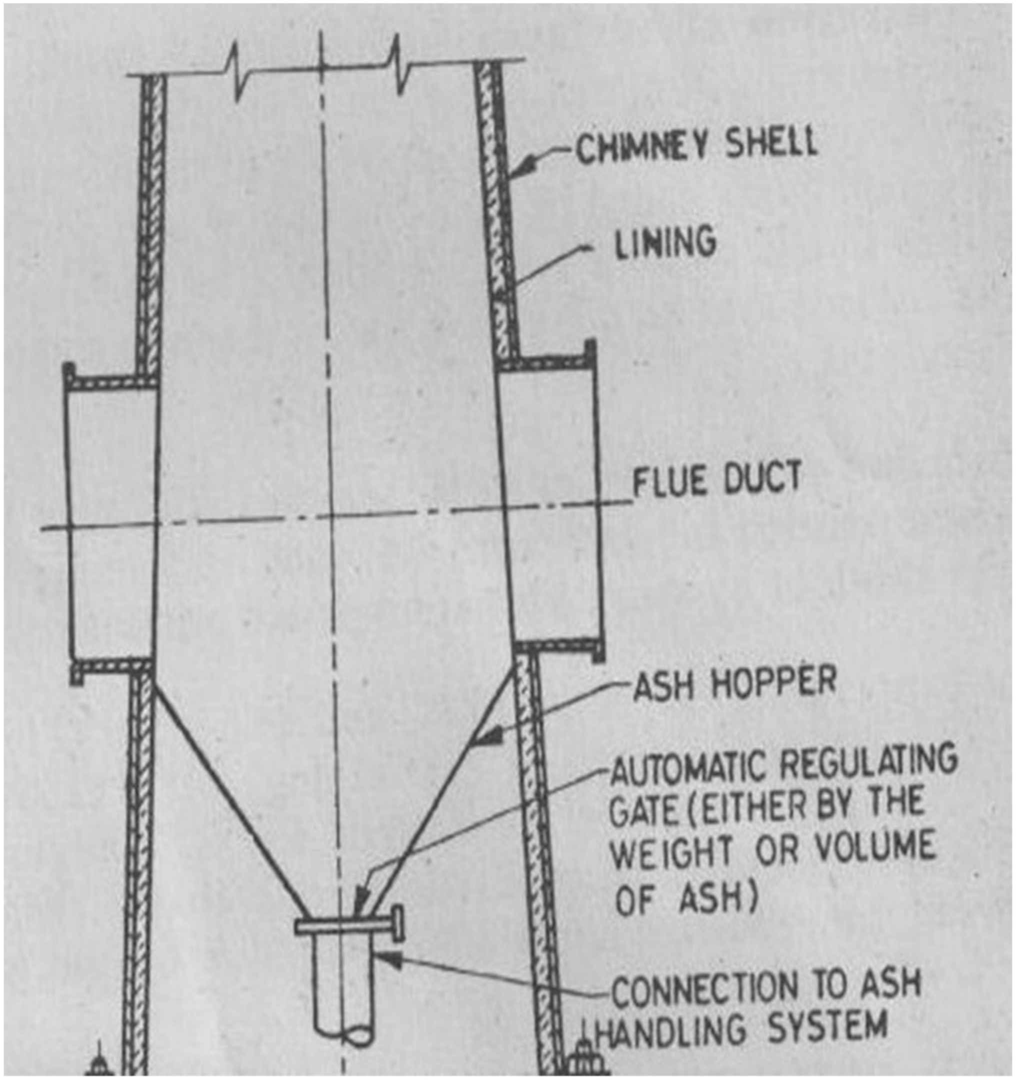


Fig. 5.2 Section Through Multi-Flue Chimney

3-FLUES
CHIMNEY
to
CATER
FOR
THREE
BOILERS

INDUSTRIAL CHIMNEYS



CHIMNEY CROSS SECTION SHOWING LINING, FLUE DUCT OPENING, ASH COLLECTING HOPPER & ASH REMOVAL DRAIN PIPE WHICH WILL BE LINKED TO ASH HANDLING POND

INDUSTRIAL CHIMNEYS

4. CHIMNEY SIZING

Chimney sizing is governed by following factors:

- **The top clear inside diameter is governed by minimum escape velocity of flue gases at top op chimney.**

