Analysis and Design of Reinforced Concrete Chimney

By

Dave Hari Virendra

12MCLC05

DEPARTMENT OF CIVIL ENGINEERING,
INSTITUTE OF TECHNOLOGY,
NIRMA UNIVERSITY.

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Analysis and Design of Reinforced Concrete Chimney

Major Project Report

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Master of Technology in Civil Engineering

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By

Dave Hari Virendra

(12MCLC05)

Guided By

Prof. (Dr.) Sharad. P. Purohit

DEPARTMENT OF CIVIL ENGINEERING,
INSTITUTE OF TECHNOLOGY,
NIRMA UNIVERSITY.
AHMEDABAD - 382481

May - 2014

Declaration

I **Dave Hari Virendra** hereby declare that this submission is my own work and to the best of my knowledge it contains no material previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at Nirma University or any other educational institution, except where due acknowledgment is made in the thesis.Wherever contributions of others are involved, every effort is made to indicate it clearly, with due reference to the literature, and acknowledgment of collaborative research and discussions.

The work was done under the guidance of **Prof. (Dr.) Sharad P. Purohit**, at Institute Of Technology, Nirma University, Ahmedabad.

Dave Hari Virendra

12MCLC05

Certificate

This is to certify that the Major Project Report entitled "**Analysis and Design Of Reinforced Concrete Chimney**" submitted by **Dave Hari Virendra (12MCLC05)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Civil Engineering (Computer Aided Structural Analysis & Designing)** of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, have not been submitted to any other University or Institution for award of any degree.

Prof. (Dr.) Sharad P. Purohit
Associate Professor
Department of Civil Engineering,
Institute of Technology,
Nirma University,
Ahmedabad

Dr Paresh V. Patel
Professor and Head
Department of Civil Engineering,
Institute of Technology,
Nirma University,
Ahmedabad.

Dr. Ketan Kotecha
Director,
Institute of Technology,
Nirma University,
Ahmedabad.

____
Signarture Of Examiner

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ABSTRACT

A chimney is a means by which waste gases produced due to industrial processes are discharged to the atmosphere. Height of the chimney is kept such that the gases get diluted due to atmospheric turbulence. Chimney is particularly susceptible to the wind pressures, and hence, it is important to correctly estimate the design wind loads. Chimney is a vertical cantilevered shell pierced by openings where necessary and subjected to large temperature gradients. The Indian Standard, IS: 4998 (Part – 1) 1992 lays the provisions for the analysis and design of chimney structures. Apart internationally, various codes namely, ACI 307 – 08, CICIND – 2001, EUROCODE – 8 (Part – 6) are widely used for analysis and design of chimney structures.

The prime focus of the present major project work is to study the behaviour of chimney structure under the effect of wind loads, earthquake loads and temperature gradients. Analysis of the chimney is carried out considering typical loads, as specified in IS: 4998 (Part – 1) 1992 by developing excel sheets. Chimney has been modeled in STAAD.Pro using the lumped mass modeling approach, to calculate dynamic properties useful for seismic as well as wind analysis.

Recently BIS has published draft code IS: 4998 (April – 2013). The provisions of the Draft Indian Standard are studied and compared with the provisions of the existing Indian Standards viz. IS: 4998 (Part - 1) 1975 and IS: 4998 (Part - 1) 1992. Apart, a parametric study has also been carried out for an RCC chimney by keeping its height constant and varying the seismic zone and wind speeds. It is found that in locations with high seismicity the earthquake forces govern the design.

Contents

Declaration **ii**

Certificate **iii**

Acknowledgments **iv**

Abstract **vi**

Table of Contents **ix**

List of Figures **xi**

List of Tables **xv**

Nomenclatures **xvi**

1 Introduction **1**

1.1 Overview 1

1.2 Materials of Construction 2

1.3 Evolution of Tall Chimneys 5

1.4 Need of study 11

1.5 Objective of study 11

1.6 Scope Of Major Project 12

1.7 Organization of report 13

2 Literature review **14**

2.1 General 14

2.2 Wind Load Estimation 14

2.3 Seismic Analysis Of Chimneys 16

2.4 Comparison of Wind And Seismic Forces 17

2.5 Summary 18

3 Comparison of Chimney Design Standards **19**

3.1 Introduction 19

3.2 Materials and Load Assessment 20

3.3 Estimation of Wind Loads 21

3.4 Grouped Chimneys, Structural Considerations and Construction Requirements 23

3.5 Structural Considerations and Serviceability Requirements 25

3.6 Summary 26

4 Analysis Of RCC Shell **27**

4.1 Introduction 27

4.2 Problem Data 28

4.3 Lining Details 30

4.4 Preliminary Sizing and Load Calculations 30

4.5 Dead loads & Live loads 32

4.6 Seismic Analysis 44

4.7 Wind Load Analysis 52

4.8 Summary of results 92

5 Design Of RCC Shell **100**

5.1 Introduction 100

5.2 Calculation of stresses in RCC shell due to DL 101

5.3 Calculation of stresses in the shell under DL + WL combination (Governing Moments) 104

5.4 Calculation of temperature drop in RCC shell 116
5.5 Check for stresses in shell under DL + Temperature condition 120
5.6 Check for stresses in shell under DL + WL + Temperature combination . . . 124
5.7 Circumferential Stresses 126
5.8 Design of vertical reinforcement 133
5.9 Design of circumferential reinforcement 136
5.10 Design of extra reinforcement around openings 138
5.11 Foundation Design 143
5.12 Check for shear 145
5.13 Summary 145

6 Parametric study 146

6.1 Introduction 146
6.2 Details of Parametric Study 146
6.3 Parametric Study For Two Different Seismic Zones and Four Different Basic Wind Speeds 148
6.4 Summary and discussion of results 165

7 Conclusions and future scope of work 167

7.1 Summary 167
7.2 Conclusions 168
7.3 Future Scope Of Work 170

List of Figures

1.1 RCC Chimney 3

1.2 Steel Chimney 4

1.3 Single Flue RCC Chimney 10

1.4 Multi Flue RCC Chimney 10

4.1 Chimney Cross-Section 29

4.2 STAAD.Pro Model For Modal Analysis And Frequency Calculation 48

4.3 Earthquake Induced Shear Forces 51

4.4 Earthquake Induced Bending Moments 51

4.5 Simplified Method - Along Wind Load - Shear Force And Bending Moment Calculation 54

4.6 Simplified Method - Along Wind Load - Secondary Moment Calculation . . . 54

4.7 Random Response Method - Along Wind Load - Shear Force And Bending Moment Calculation 60

4.8 Random Response Method - Along Wind Load - Secondary Moment Calculation 60

4.9 Simplified Method - Across Wind Load - Shear Force And Bending Moment Calculation 69

4.10 Random Response Method - Across Wind Loads - Shear Force & Bending Moment Calculation 85

4.11 Summary Of Magnified Shear Forces (Shell Alone Condition) 95

4.12 Summary Of Magnified Shear Forces (Chimney Complete Condition) 95

4.13 Summary Of Magnified Bending Moments - Shell Alone Condition 98

4.14 Summary Of Magnified Bending Moments - Chimney Complete Condition . 98

5.1 Details Of Opening At EL (+) 21.9 m 106
5.2 Nature Of Bending Moment Diagram For Footing 143

6.1 Parametric Study : Flow Chart 147
6.2 39 - III - Variation Of Shear Forces 149
6.3 39 - V - Variation Of Shear Forces 149
6.4 39 - III - Variation Of Bending Moments 151
6.5 39 - V - Variation Of Bending Moments 151
6.6 44 - III - Variation Of Shear Forces 153
6.7 44 - V - Variation Of Shear Forces 153
6.8 44 - III - Variation Of Bending Moments 155
6.9 44 - V - Variation Of Bending Moments 155
6.10 47 - III - Variation Of Shear Forces 157
6.11 47 - V - Variation Of Shear Forces 157
6.12 47 - III - Variation Of Bending Moments 159
6.13 47 - V - Variation Of Bending Moments 159
6.14 50 - III - Variation Of Shear Forces 161
6.15 50 - V - Variation Of Shear Forces 161
6.16 50 - III - Variation Of Bending Moments 163
6.17 50 - V - Variation Of Bending Moments 163
6.18 Deflection 165

List of Tables

3.1 Construction Material And Load Assessment . . . 21

3.2 Estimation of wind loads . . . 22

3.3 Construction Requirements & Structural Considerations . . . 24

3.4 Structural Considerations and Serviceability Requirement . . . 25

4.1 Problem Formulation . . . 28

4.2 Elevations of important locations of the chimney. . . . 30

4.3 Section properties of the shell at different levels . . . 33

4.4 Lining weight calculation . . . 34

4.5 Corbel weight calculation . . . 35

4.6 Spiral staircase and ladder weight calculation . . . 36

4.7 External platform loads (RCC Full and Partial) . . . 38

4.8 Summary of total weights . . . 41

4.9 Details Of Axial Loads . . . 42

4.10 Masses Of The Chimney . . . 43

4.11 Spectral Acceleration Coefficient . . . 45

4.12 Section Properties For Beam Elements : STAAD.Pro . . . 46

4.13 Details Of Lumped Mass or Nodal Loads : STAAD.Pro . . . 47

4.14 Frequency Of The Chimney In The First Six Modes . . . 48

4.15 Mode Shapes Of The Chimney . . . 49

4.16 Seismic Loads On The Chimney . . . 50

4.17 Summary Of Along Wind Forces : Simplified Method - Shell Alone Condition 55

4.18 Summary Of Along Wind Loads : Simplified Method - Chimney Complete Condition . . . 56
4.19 Summary Of Along Wind Loads : Random Response Method - Shell Alone Condition . . . 62
4.20 Summary Of Along Wind Loads : Random Response Method - Shell Alone Condition (Contd.) . . . 63
4.21 Summary Of Along Wind Loads : Random Response Method : Chimney Complete Condition . . . 64
4.22 Summary Of Along Wind Loads : Random Response Method - Chimney Complete Condition (Contd.) . . . 65
4.23 Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 1) . . . 72
4.24 Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 1) (Contd.) . . . 73
4.25 Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 2) . . . 74
4.26 Summary Of Across Wind Loads : Shell Alone Condition (Mode - 2) (Contd.) 75
4.27 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) . . . 76
4.28 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Effect Of Other Lumped Masses) . . . 77
4.29 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Contd.) . . . 78
4.30 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Resultant Forces) . . . 79
4.31 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) . . . 80
4.32 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Effect Of Other Lumped Masses) . . . 81
4.33 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Contd.) . . . 82

4.34 Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Resultant Forces) 83
4.35 Summary Of Across Wind Loads : Random Response Method - Shell Alone Condition (Mode - 1) 86
4.36 Summary Of Across Wind Loads : Random Response Method - Shell Alone Condition (Mode - 2) 87
4.37 Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 1) 88
4.38 Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 1) (Resultant Forces & Moments) 89
4.39 Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 2) 90
4.40 Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 2) (Resultant 91
4.41 Summary Of Axial Loads 93
4.42 Summary Of Shear Forces (Shell Alone Condition) 94
4.43 Summary Of Shear Forces (Chimney Completed Case) 96
4.44 Summary Of Bending Moments (Shell Alone Condition) 97
4.45 Summary Of Bending Moments (Chimney Complete Condition) 99