- **Height is governed by gas plume dispersion at top of chimney. The height should be such as to ensure required draft and exit velocity of flue gases such that the Ground Level Concentration (GLC) of pollutants, after atmospheric dispersion, is within the limits prescribed by the local pollution regulatory standards**

- **Structural considerations : A taper of 1 : 50 to 1:100 is usually selected to suit the concrete shell diameter at foundation top, required from design for wind/seismic loading considerations**

INDUSTRIAL CHIMNEYS

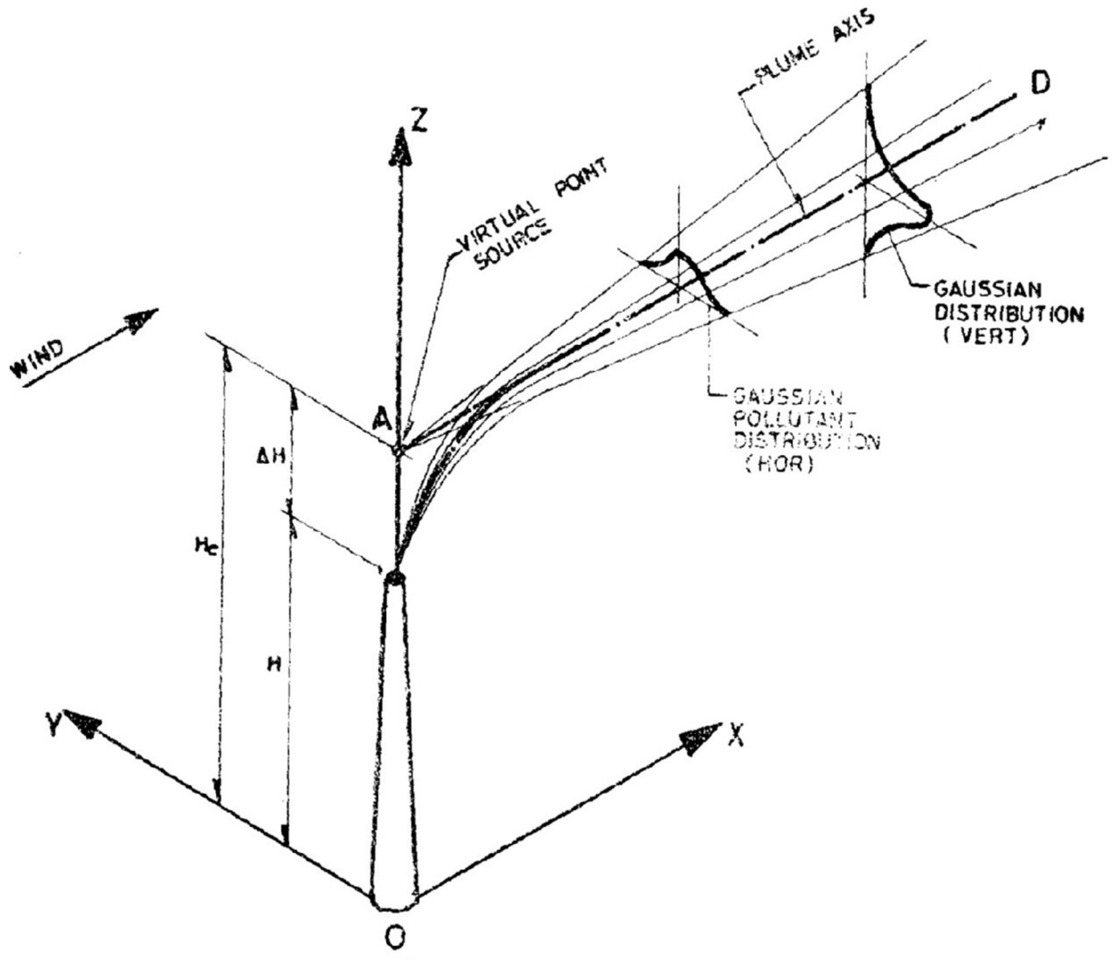


Fig. 2.2[166] Spread of a Plume

EXIT VELOCITY
and
SPREAD OF PLUME & GROUND LEVEL CONCENTRATION (GLC) OF POLLUTANTS IN FLUE GAS WILL DECIDE ON THE HEIGHT OF CHIMNEY

INDUSTRIAL CHIMNEYS

5. DESIGN LOADS

- **Dead Loads (weight of chimney shell & lining)**
- **Wind Loads (as per IS:875; Part-3)**
- **Seismic Loads (as per IS;1893)**
- **Temperature Loads (depends on flue gas temperature)**