5.1 Stress In RCC Shell Due To Dead Loads (DL) : Shell Alone Condition . . . 102
5.2 Stresses In RCC Shell Due To Dead Loads (DL): Chimney Complete Condition 103
5.3 Stresses In RCC Shell Due To DL + WL (Shell Alone Condition) 107
5.4 Stresses In RCC Shell Due To DL + WL (Shell Alone Condition - Contd.) . 111
5.5 Stresses In RCC Shell Due To DL + WL (Shell Alone Condition - Contd.) . 112
5.6 Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition) . . 113
5.7 Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition - Contd.) 114
5.8 Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition - Contd.) 115
5.9 Temperature Drop Across The Shell 118

5.10 Temperature Drop Across The Shell Contd. 119
5.11 Stresses Due To DL + Temp 122
5.12 Stresses Due To DL + Temp (Contd.) 123
5.13 Stresses In RCC Shell Under DL + WL + Temperature 125
5.14 Circumferential Stresses In Concrete Due To Temperature Alone 127
5.15 Circumferential Stresses In Shell Due To Temperature Alone 128
5.16 Circumferential Tensile Stresses In Concrete Due To Wind Induced Ring Moment 130
5.17 Circumferential Compressive Stresses In Concrete Due To Wind Induced Ring Moment 132
5.18 Vertical Reinforcement Requirement 134
5.19 Requirement Of Vertical Reinforcement (Contd.) 135
5.20 Details Of Circumferential Reinforcement 137
5.21 Details Of Extra Vertical Reinforcement Around Openings 140
5.22 Details Of Extra Circumferential Reinforcement Around Openings 141
5.23 Details Of Diagonal Reinforcement Around Openings 142

6.1 Combination (A) - Variation Of Shear Forces 148
6.2 Combination (A) - Variation Of Bending Moments 150
6.3 Combination (B) - Variation Of Shear Forces 152
6.4 Combination (B) - Variation Of Bending Moments 154
6.5 Combination (C) - Variation Of Shear Forces 156
6.6 Combination (C) - Variation Of Bending Moments 158
6.7 Combination (D) - Variation Of Shear Forces 160
6.8 Combination (D) - Variation Of Bending Moments 162
6.9 Deflection Values Across The Chimney Height 164

Nomenclatures

A_c	area of concrete section under consideration in mm^2
B	Background factor indicating slowly varying component of wind fluctuation
β	Structural damping as a fraction of critical damping to be taken as 0.016
CC	Chimney complete condition
C_D	Drag coefficient of the chimney to be taken as 0.8
C_L	Peak oscillatory lift coefficient to be taken as 0.16
$\bar{C}_L$	RMS oscillatory lift coefficient to be taken as 0.12
d_z	diameter of the chimney at a height z in m
d	effective diameter taken as average diameter over the top 1/3 height of the chimney
D_{bo}	outside diameter of chimney at base in mm
D_c	mean diameter of concrete chimney shell at section under consideration in mm
D_{ci}	inside diameter of concrete chimney shell at section under consideration in mm
D_{co}	outside diameter of concrete chimney shell at section under consideration in mm
D_{to}	outside diameter of chimney top in mm
D_{wo}	outside diameter of chimney at 1/3 height from top in mm
e	distance between central line of the shell and the center of gravity of the local load in m
E	Measure of the available energy in the wind at the natural frequency of the chimney
E_c	modulus of elasticity of concrete N/mm^2
E_d	dynamic modulus of elasticity of concrete in N/mm^2
E_s	modulus of elasticity of steel in N/mm^2
f	natural frequency of the chimney in Hz
f_i	natural frequency of the chimney in the i^{th}mode of vibration
g	acceleration due to gravity

G — gust factor

g_f — peak factor defined as the ratio of the expected peak value to the RMS value of the fluctuating load

H — height of the chimney in m

k_a — aerodynamic damping coefficient to be taken as 0.5

K_{si} — mass damping parameter for the i^{th}mode of vibration

L — correlation length in diameters to be taken as 1.0 in the absence of adequate field data

SA — Shell alone

σ_{cwct} — maximum circumferential tensile stress in concrete due to wind induced ring moment in N/mm^2

σ_{cwcc} — maximum circumferential compressive stress in concrete due to wind induced ring moment in N/mm^2

$\sigma_{cv-comb}$ — maximum vertical compressive stress in concrete due to combined effect of wind, dead loads and temperature occurring at the inside of the chimney shell in N/mm^2

$\sigma_s T_c$ — maximum circumferential tensile stress in steel due to temperature alone in N/mm^2

$\sigma_s T_v$ — maximum vertical tensile stress in steel due to temperature in N/mm^2

σ_{sv} — maximum stress in vertical reinforcement in N/mm^2

σ_{swct} — maximum circumferential tensile stress in steel due to wind induced ring moment in N/mm^2

$\sigma_{sv-comb}$ — maximum vertical tensile stress in steel due to combined effect of dead load, wind load and temperature in N/mm^2

σ_{sy} — yield or proof stress of steel in N/mm^2

Chapter 1

Introduction

1.1 Overview

A Chimney is a tall slender structure by means of which the waste gases are discharged into the outside atmosphere at a high enough elevation via stack effect. Chimneys are typically vertical or as near as possible vertical, to ensure that the gases flow smoothly, under the influence of what is known as stack or chimney effect. The space inside the chimney is called a flue. The primary function of the chimney is to discharge pollutants into the atmosphere at such heights and velocities that after dilution due to atmospheric turbulence the concentration of pollutants and the entrained solid particulates deemed harmful to the environment are kept within acceptable limits at ground level and facilitate compliance with regulatory limits.The height of the chimney greatly influences its ability to transfer flue gases to the external environment via stack effect.

1.1.1 Function and Working Principle

The basic and most important function of a chimney is to convey and discharge combustion or flue gases away from the operating area of the industry as well as the human occupancy.

WORKING PRINCIPLE: Stack effect or Chimney effect is the driving force responsible for conveyance and discharge of the flue gases. Stack effect is the movement of air into and out of building, chimneys, flue gas stacks and is driven by buoyancy. Buoyancy occurs due to difference in indoor - to - outdoor air density resulting from temperature or moisture differences. The result is either a positive or negative buoyancy force. The greater the thermal difference and the height of the structure the greater are the buoyancy force, and thus the stack effect. The stack effect is also referred to as chimney effect.

The combustion flue gases inside the chimney or stacks are much hotter than the ambient outside air and therefore less dense than ambient air. This causes the bottom of the vertical column of hot flue gases to have a lower pressure than the pressure at the bottom of the corresponding column of outside air. The higher pressure outside the chimney is the driving force that moves the required combustion air into the combustion zone and also moves the flue gas up and out of the chimney. The movement of air or flow of combustion air and flue gases is called natural draft / natural ventilation / chimney effect / stack effect.

A chimney being highly reliable does not require standby.

1.2 Materials of Construction

Man has always been is search of an effective system to dispose of undesirable gaseous products of combustion. The earliest form of such a system was a small vent. Over the years there was an increase in the both the draft requirements and volume of gases to be handled and as a result vents were replaced by small brick chimneys. The size of such chimneys continued to increase and those larger than 500 mm in diameter came to be known as industrial chimneys.

Until the beginning of this century, the popular materials for chimney construction were brick and steel. As chimneys grew taller, brick chimneys were replaced by steel chimneys - both self supporting and guyed.

1. 1876 - First concrete chimney was built in Germany
2. 1900 - Advent of RCC Chimney construction in USA and USSR
3. 1907 - Reinforced concrete chimneys introduced in UK and Europe
4. 1910 - Tapering of concrete chimney gained existence
5. 1916 - 165 m tall chimney built in Japan
6. 1928 to 1932 - Marked technical improvements observed in the field of concrete Chimneys
7. 1950 - Effective solution to control cracking in concrete due to temperature gradient evolved and concrete attained its present predominant status as a construction material

The early reinforced concrete chimneys were sometimes unlined. On other occasions they were only lined near the bottom with brick or with a second wall of concrete. They were often insufficiently reinforced to resist temperature stresses and many developed serious cracks. In others the concrete suffered as a direct result of being exposed to the heat of the hot gases. A large number of different insulation and lining materials and methods of support are available. The four main types are, those in which the windshield is independent of the flues, those where the flues are supported at intervals from the windshields, those where the flues are carried on skeletal frame, and finally precast concrete chimneys.

Figure 1.1 shows a typical RCC chimney with cylindrical geometry up to certain height from the top followed by a tapered profile up to the base.

Figure 1.1: RCC Chimney

Figure 1.2 shows a typical steel chimney having a cylindrical profile up to certain height from the top followed by a tapered profile up to the base. The cylindrical portion at the top is provided with strakes to minimize the effect of vortex shedding.

Figure 1.2: Steel Chimney

1.2.1 Lining

Early chimneys were unlined. Developments in boiler and fuel technology led to low flue gas temperatures which aggravated the corrosion problem and forced the introduction of protective lining. Initially, self supporting, acid - resisting brickwork backed by an insulating medium was used as a lining, but soon insulating bricks were introduced in 1950's. As a subsequent development, such a lining was supported from corbels (at intervals) off the concrete shell instead of being independent of the shell. However, gases penetrating through the brick lining caused corrosion of the concrete shell and to overcome this deficiency, a ventilated air gap was introduced between the lining and concrete shell. At present, steel liners are popular because they are impervious to gases and compared to bricks, and permit a higher gas velocity.

1. 1960 - Insulated steel liners made their appearance
2. 1971 - Problem of buckling of steel liners came to the forefront and design modifications had to be introduced to cater for temperature differential effects etc.

In recent years, plastics are being tried out as a lining material and if new technology can achieve cost reduction and efficient performance, plastic may well prove to be the primary lining material in the future.

1.3 Evolution of Tall Chimneys

With ever growing demand for power, engineering industry is churning out power plants of progressively higher capacity. To maintain ecological balance as well as limit the environmental pollution, chimneys emitting the spent flue gases are also getting higher and higher everyday. In India it is now mandatory that for all fossil fuel power plants the height of the chimneys be minimum 200 m for 210 MW unit and 275 m for 500 MW.

The enforcement of stricter air-pollution control standards has led to the construction of increasingly tall chimneys worldwide. Chimneys as an indirect means of air pollution control are immensely popular.Height and aspect ratio are two important criterion's to classify a chimney as a tall chimney. Usually a chimney with height exceeding 150 m and having an aspect ratio such that it calls for evaluation of the structures response to dynamic wind loads is considered as a tall chimney.

The recent trend to adopt multi-flue chimneys to serve more than one boiler is a distinct asset to an architect. Single-flue chimneys are too thin to hold the eye but multi-flue chimneys, because of their larger width, lend strength and character to a chimney and hence are aesthetically preferred. Such chimneys are generally cylindrical but the introduction of a taper is both technically meaningful and aesthetically desirable. The cost of a multi-flue chimney is greater than that of a single-flue chimney of comparable flue area but may produce advantages in operation and maintenance. In order to avoid acid condensation in the flues it is advisable to maintain high flue velocity which in turn minimizes the loss of heat due to downwash etc.

1.3.1 Important Components of Parts of an RCC Chimney

A chimney primarily comprises of the following structural components.

1. Flue
2. Flue ducts and insulation.
3. Flue Lining.
4. Landings and Platforms (internal or external) for inspection and maintenance.
5. Staircase and/or elevators.

1.3.2 Governing Loads For Chimney Design

As per IS : 4998 (Part - 1) 1992 Pg. 2 Clause 5

The various loads to be taken in to account for design of chimneys shall be as follows:

- Dead loads
- Imposed loads
- Lateral and circumferential wind loads
- Earthquake loads
- Effect of temperature both vertical and circumferential.

For the overall design of the chimney shell and foundation, imposed loads need not be considered, However, for the design of individual structural elements such as platform, etc for local structures such as platforms, etc. and for local strengthening of the shell, appropriate imposed loads shall be considered.

1.3.3 Dead loads

The dead loads to be considered for design mainly comprises of the following:

- Concrete wind shield.
- Flue ducts.
- Lining together with brackets and Insulation.
- Staircases and/or Elevators
- Platforms for inspection and maintenance.

1.3.4 Wind Loads

Wind load data usually varies with location and is available in the design standards in the form of basic wind speed for most of the important locations. At locations where wind blows in a haphazard fashion the designers are advised to resort to wind rose. Wind forces need to be analyzed for both static as well as dynamic effects. Various methods for along wind and across wind analysis are available in majority of the internationally accepted design standards. Circumferential effects of wind also need to be considered.

1.3.5 Earthquake Loads

Chimneys are particularly vulnerable to earthquake 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. Tall chimneys are an important feature of power and petrochemical industry. Damage to them during an earthquake can have a severe consequence both in terms of economy and loss of human life.

Unlike other tall structures the most dangerous thing about chimney is that these structures are basically a cantilever structure having one line of defense (the structure itself) and has practically no redundancy built in it. Thus during an earthquake if any portion develops a hinge it would invariably make the system a mechanism with collapse being imminent. It is for this reason that the dynamic behaviour of the chimney structure under earthquake loading is of primary importance, and needs to be very carefully addressed to during the analysis and design.

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 safely resist. Chimney vibration is essentially a dynamic problem of a transient nature. For analysis, a chimney (where the mass is never evenly distributed) is treated as a cantilever beam with predominant flexural deformations and is analyzed by one of the following methods:

- Response-Spectrum Method (First Mode)
- Modal-Analysis Technique (Using Response Spectrum).
- Time-History Response Analysis.

The use of response-spectrum method is limited to short chimneys (usually less than 90 m high). Seismic analysis is usually performed using the response spectrum method. Earthquake forces are location specific and are derived using the guidelines available in the relevant design standards. The Indian standard for stack like structures is IS : 1893 (Part - 4) 2005 which is to be used in conjunction with IS : 1893 (Part - 1) 2002. As per IS: 1893 (Part - 4) 2005 RCC Chimney is categorized as Industrial Structure of Category 2 and has been assigned an importance factor of 1.75 which can be increased at the discretion of the design engineer or project authorities.

1.3.6 Temperature Effects

Essentially, chimney structures are vertical cantilevered shells pierced by openings where necessary and subjected to large temperature gradients.

The principle specialized problems concerning chimneys arise from the thermal and corrosive effects of the elevated temperatures and differential temperature movements between concrete and the insulating materials. High temperature flue gases give rise to insulation and movement problems, while low temperature gases induces difficulties due to acid condensation. These effects necessitate the protection of the concrete from elevated temperatures and differential temperature movements between concrete and the insulating materials. Temperature gradient induced vertical and circumferential stresses can be determined after establishing the magnitude of the thermal gradient.

1.3.7 Type of chimneys

Chimneys may be classified in a variety of ways as illustrated further in the discussion. Some of the important aspects are as follows:

- HEIGHT: Initially chimneys with a height greater than 150 m were considered to be tall chimneys. However with recent emphasis on structural dynamics, it is generally accepted that a chimney may be considered as tall when its height exceeds 150 m and in addition its aspect ratio is such that it calls for evaluation of structures response to 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.

- NUMBER OF FLUES: Often a single chimney serves more than one boiler. In such a case when one of the gas sources is shut down (say for maintenance) the gas exit velocity will reduce because of a reduction in total volume of 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 flues housed in a common enclosing concrete windshield. These are popularly called multi - flue chimneys.

- CONSTRUCTION MATERIAL: Above a certain height, an RCC chimney requires less materials, is lighter and is less expensive than a brick chimney. RCC chimney offers great resistance against wind - induced vibrations, rheological strains, foundation settlement. Today reinforced concrete is dominant material used for construction of tall chimneys and for short chimneys precast concrete with or without prestressing is used. In latter range reinforced concrete has to face severe competition from steel - and glass - reinforced plastic. The principle specialized problems concerning chimneys arise from the thermal and corrosive effects of the flue gases. These effects necessitate the protection of the concrete from elevated temperatures and differential temperature movements between the concrete and insulating materials. High-temperature flue gases give rise to insulation and movement problems, while low-temperature gases induce difficulties due to acid condensation.

Figure 1.3 shows a typical single flue RCC chimney.

Figure 1.3: Single Flue RCC Chimney

Figure 1.4 shows a typical multi-flue RCC chimney.

Figure 1.4: Multi Flue RCC Chimney

1.4 Need of study

With ever growing demand for power, engineering industry is churning out power plants of progressively higher capacity. To maintain ecological balance as well as limit the environmental pollution, chimneys emitting the spent flue gases are also getting higher and higher everyday. In India it is now mandatory that for all fossil fuel power plants the height of the chimneys be minimum 220 m for 210 MW unit and 275 m for 500 MW unit. While this though reduces the ground pollution concentration significantly, has posed new challenges to structural engineers to come up with a safe design of these tall chimneys under wind and earthquake, which affects its behaviour significantly. The following are the major concerns to undertake the study:

- The effect of temperature gradient and the subsequently induced stresses is not studied in depth.

- The design specifications for RCC chimney need to be clearly understood, specifically the dependence of shell thickness and reinforcement requirement based on the stresses induced in the shell due to various combination of loads.

1.5 Objective of study

The present major project work deals with the in depth study of the behaviour or response of the chimney structure under the effect of wind loads, earthquake loads and temperature effects. Following are the objectives of the study:

- To study in detail the loads governing the analysis and design of chimney structures based on Indian Standard.
- To analyze and design a single flue reinforced concrete chimney, with main emphasis on the effect of temperature, wind and earthquake on the structural behaviour and subsequently the design of the chimney.
- To carry out a parametric study with respect to different seismic zones, varying basic wind speed.

1.6 Scope Of Major Project

- To study the governing loads, analysis and design procedure slated in IS : 4998 (Part -) 1992 and IS : 4998 (Part - 1) 1975 respectively for the analysis and design of RCC chimney.
- To study the provisions of widely used chimney design standards viz. ACI 307 - 08 and CICIND - 2001.
- To study the provisions of the latest revision of IS: 4998 published by Bureau of Indian Standard and compare the provisions of the same with the existing chimney design standard as well as ACI 307 -08
- To analyze and design reinforced concrete chimneys using IS 4998 (Part - 1) 1992 and IS : 4998 (Part - 1) 1975
- To prepare excel sheets for the wind analysis of the chimney using the simplified method and random response methods for along wind loads and across wind loads as recommended by IS: 4998 (Part - 1) 1192.
- To model the chimney as an assembly of beam elements using STAAD.Pro for calculation of natural frequencies and mode shapes and subsequent seismic analysis of the chimney using Response Spectrum Method in accordance with IS: 1893 (Part - 4) 2005 used in conjunction with IS: 1893 (Part - 1) 2002.
- To prepare excel sheets to check for the stresses induced in concrete and steel due to various combination of loads as recommended by IS: 4998 (Part - 1) 1975 and check for their magnitudes to be limited to the permissible values.
- To perform a parametric study by varying seismic zone and wind speed for a constant height of the chimney.

1.7 Organization of report

Chapter 1 deals with the general overview of the topic, introduction to chimneys, important loads and load combinations governing the analysis and design of chimneys, need of study, objective of study and scope of work.

Chapter 2 includes the details of the literature review. A brief summary of the referred research papers based on the work done in past basically on wind and earthquake analysis of chimney has been given.

Chapter 3 details brief tabulated comparison of the provisions of IS : 4998 (Part - 1) 1992 and Draft Indian Standard i.e. IS : 4998 (Part - 1) - April 2013.

Chapter 4 covers the entire analysis of the RCC shell including load calculations, modeling procedures, seismic analysis and wind analysis in accordance with the relevant Indian standards.

Chapter 5 starts with the calculation of stresses induced in the shell as well as the steel under the effect of dead loads, wind loads and temperature loads individually as well in a set of load combinations as mentioned in IS : 4998 (Part - 1) 1975. The design of vertical reinforcement, circumferential reinforcement and extra reinforcement around the ducts/openings has also been incorporated.

Chapter 6 gives details of the parametric study carried out by varying the seismic zone for a set of four different basic wind speeds.

Chapter 7 includes brief summary of the work done in the major project, important conclusions and future scope of work.

Chapter 2

Literature review

2.1 General

Analysis and design of RC chimneys has been explored to a considerable extent by various researchers. A variety of analytical as well as experimental approaches have been implemented to simulate and understand the actual structural behaviour of the chimney.With passage of time more realistic and reliable concepts have evolved. In this chapter studies carried out by few researchers have been highlighted.

2.2 Wind Load Estimation

This section of the chapter summarizes the important findings from the studies carried out by various researchers to simulate and understand the behaviour of chimneys under the effect of wind loads.

Menon & Rao (1997) [1] - reviewed the prevailing international codal procedures to evaluate across-wind response of R/C chimneys. The paper mentions about the Vickery-Basu Model whose modified version has been incorporated as "Simplified Method" in IS : 4998 (Part - 1) 1992. The paper also describes the significance of chimney classification based on taper and highlights that the concept of taper should ideally relate to the slope in the elevation of the tower and should involve slenderness ratio along with taper ratio. Only IS : 4998 (Par - 1) 1992 is the one that takes this fact into consideration as per the author. In the paper the author tries to establish an expression for the expected maximum bending moment. The major findings of the study are as follows:

- Across wind loading condition cannot be ignored, and is likely to govern the design, particularly, in case of relatively stocky and cylindrically shaped chimneys (usually multi-flue chimneys)

- The paper highlights that the random response method of analysis based on Vickery-Basu model incorporated in the IS : 4998 (Part - 1) 1992 gives fairly accurate results of across-wind response but because of the codal recommendation to consider higher estimate for designs the results of simplified analysis govern.
- Author also establishes relations in terms of ratio of diameter at top and diameter at base and height of the chimney to diameter at base to assert that the across-wind loading dominates the along-wind loading conditions related to structure geometry.
- In towers that are slender but cylindrical, there are possibilities of second mode (across wind) condition becoming critical - particularly with respect to moments in the upper half of the tower.