Note: wind and seismic loads are not considered to act simultaneously as both are environmental loads

6. LOAD COMBINATIONS

- **Dead load + Wind load**
- **Dead load + Seismic load**
- **Dead load + Temperature load**
- **Dead load + Wind load + Temperature load**
- **Dead load + Seismic load + Temperature load**

INDUSTRIAL CHIMNEYS

7. WIND LOADS

- **Along wind loads (i.e. in the direction of wind)**
- **Across wind loads (i.e. Vortex shedding loads)**

7.1 Along Wind Loads

- **Chimneys are slender structures with aspect ratio (Height/Diameter) greater than 5. Gust loading as per Cl.8.3 of IS:875(Part-3) governs**
- **Gust factor, G = (Peak Load/Mean Load)**
- **$G = 1 + g_f r\, [B(1+x)^2 + (SE/b)]^{1/2}$**

G_f=peak factor (peak value/root mean value)

r = roughness factor (depends on size of structure and ground roughness)

B= Background factor (measure of fluctuating component of wind load)

SE/b = measure of resonant component of fluctuating wind load

S = size reduction factor

E = measure of available energy in the wind

b = structural damping coefficient as a fraction of critical damping (0.016 for RC structures; 0.2 for bolted steel structures; 0.1 for welded steel structures)

INDUSTRIAL CHIMNEYS

Along Wind Loads …. contd

Along wind load, $F_d = C_f A_e p_z G$

C_f = Force coefficient

= 0.8 for circular portion without strakes
= 1.2 for the top portion fitted with strakes

A_e = Effective frontal projected area (m^2) normal to wind

p_z = Design pressure
= $0.6\, V_z^2$ (N/m^2)

V_z = Design wind speed (m/sec) at height z above ground

V_z = k1 k2 k3 V_b

k1 = Probability factor (as per Table-1 of IS:875)
k2 = Terrain and height factor (as per Table-33 of IS:875)
k3 = Topography factor (as per cl. 5.3.3 of IS:875)

V_b = Basic wind speed (m/sec) at 10m above ground

INDUSTRIAL CHIMNEYS

7.2 Across wind loads

- These are wind loads produced due to alternate shedding of vortex due to dynamic behaviour of chimney under along wind loads.
- Vortex induced loads act perpendicular to wind direction.

7.2.1 Vortex Formation

When wind flow crosses the chimney, vortices are shed alternately from the sides causing pressure drop. Such pressure changes at regular intervals cause a lateral force perpendicular to the direction of wind.

Vortex formation depends on Reynold's number, R_e

R_e = Wind Inertia Force/Viscous drag force

$R_e < 3*10^5$ (sub-critical range)

$3*10^5 < Re < 3.5*10^6$ (super-critical range)

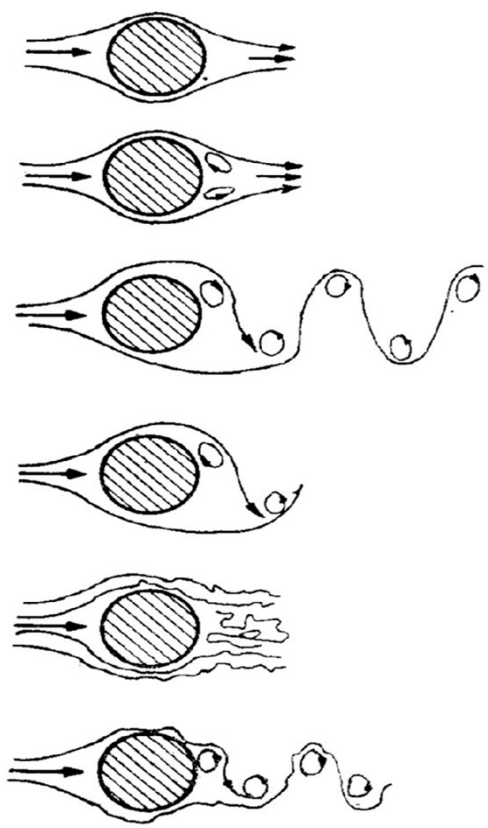
Vortex Shedding Frequency, $f = SV/D_{co}$

S = Strouhal number (= 0.2 for $R_e < 2*10^5$)

V = Wind velocity (m/sec)

D_{∞}= Critical outside dia of chimney (i.e dia at 1/3 height from top)

7.2.2 VORTEX SHEDDING



i) $Re < 5$
Regime of unseparated flow

ii) $5 \leq Re < 40$
A fixed pair of vortices in wake

iii) $40 < Re < 150$
Vortex street is laminar

iv) $150 < Re \lesssim 3 \times 10^5$
Vortex street changes from laminar to turbulent

v) $\backsim 3 \times 10^5 < Re < 3.5 \times 10^6$
Turbulent transition. Wake is narrower and disorganised.

vi) $3.5 \times 10^6 \leq Re$
Re-establishment of turbulent vortex street.