Agarwal & Lakshmy (1993) [2] - gave an insight in to the background of codal provisions of the revised IS : 4998 (Part -1) 1992., and even describes the methodology to be used for the assessment of wind load on chimneys including interference effects and design of strakes. Analysis of 150 mm tall RC chimney has also been done using the codal provisions for a better understanding.

Based on the results of the analysis the author advocates that the methodology given in the code is reasonably good for applications in design offices. Author also points out the uncertainties in the wind patterns due to formation of cyclones, thunderstorms, etc.

Menon & Rao (1997) [3] - reviewed the then prevailing international codal recommendations to determined the design along-wind moments in reinforced concrete (RC) chimneys an towers. The study revolves around the ACI 307, NBCC - 1980, DIN 1056 and CICIND - 1984 code-based methods of analysis. The study covers a number of linearly tapered RC chimneys with heights in the range of 100 m to 400 m, located in different terrain conditions and subject to the range of wind speeds encountered in practice. Based on the accuracy in the prediction of Gust factor it was observed that ACI and CICIND methods reflect considerable accuracy.

2.3 Seismic Analysis Of Chimneys

Carrion et. al. [4] established a simplified method that allows obtaining parameters like fundamental period of vibration, lateral displacement, shear force, and bending moment through a set of equations with an error <10%. Two methods were used for discretization:

- Consistent masses criteria (Shear, Flexion, and Rotational Inertia)
- Lumped masses criteria (Flexion)
- In majority cases flexion only governs the height of the discrete element. Hence shear effect can be ignored in the analysis. If the effect of rotational inertia is ignored the error in computing fundamental vibration < 3% hence the effect of rotational inertia can also be neglected.

J. L. Wilson [5] studied the behaviour of tall reinforced concrete chimneys subjected to earthquake excitation. An inelastic analysis procedure Limited Ductility Design Approach was developed based on the experimental results which advocates capacity based design and seismic detailing to encourage limited ductile behaviour rather than brittle behaviour through formation of multiple plastic hinges in the windshield away from the openings to dissipate the seismic energy and minimize the induced seismic forces.

On comparison of analysis results for a 245 m tall power station chimney using the developed procedure and varied code recommendations the following ascending sequence of design methodology acceptance with respect to design, construction, and cost (mainly) implications is proposed:

- Limited ductility design approach
  - UBC - 97
  - EC8 - 3
  - CICIND and
  - ACI 307 - 95

Jain et. al. [6] reviewed the provisions of IS 1893 : 1984 for earthquake analysis and design of tall chimneys. Analysis results of 10 chimneys with height ranging from 107.5 m to 336.2 m done using provisions of IS and ACI 307: 79 design standards has also been presented. Major findings: IS code expression for time period gives a value around 13 % higher as compared to ACI code based value. IS code over estimates the base shear by 45% to 71% and Base Moment by 2% to 13%. Expression for shear distribution along the height given by the code gives quite accurate and acceptable outputs. Expression for moment distribution along the height gives quite conservative values near the top of the chimney.

2.4 Comparison of Wind And Seismic Forces

Reddy et. al. [7] presents the comparison of wind loads with that of earthquake loads to decide the critical loads for design purpose. Wind analysis (along wind and across wind) is done as per IS 4998 (Part 1) 1992 in conjunction with IS 875 (Part 3) 1987 and Earthquake analysis as per IS 1893 (Part 4) 2005. For analysis purpose two chimneys of heights 217 m and 220 m were modeled as a vertical cantilever fixed at base using beam element NKTP12 in NISA (EMRC - 1998). Chimney is idealized as MDOF system with lumped mass at floor levels. On studying the content of the paper the following conclusions be made:

- Along wind response is more critical as compared to across wind response in majority cases.

- Wind loads are found to govern the design of chimneys in comparison with earthquake loads.
- In high seismicity zone if the chimney is designed to behave in-elastically there are chances of earthquake force to match more or less with wind forces.

Shaikh & Khan [8] carried out the analysis of tall reinforced concrete chimneys with focus on comparison of wind analysis results with seismic analysis results.Seismic analysis of chimney was performed by response spectrum method using STAAD.Pro 2007 wherein the chimney was modeled as vertical cantilever structure fixed at the base and having varying cross-sectional area, inertia, mass along the height. 220 m height of the chimney was divided into 27 elements. Effect of wind forces is quite significant as compared to earthquake forces.

Reddy et. al. (2012) [9] presented the methods of evaluation of combined design moments of along and across-wind response adopted by the Indian Standard, Australian/New Zealand Standard, and the American Standard. Four different type of chimneys were considered for analysis viz. Uniformly tapered chimneys with heights 180 m, 217 m, 220 m, and 273 m. Based on the analysis it was found that in majority of the cases it was observed that the along wind forces are on higher side as compared to the across wind forces as well as the combined response excepting the case of 220 m high chimney. In case of 220 m high chimney the combined results were found to be dominating.

2.5 Summary

This chapter detailed the studies carried out by various researchers in the area of chimney structures and their response under the effect of wind and earthquake. The work carried out by Sudhir K. Jain, B.P. Singh, B.K.Gupta, J. L. Wilson, S.K.Agarwal, P. Lakshmy is a significant contribution towards increasing the understanding of the practicing engineers and professionals regarding the response and structural behaviour of the chimney under the effect of wind and earthquake. The study of temperature gradient and the stresses induced due to various combination has a wider scope.

Chapter 3

Comparison of Chimney Design Standards

3.1 Introduction

At present IS: 4998 (Part - 1) 1992 and IS: 4998 (Part - 1) 1975 are the standards used extensively by the practicing engineers for load assessment and design of chimneys to be constructed in India.The rapid growth of RC chimney construction with a significant increase in capacity, size and height has led to several queries being raised by designers and practicing engineers with regard to procedures recommended in IS: 4998 (Part - 1) 1992 for estimation of dynamic wind loads and responses of chimneys. These include,

- Use of simplified method for calculation of across-wind loads,
- Use of discrete strakes as aerodynamic remedial measures for suppressing or alleviating vortex induced oscillations,
- High values of magnification factors to be used for wind induced interference effects, and
- Incorporation of limit state design.

Keeping the above things in view the Bureau of Indian Standards published the newly revised chimney design standard (draft) for examination and review. This chapter gives an overview of the draft design standard and the provisions of the same are compared with the existing chimney design standard IS : 4998 (Part - 1) 1992 and IS : 4998 (Part - 1) 1975. Major modifications in the procedures for load estimation, analysis and design criterion's have been highlighted accordingly in the sections to follow. The provisions of the draft Indian standard are also compared with ACI 307 - 08 and it was found that the provisions are in line with the provisions of ACI 307 - 08.

3.2 Materials and Load Assessment

This section of the chapter compares the provisions pertaining to construction materials and loading criteria for chimney analysis and design.

Table 3.1 gives an overview of the changes in the provisions for construction material and loading criteria in draft Indian standard as compared to IS: 4998 (Part - 1) 1992.

Table 3.1: Construction Material And Load Assessment

PARAMETER	IS 4998 (Part - 1) 1975/1992	IS 4998 DRAFT CODE
MATERIALS		
Concrete	As per IS 456 : 2000 provisions which specifies M20 as the the minimum grade of concrete for any kind of construction work.	M25
Steel	Fe250 or Fe415	Fe250 or Fe415
LOADS		
Dead Loads	In accordance with IS 875 (Part - 1)	
Live Loads	In accordance with IS 875 (Part - 2)	
Temperature Effects	Special provisions for calculation of temperature gradient, and stresses induced in concrete in steel due to temperature alone as well as in combination with other type of loadings.	Provisions to consider temperature effects are: (A) Design for combined axial load, uni-axial bending and temperature effects. (B) Design for combined circumferential ring moments due to wind and temperature effects. (C) Calculations for stresses due to temperature effects.

3.3 Estimation of Wind Loads

This section of the chapter covers the modifications suggested in the procedure of wind load estimation in the draft chimney design standard in circulation by Bureau of Indian Standards. Table 3.2 gives details of the changes in the procedure for wind load estimation as recommended by the draft Indian standard in comparison with the provisions of IS: 4998 (Part - 1) 1992. From the comparison it is evident that major modifications have been introduced as far as estimation of wind loads is concerned.

Table 3.2: Estimation of wind loads

PARAMETER	IS 4998 (Part - 1) 1975/1992	IS 4998 DRAFT CODE
WIND LOAD ANALYSIS		
Wind Loads	Calculations in accordance with IS 875 (Part-3) 1987	Calculations in accordance with IS 875 (Part-3) **** Draft Code
ALONG WIND LOADS		
Analysis Approach	Analysis methods used: (A) Simplified Method (B) Random Response Method	Use of only Random Response Method is recommended.
k2 (terrain, height and structure size factor)	Value of k_2 shall be obtained from IS 875 (Part - 3) 1987	Empirical expression is available to determine the value of k_2 for height $>$ 10 m. k_2 = Terrain, height and structure size factor for hourly mean speed
Frequency Calculations	Suggests to calculate the natural frequency of the chimney by using any of the standard methods involving discretization of the structure and assuming it be made of a homogeneous material with suitable young's modulus.	Dedicated formula to approximately calculate the natural frequency of the chimney in the first and second mode of vibration is available.
ACROSS WIND ANALYSIS		
Analysis Approach	Analysis methods used: (A) Simplified Method (B) Random Response Method	Recommends the use of the generalised method developed by Vickery and his group.
Requirement of across wind analysis	Resonance check is given based on the critical wind speed in any mode exceeding 1.1 times the maximum possible wind speed in that particular town	Specifies a particular range in terms of critical wind speed within which across wind loads due to vortex shedding needs to be calculated.

3.4 Grouped Chimneys, Structural Considerations and Construction Requirements

This section of the chapter gives details regarding the consideration of the aerodynamic interference effect and provision of strakes, which comes in to picture when a group of chimneys are standing close to each other. The section also throws light on the minimum sizes of various components such as shell, corbel, lining and platforms. Reinforcement requirement as suggested by the draft design standard and the existing chimney design standard have also been studied and compared.

Table 3.3 gives details of the codal provisions addressing the issues of grouped chimneys or cluster of chimneys, structural design requirements, thickness of RCC components and Reinforcement requirement.

Table 3.3: Construction Requirements & Structural Considerations

PARAMETER	IS 4998 (Part - 1) 1975/1992	IS 4998 DRAFT CODE
GROUPED CHIMNEYS OR CLUSTER OF CHIMNEYS		
Governing parameter	Governing parameter is C_D	Governing parameter is C_L
Provision of strakes	Recommends strakes to suppress the vortex excited oscillations.	No such provision.
STRUCTURAL DESIGN OR CONSTRUCTION REQUIREMENTS:		
Recommended design approach	Working stress method	Limit state method
Chimney height	Height suggestions based on down draught, down wash & SO_2 and ash content of the flue gases.	No such provision.
MINIMUM THICKNESS OF RCC SHELL AND COMPONENTS		
Internal diameter $\leq$ 6 m	150 mm	
Internal diameter $>$ 6 m	$15 + \left(\frac{d_{ci} - 6000}{120}\right)$	
Corbels	$\geq$ 100 mm	
Hopper Shell	$\geq$ 100 mm	
Platform	$\geq$ 100 mm	
VERTICAL REINFORCEMENT		
Minimum Requirement (in % of concrete area under consideration)	HYSD Bars : 0.25%	
	MS Bars : 0.30%	
Minimum diameter of bar	$\geq$ 12 mm	
c/c spacing of reinforcement	Single layers : $\leq$ 300 mm	
	Two layers : $\leq$ 600 mm in each layer and staggered symmetrically	

3.5 Structural Considerations and Serviceability Requirements

This section of the chapter gives information about the minimum circumferential reinforcement required for the RCC shell and extra reinforcement around the openings. The maximum permissible tip deflection for any chimney under the effect of lateral loads has also been discussed.

Table 3.4 houses the provisions addressing the circumferential requirement for the RCC shell, provisions to consider the effect of openings in the chimney and the tip deflection.

Table 3.4: Structural Considerations and Serviceability Requirement

PARAMETER	IS 4998 (Part - 1) 1975/1992	IS 4998 DRAFT CODE
CIRCUMFERENTIAL REINFORCEMENT		
Deformed Bars	0.2% of concrete area in the vertical section under consideration subject to a minimum of 400 mm^2 per m height of the chimney	
Mild Steel Bars	0.25% of concrete area in the vertical section under consideration subject to a minimum of 400mm^2 per m height of the chimney	
Reinforcement provided in two layers	If vertical reinforcement is provided in two layers then the circumferential reinforcement shall also be provided in two layers and the minimum reinforcement shall be distributed equally in two layers.	
Reinforcement spacing	$\leq$ Minimum (300 mm, shell thickness)	
OPENINGS		
Reinforcement Requirement	Suggests to replace the steel bars cut by the openings with equivalent area of steel but nothing mentioned in connection with minimum requirement or detailing.	Advocates the use of additional reinforcement around the openings with specialized detailing requirements.
Maximum permissible deflection of chimney tip under all service conditions	H / 500	

3.6 Summary

The Gust Response Factor (GRF) method, developed by Davenport, and modified later by Vickery for the computation of response of chimney is widely recognized and being used in most of the international codes and hence the same method is recommended in this standard. Although a complete understanding of the across-wind response of a chimney due to vortex shedding is presently not available, the semi-empirical method developed by Vickery and his coworkers is regarded as most satisfactory method and it is included in the international codes of ACI 307 - 08 and CICIND. The method that is in line with ACI 307 - 08 is recommended in the Draft Indian Standard. In the structural design provisions, the philosophy of limit states design is adopted in the Draft Indian Standard, in line with international practices.

Chapter 4

Analysis Of RCC Shell

4.1 Introduction

This chapter outlines the primary design parameters, assumptions, problem formulation, load calculations. The chapter also covers the seismic analysis of the chimney, done in accordance with IS: 1893 (Part - 4) 2005. STAAD modeling adopted for calculation of mode shapes and natural frequencies is also explained. Detailed procedure of estimation of wind loads in accordance with IS: 4998 (Part - 1) 1992 is included in the chapter. The chapter ends with a detailed comparison of the forces and moments obtained by wind and seismic analysis.

- IS: 4998 (Part - 1) 1992 – *Criteria For Design Of Reinforced Concrete Chimneys : Assessment Of Loads (Second Revision)*, Bureau Of Indian Standards, New Delhi.
- IS: 4998 (Part – 1) 1975 – *Criteria For Design Of Reinforced Concrete Chimneys : Design Criteria (First Revision)*, Bureau Of Indian Standards, New Delhi.
- IS: 456 – 2000 – *Plain And Reinforced Concrete : Code Of Practice (Fourth Revision)*, Bureau Of Indian Standards, New Delhi.
- IS: 875 (Part – 3) 1987 – *Code Of Practice For Design Loads (Other Then Earthquake) For Building And Structures : Wind Loads (Second Revision)*, Bureau Of Indian Standards, New Delhi.
- IS: 1893 (Part – 4) 2005 – *Criteria For Earthquake Resistant Design Of Structures : Industrial Structures Including Stack Like Structures,* Bureau Of Indian Standards, New Delhi.

4.2 Problem Data

This section outlines the preliminary data defining the geometry of the chimney and various other parameters such as exit velocity, maximum and minimum ambient temperature, temperature of flue gas, volume of gas to be handled, details of openings, location of the chimney and materials of construction as shown in Table 4.1

Table 4.1: Problem Formulation

Height of the chimney above the ground level (m):	175	
Clear internal diameter of the RCC shell at the top (m):	4.5	
Clear internal diameter of the stainless steel venturi at exit (m):	2.8	
Exit velocity of flue gas (km/hr):	100	
Flue gas volume from the flue (s) or maximum flow through the chimney ($m^3/hour$):	720000	
Maximum temperature of flue gas at chimney inlet ($^\circ C$):	45	
Number of flues:	1	
Number of openings (for flue ducts or door access etc.) their sizes and location:	Width (m)	Height (m)
1. Access door at level EL (+) 0.00	1.2	2.2
2. Inspection door with bottom at level EL (+) 17.00	1.2	2.2
3. Plenum 1 with center at level EL (+) 25.50	3.5	6.7
4. Plenum 2 with center at level EL (+) 25.50	3.5	6.7
5. Plenum 3 with center at level EL (+) 18.025	5.9	1.9
Maximum ambient temperature ($^\circ C$):	45	
Minimum ambient temperature ($^\circ C$):	15	
Location:	Bharuch, Gujarat	
Seismic zone:	III	
Basic wind Speed / Location of site (m/s):	44	
Safe bearing capacity of soil strata (kN/m^2):	270	
Required / Suggested depth of foundation after geotechnical investigation (m):	4.8	
Type of foundation suggested or required:	Raft Foundation	
Proximity to other chimney or any other structure whose presence can influence and alter the speed, orientation and effect of wind on the chimney being designed:	None	
Grade of concrete used shall be as mentioned below:		
RCC Shell	M35	
Raft	M30	
Floor slab or Grade slab	M25	
Reinforcement grade:	Fe500	

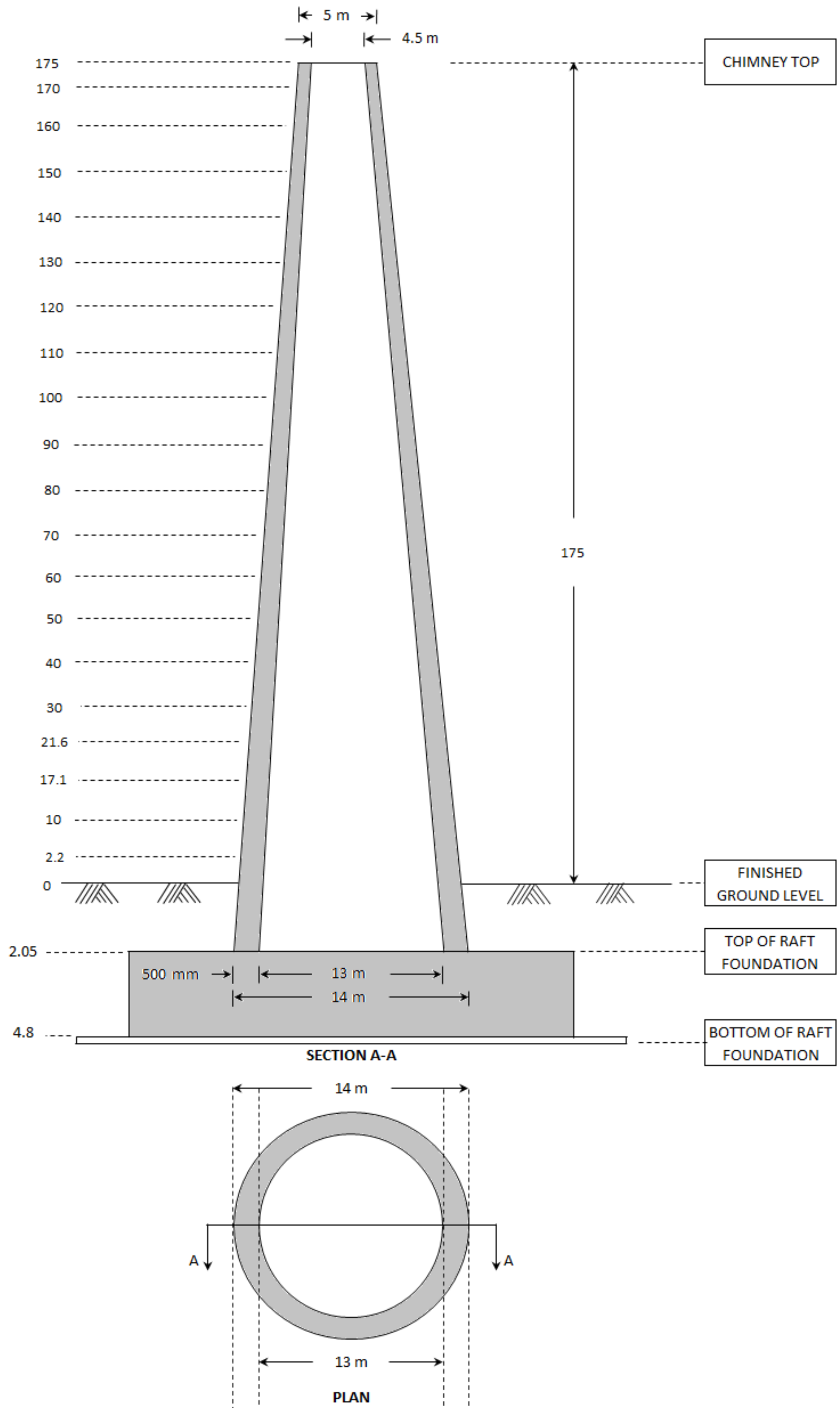

Figure 4.1: Chimney Cross-Section

Table 4.2 houses the details of the elevations of the important locations along the height of the chimney and the density of various materials useful for dead weight calculations.

Table 4.2: Elevations of important locations of the chimney.

COMPONENT	ELEVATION (m)
Chimney top	175
Finished Ground Level (FGL)	0
Finished Floor Level (FFL)	0.5
Bottom Of Raft	4.8
Assumed Thickness Of Raft	2.75
Top Of Raft	2.05

DENSITY OF VARIOUS MATERIALS FOR LOAD CALCULATIONS	
Concrete (kN/m^3)	25
Acid Resistant Brick Lining (kN/m^3)	23
Structural Steel (kN/m^3)	78.5
Sludge Layer Load (kN/m^3)	4

4.3 Lining Details

75 mm thick acid resistant brick lining is provided on the inner face of the chimney from the level EL (+) 17.100 m to EL (+) 41.9 m and PU/Epoxy painting for the remaining height of the chimney.