Fig. 3.5 Regimes of Fluid Flow Across Circular Cylinders

7.2.3 Across wind forces - Computation

Lateral force due to Vortex Shedding can be expressed as,

$F_{(z,l)} = p_z C_L D_z \text{Sin } 2\pi f_s + p(z)$

p_z = Wind pressure at height Z

C_l = lift coefficient

=0.67

f_s = Vortex Shedding frequency (Hz) at level z

= (V_z/D_z)*S

D_z = Diameter at level z

Vz = Wind velocity at level Z

S = Strohaul number

INDUSTRIAL CHIMNEYS

7.2.4 Supression of Vortex Shedding

- **If vortex shedding can be avoided, the chimney design can ignore design for across wind loads. Design for across wind loads could be costlier**

- **Methods of suppresing vortex shedding include:**

  Providing stakes (discrete plates) for top 1/3rd height

  Providing shroudes

  Providing dampeners in the form of hanging steel chains

INDUSTRIAL CHIMNEYS

7.2.5 Strakes

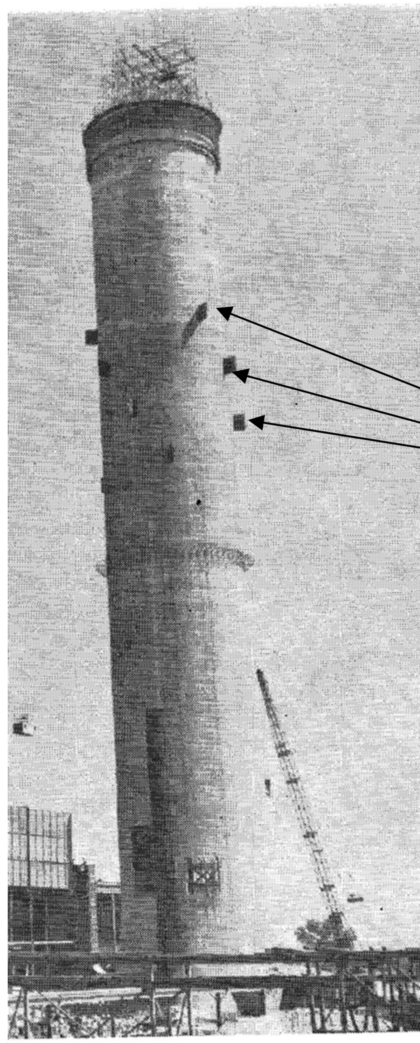
- **Strakes are discrete vertical plates attached on top portion of Chimney to break the formation of Vortex shedding (very common practice in Indian Chimneys)**
- **Provided in helical form for top 1/3 height.**
- **Projection from chimney surface = 0.12D; Height 1 t0 1.5m**

  where, D = top diameter of chimney

6. Shrouds

- Metal skin cover, with perforations, attached to top of Chimney.
- Gap between chimney and shroud = 0.12D
- Area of openings/Gross area of shroud = about 30%, is most effective

INDUSTRIAL CHIMNEYS



Chimney fixed with strakes at top to avoid Vortex Shedding

INDUSTRIAL CHIMNEYS

Fig. 9.2 Strakes

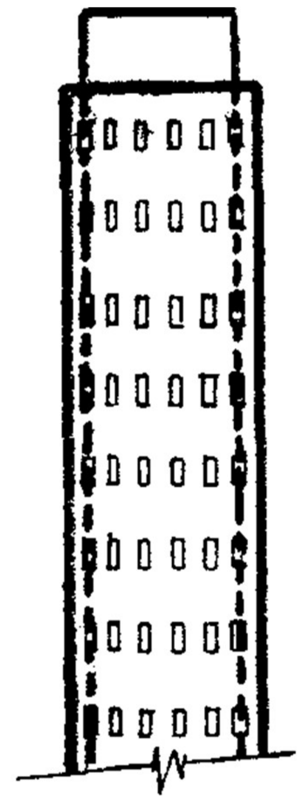


Fig. 9.3 Shroud

INDUSTRIAL CHIMNEYS

7.3 Earthquake/Seismic Load

Total lateral base shear , V_b= 0.35 Z W/(T)$^{1/2}$

(Basis : Uniform Building Code of Canada; IS code has slightly different appraoach)