4.4 Preliminary Sizing and Load Calculations

This section of the chapter gives details regarding the preliminary sizing of the chimney based on the provisions of IS : 4998 (Part – 1) 1975 and subsequently it also houses the detailed calculations for various loads acting on the chimney, Analysis for various loads to get the governing force as per IS : 4998 (Part – 1) 1992 for the design of RCC wind shield and foundation. The various loads acting on the shell are:

4.4.1 Dead Loads & Live Loads

Weight of the chimney as well as other accessories required to be considered for the analysis and design of the RCC shell and foundation are as listed below:

- Weight of the RCC Shell.
- Weight of Lining and Corbels.
- Weight of Full & Partial (external and/or internal) RCC Platforms.
- Weight of Hand Rails, MS Spiral Staircase, SS cage Ladders.
- Weight of Plenums, Venturi and Sludge Loads.
- On platforms live load of 5 kN/m^2 is considered. As per IS : 4998 (Part – 1) 1992 Pg. 2 Clause 5.1.1, for the overall design of the chimney shell and foundation, imposed loads need not be considered.

4.4.2 Wind loads

The wind load exerted at any point on a chimney can be considered as the sum of static and a dynamic component. Two methods of estimating of wind loads are given in IS: 4998 (Part - 1) 1992 and have been adopted for calculating the response of the chimney for following cases:

- Along wind loads as per Simplified Method & Random Response Method (Shell Alone & Chimney Complete).
- Across wind loads as per Simplified Method & Random Response Method (Shell Alone & Chimney Complete).

4.4.3 Seismic loads

The seismic analysis of the chimney is done using IS: 1893 (Part - 4) 2005 used in conjunction with IS: 1893 (Part - 1) 2002. The seismic analysis of the chimney is done using STAAD.Pro. Chimney is modeled as free standing cantilever as an assembly of beam elements.

- Seismic analysis by Response Spectrum Method for Shell Alone & Chimney complete condition.

4.5 Dead loads & Live loads

This section of the chapter covers the detailed procedure for the calculation of the dead weight of the structure and other accessories to be considered for subsequent analysis and design.

4.5.1 Preliminary Assumptions

Shell thickness at top (mm):	As per IS : 4998 (Part - I) 1975 Pg. 12 Cl. 9.1	= 250
Shell thickness at bottom (mm):	As per IS : 4998 (Part - I) 1975 Pg. 12 Cl. 9.1	= 500
Internal diameter of the shell at the top (m):		= 4.5
External diameter of the shell at the top (m):		= 5
External diameter of the shell at the bottom (assume from H/16 to H/12) (m):		= 14
Internal diameter of the shell at the bottom (m):		= 13

4.5.2 Weight of RCC Shell

SAMPLE CALCULATION : SECTION PROPERTIES OF THE SHELL AT EL (+) 100 m

Internal diameter of the shell = $I_d = 8.101\ m$

Thickness of the shell = $t = 0.356\ m$

External diameter of the shell = $O_d = 8.812\ m$

Unit weight of RCC = $\delta = 25\ kN/m^3$

Area of the shell = $\pi \times (I_d + t) \times t = 9.455\ m^2$

Moment of inertia = $\frac{\pi}{64} \times (O_d^2 - I_d^2) = 84.673\ m^4$

Area of the shell at EL (+) 100 m = $A_1 = 9.455 m^2$

Area of the shell at the level above i.e EL (+) 110 m = $A_2 = 8.550\ m^2$

Height interval h = $10\ m$

Weight of Shell = $W_t = \dfrac{\delta \times \left(A_1 + A_2 + \sqrt{A_1 + A_2}\right) \times h}{3} = 2249.70 kN$

Table 4.3 gives details of regarding the section properties viz. area, moment of inertia and weight of the chimney at the assumed lumped mass levels.

Table 4.3: Section properties of the shell at different levels

Levels (m)	Shell Thickness (m)	Ext. diameter of shell (m)	Int. diameter of shell (m)	Area (m^2)	Moment Of Inertia (m^4) [$I_x = I_z$]	Weight (kN)
175	0.250	5.000	4.500	3.731	10.551	0
170	0.257	5.254	4.740	4.036	12.630	485.30
160	0.271	5.762	5.220	4.678	17.677	1088.30
150	0.285	6.271	5.700	5.365	24.080	1254.50
140	0.299	6.779	6.180	6.095	32.058	1431.60
130	0.314	7.287	6.660	6.869	41.847	1619.70
120	0.328	7.796	7.140	7.688	53.698	1818.70
110	0.342	8.304	7.621	8.550	67.879	2028.70
100	0.356	8.812	8.101	9.455	84.673	2249.70
90	0.370	9.321	8.581	10.405	104.379	2481.60
80	0.384	9.829	9.061	11.398	127.314	2724.50
70	0.398	10.337	9.541	12.436	153.809	2978.40
60	0.412	10.846	10.021	13.517	184.213	3243.20
50	0.427	11.354	10.501	14.642	218.888	3519.00
40	0.441	11.862	10.981	15.811	258.216	3805.70
30	0.455	12.371	11.461	17.024	302.592	4103.40
21.6	0.467	12.798	11.865	18.076	344.070	3685.00
17.1	0.473	13.027	12.081	18.653	367.962	2066.00
10	0.483	14.387	12.421	19.581	408.153	3392.90
2.2	0.494	13.784	12.796	20.625	455.991	3919.70
0	0.497	13.896	12.902	20.925	470.211	1142.70
-2.05	0.500	14.000	13.000	21.206	483.756	1079.60
						50118.20

4.5.3 Weight of lining

As the lining is supported by the corbels, the lining weights are calculated at corbel levels.

SAMPLE CALCULATION OF LINING WEIGHT AT EL (+) 24.4 0 m

External diameter of the lining = Internal diameter of the shell

$$
\begin{aligned}
\text{Outer diameter of the lining} &= \; O_d = 11.730m \\
\text{Thickness of the lining} &= \; t = \mathit{0.075}\ m \\
\text{Internal diameter of the lining} &= \; I_d = 11.58\ m \\
\text{Area of the lining} &= \; \pi \times (I_d + t) \times t = 2.746m^2 \\
\text{Unit weight of lining material} &= \; \delta = 23\ kN/m^3 \\
\text{Area of lining at level EL (+) 24.4 m} &= \; A_1 = 2.746m^2 \\
\text{Area of lining at EL (+) 26.9 m} &= \; A_1 = 2.718\ m^2 \\
\text{Height of the segment} &= \; h = 2.5m \\
\text{Weight of the lining} &= \; W_t = \frac{\delta \times \left(A_1 + A_2 + \sqrt{A_1 + A_2}\right) \times h}{3} = 157.09\ kN
\end{aligned}
$$

Table 4.4 gives details of the lining weight at the corbel levels. These weights would be subsequently added to the corresponding levels assumed in the lumped mass modeling.

Table 4.4: Lining weight calculation

Levels (m)	Ext. diameter of lining (m)	Lining thickness (m)	Int. diameter of lining (m)	Area (m^2)	Height interval (m)	Weight (kN)
41.9	10.890	0.075	10.740	2.548	0	0
39.4	11.010	0.075	10.860	2.577	2.5	147.34
36.9	11.130	0.075	10.980	2.605	2.5	148.96
34.4	11.250	0.075	11.100	2.633	2.5	150.59
31.9	11.370	0.075	11.220	2.661	2.5	152.21
29.4	11.490	0.075	11.340	2.690	2.5	153.84
26.9	11.610	0.075	11.460	2.718	2.5	155.47
24.4	11.730	0.075	11.580	2.746	2.5	157.09
21.9	11.850	0.075	11.700	2.774	2.5	158.72
19.4	11.970	0.075	11.820	2.803	2.5	160.34
17.1	12.081	0.075	11.931	2.829	2.3	148.95
					24.8	**1533.51**

4.5.4 Weight of corbels

SAMPLE CALCULATION OF CORBEL WEIGHT AT LEVEL EL (+) 24.4 M

$$
\begin{aligned}
\text{Internal diameter of the shell} &= \quad I_d = 11.730\ m \\
\text{Total width of the corbel} &= \quad \pi \times I_d = 36851.4\ mm \\
\text{Depth of corbel at shell interface} &= \quad D_1 = 300\ mm \\
\text{Depth of corbel at outer face} &= \quad D_2 = 100 mm \\
\text{Thickness of corbel} &= \quad t = \mathit{100mm} \\
\text{Unit weight of RCC} &= \quad \delta = 25\ kN/m^3 \\
\text{Weight of corbel} &= \quad \pi \times I_d \times (0.5 \times (D_1 + D_2) \times t \times \delta = 27.6\ kN
\end{aligned}
$$

Table 4.5 gives details of the corbel weights. These weights would be subsequently added to the corresponding levels assumed in the lumped mass modeling.

Table 4.5: Corbel weight calculation

Levels (m)	Inner dia. of shell (m)	Number of corbels	Length of corbel (m)	Depth of corbel at shell interface (m)	Depth of corbel at projected face (m)	Projection of corbel (m)	Weight (kN)
41.9	10.890	2	34.2120	0.300	0.300	0.100	25.70
39.4	11.010	2	34.5890	0.300	0.300	0.100	26.00
36.9	11.130	1	34.9661	0.300	0.300	0.100	26.30
34.4	11.250	1	35.3431	0.300	0.300	0.100	26.60
31.9	11.370	1	35.7202	0.300	0.300	0.100	26.80
29.4	11.490	1	36.0973	0.300	0.300	0.100	27.10
26.9	11.610	1	36.4743	0.300	0.300	0.100	27.40
24.4	11.730	1	36.8514	0.300	0.300	0.100	27.70
21.6	11.865	1	37.2737	0.300	0.300	0.100	28.00
19.4	11.970	1	37.6055	0.300	0.300	0.100	28.30
17	12.085	1	12.6558	0.200	0.200	0.150	9.50
16.4	12.114	1	25.3720	0.450	0.300	0.400	95.14
							374.54

4.5.5 Ladder weight

Spiral MS staircase is considered from EL (+) 21.9 m to EL (+) 100.00 m level and SS cage ladder is considered from EL(+) 100m to EL (+) 173.5 m level.

SAMPLE CALCULATION OF CAGE LADDER WEIGHT AND SPIRAL STAIRCASE WEIGHT

Assumed weight of cage ladder	0.4 kN/m
Ladder weight at EL (+) 110.0m =	= 0.4×(120 - 110) = 4kN

Assumed weight of spiral staircase	3.75 kN/m
Spiral staircase weight at EL (+) 80.0 m level =	= 3.75×(90 - 80) = 37.5 kN

Table 4.6 gives calculations of the weights of the spiral staircase and ladder at the corresponding levels as tabulated. These weights would then be subsequently added to the corresponding levels for lumped mass modeling.

Table 4.6: Spiral staircase and ladder weight calculation

Levels (m)	Spiral stair + Ladder Weight (kN)
173.5	0.70
17	2.70
160	4.00
150	4.00
140	4.00
130	4.00
120	4.00
110	4.00
100	20.75
90	37.50
80	37.50
70	37.50
60	37.50
50	37.50
40	37.50
30	37.50
21.9	15.75
	326.4000

4.5.6 External platform loads (RCC full & Partial platforms)

Total number of full RCC platforms:	5
Width of platform (m):	1
Thickness of platform (m):	0.15
Live load on platform (kN/m^2)	5

Total number of partial RCC platforms:	6
Width of platform (m):	1
Thickness of platform (m):	0.15
Live load on platform (kN/m^2)	5

SAMPLE CALCULATION OF EXTERNAL PLATFORM LOAD AT EL (+) 100.0 m

Internal diameter of platform = D_1= 8.08 m
Width of RCC full and Partial platform = $1m$
Outer diameter of the platform = D_2= $10.808m$
Area of the platform = $\pi\times(D_2{}^2$ - $D_1{}^2)\times0.25 = 30.81\ m^2$
Unit weight of concrete = $\delta = 25kN/m^3$
Assumed thickness of the slab = $0.15m$
Assumed weight of the handrail / m length = $0.2kN/m$
Weight of the slab = $25\times0.15\times30.81 = 115.5375\ kN$
Length of the handrail = $\pi\times10.808 = 33.95\ m$
Total weight of the handrail = $0.2\ \times33.95 = 6.79\ kN$
Total weight of the external platform = $115.5375 + 6.79 = 122.328\ kN \approx 125\ kN$

FOR PARTIAL PLATFORMS AT 110, 120, 130, 150, 160 AND 170 m LEVELS

Area of platform considered = $1\times2.5 = 2.5\ m^2$
Weight of slab = $2.5\times25\times0.15 = 9.375kN$
Length of handrail = $5\ m$
Total weight of the handrail = $1\ kN$
Total weight of external partial platform = $9.375 + 1 = 10.375kN \approx 12kN$

Table 4.7 gives details of the platform weights at various levels which need to be added at the corresponding levels in the lumped mass model.

Table 4.7: External platform loads (RCC Full and Partial)

Levels (m)	Platform type (Full / Partial)	Platform diameter (m)		Length of hand rail (m)	Weight of hand rail (kN)	Slab Area (m^2)	Weight of slab (kN)	Total Loads (kN)	
		Internal	External					Dead Load	Live Load
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9] = [6] + [8]	[10]
173.5	Full	5.076	7.076	22.231	4.446	19.089	71.584	76.030	95.44
170	Partial	5.254	7.254	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
160	Partial	5.762	7.762	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
150	Partial	6.271	8.271	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
140	Full	6.779	8.779	27.581	5.516	24.439	91.646	97.162	122.19
130	Partial	7.287	9.287	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
120	Partial	7.796	9.796	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
110	Partial	8.304	10.304	$4.500 \approx 5$	1.000	2.500	9.375	10.375	12.5
100	Full	8.812	10.812	33.968	6.794	30.827	115.601	122.394	154.134
60	Full	10.846	12.846	40.356	8.071	37.215	139.555	147.626	186.07
21.6	Full	12.798	14.798	46.489	9.298	44.347	162.551	171.849	216.73
17.1	Partial	13.027	15.027	35.405	7.081	33.049	123.935	131.016	165.24

4.5.7 Miscellaneous loading

This section houses the calculations of loading due to internal RC platforms, acid resistant bricks laid in slope, profile deck sheet, structural beams, sludge loads, plenum loads, and stainless steel venturi.

SAMPLE CALCULATION OF INTERNAL PLATFORM LOAD AT EL (+) 17.100 m

$$\begin{aligned}
\text{Internal diameter of the platform} &= D_1 = 12.08\ m \\
\text{Area of the platform} &= \frac{\pi}{4} \times D_1^2 = 114.62\ m^2 \\
\text{Unit weight of concrete} &= 25\ kN/m^3 \\
\text{Unit weight of acid resistant bricks} &= 23\ kN/m^3 \\
\text{Unit weight of steel} &= 78.5\ kN/m^3 \\
\text{Assumed thickness of slab} &= 0.15\ m \\
\text{Thickness of acid resistant bricks} &= 0.075\ m \\
\text{Weight of the slab} &= 0.15 \times 25 \times 114.62 = 429.825\ m^2 \\
\text{Weight of acid resistant bricks} &= 0.075 \times 23 \times 114.62 = 197.7195\ m^2 \\
\text{Ass. thickness of profile deck sheet} &= 0.001\ m \\
\text{Weight of profile deck sheet} &= 13.5\ kN \\
\text{Total weight} &= 429.82 + 197.92 + 13.5 = 641.24\ kN \\
\text{Weight of structural beams} &= 1.226\ kN/m\ \text{(ISMB600)} \\
\text{Average length of the beams} &= 10.5\ m \\
\text{Weight of single beam} &= 12.873\ kN \\
\text{Number of beams} &= 8 \\
\text{Total weight of structural beams} &= 102.984\ kN \\
\text{Weight of sludge deposit on slab} &= 5\ kN/m^2 \\
\text{Total weight of sludge} &= 573.1\ kN \\
\text{Total weight of internal platform} &= 1317.13\ kN \approx 1350\ kN
\end{aligned}$$

SAMPLE CALCULATION FOR WEIGHT OF PLENUM AT EL (+) 17.100 m

$$\begin{aligned}
\text{Length of plenum chamber} &= 4.0\ m \\
\text{Width of plenum chamber} &= 5.1\ m \\
\text{Height of plenum chamber} &= 5.1\ m \\
\text{Thickness of plenum chamber wall} &= 0.3\ m \\
\text{Total weight of plenum wall 1 and 2} &= 2 \times (0.3 \times 5.1 \times 4 \times 25) = 306 kN \\
\text{Weight of plenum wall 3} &= 0.3 \times 5.1 \times 5.1 \times 25 = 195.075\ kN
\end{aligned}$$

WEIGHT OF SLAB PROJECTION ABOVE AND BELOW THE PLENUM

$$\begin{aligned}
\text{Length of the slab} &= 4.0\ m \\
\text{Width of the slab} &= 4.5\ m \\
\text{Thickness of the slab} &= 0.3m \\
\text{Total weight of top and bottom slab} &= 2\times(0.3\times4.5\times4\times25) = 270kN \\
\text{Total weight of plenum chamber 1} &= 306 + 195.075 + 270 = 771.075\ kN \\
\text{Total weight of plenum 1 and 2} &= 2\times771.075 = 1542.15\ kN
\end{aligned}$$

ASSUME PIPE HAVING DIAMETER OF 1.5 m, THICKNESS OF 8 mm, AND LENGTH OF 3m

$$\begin{aligned}
\text{Weight of pipe (say 13 pipes)} &= 140\ kN \\
\text{Hence total weight of plenum with pipes} &= 1542.15 + 140 = 1682.15\ kN \approx 1800kN \\
\text{Load on the shell (plenum and pipes)} &= 0.5\times1800 = 900kN \\
\text{Total load at EL(+) 17.1}\ m &= 1350 + (0.5\times900) = 1800\ kN \\
\text{Total load at EL(+) 21.6}m &= 0.5\times900 = 450\ kN
\end{aligned}$$

Note: The load on the shell due to the plenum and pipes shall be distributed equally between the levels EL (+) 17.10 m and EL (+) 21.6 m.

WEIGHT OF VENTURI AT LEVEL EL (+) 170.0 m

$$\begin{aligned}
\text{Venturi height} &= 6\ m \\
\text{Thickness of stainless steel plate} &= 0.01\ m \\
\text{Inner diameter of the shell at EL(+) 170} &= 4.740\ m \\
\text{Perimeter of the shell} &= \pi \times 4.740 = 14.891\ m \\
\text{Weight of the SS Venturi} &= 68.34\ kN \\
\text{Weight at EL (+) 170.0}\ m\ \text{level} &= 0.5 \times 68.34 = 34.17\ kN \approx 40\ kN \\
\text{Weight at EL (+) 175.0}\ m\ \text{level} &= 0.5 \times 68.34 = 34.17\ kN \approx 40\ kN
\end{aligned}$$

4.5.8 Total weights

Table 4.8 summarizes the total weight of the particular segment between two lumped mass levels as well as the total weight of the structure.

Table 4.8: Summary of total weights

Elevation (m)	RCC Shell Weight (kN)	Lining Weight (kN)	Corbel Load (kN)	Ladder Load (kN)	External Platform Loads (kN)	Miscellaneous Loads (kN)	Total (kN)
175	0.0	—	—	0.70	80	40	120.70
170	485.3	—	—	2.70	12	40	540.00
160	1088.3	—	—	4.00	12	—	1104.30
150	1254.5	—	—	4.00	12	—	1270.50
140	1431.6	—	—	4.00	100	—	1535.60
130	1619.7	—	—	4.00	12	—	1635.70
120	1818.7	—	—	4.00	12	—	1834.70
110	2028.7	—	—	4.00	12	—	2044.70
100	2249.7	—	—	20.75	125	—	2395.45
90	2481.6	—	—	37.50	—	—	2519.10
80	2724.5	—	—	37.50	—	—	2762.00
70	2978.4	—	—	37.50	—	—	3015.90
60	3243.2	—	—	37.50	150	—	3430.70
50	3519.0	—	—	37.50	—	—	3556.50
40	3805.7	296	78.00	37.50	—	—	4217.50
30	4103.4	612.11	107.90	37.50	—	—	4860.91
21.6	3685.0	476.15	84.00	15.75	175	450	4885.90
17.1	2066.0	148.95	104.64	—	132	1800	4251.60
10	3392.9	—	—	—	—	—	3392.90
2.2	3919.7	—	—	—	—	—	3919.70
0	1142.7	—	—	—	—	—	1142.70
-2.05	1079.6	—	—	—	—	—	1079.60
Total	50118.2	1533.51	**374.5**	**326.40**	**834**	**2330**	**55516.6**

Table 4.9 houses the values of cumulative axial loads acting at various levels of the chimney. The values are given for both shell alone as well as chimney complete condition and will be further used in the calculations for the stress calculations in various combination of loads.