Z = Zone coefficient
= 3/16 (Zone-1)
= 3/8 (Zone-2)
= 3/4 (Zone-3)
= 1.0 (Zone-4)

W = Total weight of Chimney (including lining & other dead loads)

T = First mode period (in sec); to obtained from detailed dynamic analysis

Base shear, V_b will be distributed over the height as per provisions of IS:1893, Code for earthquake resistant structures.

7.5 Temperature Loads

- **Inside surface is at Flue gas temperature, T**
- **Outside surface is at atmospheric temperature, T_0**
- **T can vary from 100 to 175^0C**
  T_0 can vary from 20 to 45^0C
- **Differential temperature,**
  $T_x = T - T_0$

Concrete to be designed for this temperature differential.

If the temperature difference is very high, then internal lining is required to be provided for flattening the temperature gradient.

Temperature stress, $f_t = (\alpha E_c T_x)/2$

α = coefficient of expansion of concerete
E_c = Concrete modulus

8. LINING OF CHIMNEYS

- When the gradient $T_x > 40^0C$, lining will be required to reduce thermal stresses in concrete and steel.
- Materials used for lining are:

  Acid resistant bricks (very common)

  Acid resistant Fire bricks (very common)

  Mild steel liners
- Thickness of lining bricks will be decided by the limiting thermal gradient and design temperature.
- Bricks are built over corbels (brackets from chimney shell), which are generally at 10m height intervals.

INDUSTRIAL CHIMNEYS

Chimney Under Construction

VIEW FROM TOP SHOWS EXTERNAL LANDING PLATFORM

INDUSTRIAL CHIMNEYS

INTERNAL
LINING
UNDER
CONSTRUCTION

Acid Resistant
Fire Bricks

INDUSTRIAL CHIMNEYS

INTERNAL LINING UNDER CONSTRUCTION

Acid Resistant Fire Bricks

Coal-tar applied to Inner surface of Concrete shell to close shrinkage cracks and as protection to concrete

INDUSTRIAL CHIMNEYS

9. FOUNDATIONS

- **Generally circular raft foundations are provided.**
- **Pile foundations are also common.**
- **Diameter and thickness of raft foundation is governed by combined vertical loads and wind / seismic loads.**
- **Stability factors govern the design,**

  F.O.S (overturning) > 1.5

  F.O.S (sliding) > 1.5
- **Foundations are taken deeper to get additional soil weight on raft to assist stability.**
- **Gross bearing pressure under footing should be compressive i.e. “loss of contact” is to be avoided or limited to a maximum of 1/6 of raft diameter.**
- **220m tall chimney, in wind speeds upto about 40 m/sec, would require a 30m diameter raft x 3m thickness**

10. METHOD OF CONSTRUCTION

Following two methods are very common:

- **Jump form**
- **Slip form**

Jump Form: Construction is in stages of about 1.5 to 3.0m lifts

Slip form: Continuous construction

Formwork keeps moving upward at low speed as the concreting continues.

Eg. DHOKA System (from Austria)

Forces Acting on Steel Chimneys

The various forces acting on the self-supporting steel chimney are as follows:

1. Self-weight of the steel chimney
2. Weight of lining
3. Wind pressure
4. Seismic forces

a. self-weight of the steel chimney:

$$W_s = \rho.(\pi d).(t).(h)$$

b. Weight of lining:

$$W_L = \rho_1.\pi.d.(0.1).(h)$$

c. Wind pressure:

$$P = 0.7 \times (p_1 \times d' \times h) kN$$

INDUSTRIAL CHIMNEYS

11. REFERENCES

1. IS: 4998 – Criteria for Design of Reinforced Concrete Chimneys

2. IS: 6533 - Code of Practice for Design and Construction of Steel Chimneys

3. Tall Chimneys- Design & Construction by S.N. Manohar, Tata McGraw-Hill Publishing Company Limited.

4. Hand Book of Concrete Engineering, edited by Mark Fintel, CBS Publishers & Distributors