Table 4.9: Details Of Axial Loads

Levels (m)	Shell Alone Case		Chimney Completed Case	
	Shell Alone Loads (kN)	Cumulative Load (kN)	Completed Chimney Loads (kN)	Cumulative Load (kN)
175	0	0	120.700	120.700
170	485.300	485.3	540.000	660.700
160	1088.300	1573.6	1104.300	1765.000
150	1254.500	2828.1	1270.500	3035.500
140	1431.600	4259.7	1535.600	4571.100
130	1619.700	5879.4	1635.700	6206.800
120	1818.700	7698.1	1834.700	8041.500
110	2028.700	9726.8	2044.700	10086.200
100	2249.700	11976.5	2395.450	12481.650
90	2481.600	14458.1	2519.100	15000.750
80	2724.500	17182.6	2762.000	17762.750
70	2978.400	20161	3015.900	20778.650
60	3243.200	23404.2	3430.700	24209.350
50	3519.000	26923.2	3556.500	27765.850
40	3805.700	30728.9	4217.497	31984.347
30	4103.400	34832.3	4860.906	36844.253
21.6	3685.000	38517.3	4885.904	41730.156
17.1	2066.000	40584.3	4251.598	45981.754
10	3392.900	43976.2	3392.900	49374.654
2.2	3919.700	47895.9	3919.700	53294.354
0	1142.700	49038.6	1142.700	54437.054
-2.05	1079.600	50118.2	1079.600	55516.654

Table 4.10 gives details of the masses of the chimney in both shell alone and chimney complete cases at various levels assumed for lumped mass modeling. This value can be arrived at by taking an algebraic sum of the values obtained by dividing the weight of the chimney section at the level above and below a particular level by gravitational acceleration i.e g = 9.81 m/s^2

Table 4.10: Masses Of The Chimney

Levels (m)	Masses In Shell Alone Case		Masses In Chimney Completed Case		
	Shell Alone Weight (kN)	Shell Alone Mass ($kN-sec^2/m$)	Other Weights (kN)	Other Masses ($kN-sec^2/m$)	Total Mass ($kN-sec^2/m$)
175	0.000	24.735	120.70	12.30	37.04
170	485.300	80.204	54.70	5.58	85.78
160	1088.300	119.409	16.00	1.63	121.04
150	1254.500	136.906	16.00	1.63	138.54
140	1431.600	155.520	104.00	10.60	166.12
130	1619.700	175.250	16.00	1.63	176.88
120	1818.700	196.096	16.00	1.63	197.73
110	2028.700	218.063	16.00	1.63	219.69
100	2249.700	241.147	145.75	14.86	256.00
90	2481.600	265.347	37.50	3.82	269.17
80	2724.500	290.668	37.50	3.82	294.49
70	2978.400	317.105	37.50	3.82	320.93
60	3243.200	344.659	187.50	19.11	363.77
50	3519.000	374.328	37.50	3.82	377.15
40	3805.700	403.114	411.80	41.98	445.09
30	4103.400	396.962	757.51	77.22	474.18
21.6	3685.000	293.119	1200.90	122.42	415.54
17.1	2066.000	278.231	2185.60	222.79	501.02
10	3392.900	372.712	0.00	0.00	372.71
2.2	3919.700	258.022	0.00	0.00	258.02
0	1142.700	113.267	0.00	0.00	113.27
-2.05	1079.600	55.025	0.00	0.00	55.03

4.6 Seismic Analysis

Seismic analysis is carried out in accordance with IS : 1893 (Part - 4) 2005 in conjunction with IS : 1893 (Part 1) 2002. Some of the basic parameters for seismic analysis are as follows:

Seismic zone	III	(Based on the location : Bharuch, Gujarat)
Seismic zone factor (Z)	0.16	As per IS : 1893 (Part - 1) 2002 Pg. 16 Table 2
Importance factor (I)	1.5	As per IS : 1893 (Part - 4) 2005 Pg. 17 Table 8
Response reduction factor (R)	3	As per IS : 1893 (Part - 4) 2005 Pg. 17 Table 9
Damping factor	5%	
Type of soil	Medium	

The design horizontal seismic coefficient $A_h$for a structure shall be determined as follows as per IS : 1893 (Part - 4) 2005 Pg. 15 Clause 16:

$$A_h = \left(\frac{Z}{2}\right) \cdot \left(\frac{I}{R}\right) \cdot \left(\frac{S_a}{g}\right) = 0.04667 \times \left(\frac{S_a}{g}\right)$$

The values of $\left(\frac{S_a}{g}\right)$ can be obtained from IS : 1893 (Part - 1) 2002 Pg.16 Fig. 2

The seismic analysis of the chimney is carried out by response spectrum method as per IS : 1893 (Part - 1) 2002 SRSS Method. The computer program STAAD.Pro is used for the calculation of natural frequencies and mode shapes under different modes of vibration. The chimney is modeled as an assembly of beam elements, extending from corbel to corbel level. The mean sectional properties are used. The chimney is modeled for shell alone as well as chimney complete condition. The details of lumped masses given as input are as follows:

- The full load of lining resting over a corbel at levels specified in Table 4.4.
- Lumped mass of the shell at levels specified in Table 4.3 is taken as the sum of half of the shell mass above and below the node.
- Other lumped masses such as platforms, ladders may be considered at the respective levels.

Table 4.11 gives the values of spectral acceleration coefficient values for the corresponding values of time period. The values tabulated in table 4.11 shall be provided as input to STAAD.Pro as a part of the seismic definition package of STAAD.Pro. These values are deemed necessary for the seismic analysis of the chimney model using the SRSS model. The values have been interpolated for the corresponding time period values based on IS : 4998 (Part - 1) 2002 Pg. 16 Fig. 2

Table 4.11: Spectral Acceleration Coefficient

Period (sec)	Spectral Acceleration Coefficient $\left(\frac{S_a}{g}\right)$
0	1.0000
0.1	2.5000
0.2	2.5000
0.3	2.5000
0.4	2.5000
0.5	2.5000
0.55	2.5000
0.6	2.2667
0.7	1.9429
0.8	1.7000
0.9	1.5111
1.0	1.3600
1.1	1.2364
1.2	1.1333
1.3	1.0462
1.4	0.9714
1.5	0.9067
1.6	0.8500
1.7	0.8000
1.8	0.7556
1.9	0.7158
2.0	0.6800
2.1	0.6476
2.2	0.6182
2.3	0.5913
2.4	0.5667
2.5	0.5440
2.6	0.5231
2.7	0.5037
2.8	0.4857
2.9	0.4690
3.0	0.4533
3.1	0.4387
3.2	0.4250
4.3	0.4121
3.4	0.4000
3.5	0.3886
3.6	0.3778
3.7	0.3676
3.8	0.3579
3.9	0.3487
4.0	0.3400

Table 4.12 houses the properties viz. average area and average moment of inertia to be provided as an input property for the beam elements used in STAAD.Pro to generate the chimney modeled as a free standing cantilever beam fixed at bottom. In the STAAD model the values of I_x and I_z have been provided as same and the value of $I_y = I_x + I_z$.

Table 4.12: Section Properties For Beam Elements : STAAD.Pro

Height Interval (m)	Average area (m^2)	Avg. Moment Of Inertia (m^4) $I_x = I_z$
175 to 170	3.883	11.590
170 to 160	4.357	15.153
160 to 150	5.022	20.878
150 to 140	5.730	28.069
140 to 130	6.482	36.953
130 to 120	7.279	47.773
120 to 110	8.119	60.789
110 to 100	9.002	76.276
100 to 90	9.930	94.526
90 to 80	10.902	115.847
80 to 70	11.917	140.562
70 to 60	12.976	169.011
60 to 50	14.079	201.550
50 to 40	15.226	238.552
40 to 30	16.417	280.404
30 to 21.6	17.550	324.331
21.6 to 17.1	18.364	356.016
17.1 to 10	19.117	388.058
10 to 2.2	20.103	432.072
2.2 to 0	20.775	463.101
0 to -2.05	21.065	476.983

Table 4.13 gives the details of the lumped masses provided as lateral load in STAAD.Pro to perform seismic analysis and produce the results of natural frequency and mode shapes of the chimney.

Table 4.13: Details Of Lumped Mass or Nodal Loads : STAAD.Pro

STRUCTURE DETAIL		SHELL ALONE	CHIMNEY COMPLETED
Node No.	Level (m)	Lumped Mass or Nodal Load	Lumped Mass or Nodal Load
22	175	242.65	364.35
21	170	786.80	841.50
20	160	1171.40	1187.40
19	150	1343.05	1359.05
18	140	1525.65	1629.65
17	130	1719.20	1735.20
16	120	1923.70	1939.70
15	110	2139.20	2155.20
14	100	2365.65	2511.40
13	90	2603.05	2640.55
12	80	2851.45	2888.95
11	70	3110.80	3148.30
10	60	3381.10	3568.60
9	50	3662.35	3699.85
8	40	3954.55	4366.35
7	30	3894.20	4651.71
6	21.6	2875.50	4076.40
5	17.1	2729.45	4915.05
4	10	3656.30	3656.30
3	2.2	2531.20	2531.20
2	0	1111.15	1111.15
1	-2.05	539.80	539.80

The following figure shows the STAAD model of the chimney. The chimney is modeled as a free standing cantilever using assembly of various beam elements. The figure also shows the deflected profile of the chimney in the first two modes. The deflected mode of only the first two modes are shown because the across wind load analysis may be carried out only for these two modes based on the criteria specified in IS : 4998 (Part - 1) 1992 subsequently checked for in the across wind analysis calculation.

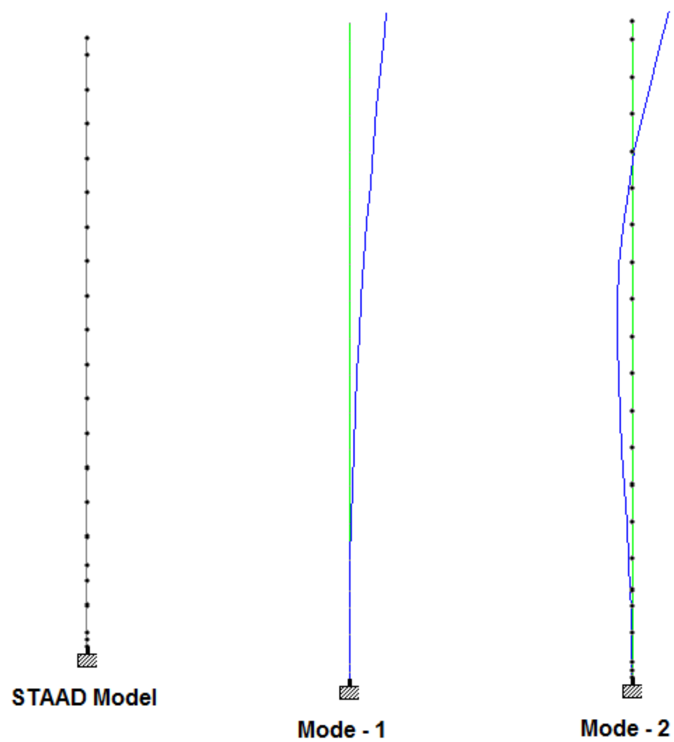

Figure 4.2: STAAD.Pro Model For Modal Analysis And Frequency Calculation

Table 4.14 details the frequency of the chimney in the first six modes for both shell alone and chimney complete condition. The values of the frequencies may be subsequently used in the calculations of the across wind load calculations based on the procedure slated in IS : 4998 (Part - 1) 1992.

Table 4.14: Frequency Of The Chimney In The First Six Modes

DESCRIPTION	FREQUENCY (Hz)	
MODE	SHELL ALONE	CHIMNEY COMPLETE
1	0.43	0.419
2	1.624	1.575
3	3.878	3.718
4	7.214	6.842
5	11.644	11.007
6	17.162	16.238

Table 4.15 gives details regarding the mode shape and the ordinates in shell alone as well as chimney complete condition at the various lumped mass levels. The values may be subsequently used in the calculation of across wind load analysis as per the procedure slated in IS : 4998 (Part - 1) 1992.

Table 4.15: Mode Shapes Of The Chimney

STRUCTURE DETAIL		MODE SHAPES FOR 1^{ST}MODE		MODE SHAPES FOR 2^{ND}MODE	
Node No.	Levels (m)	SHELL ALONE	CHIMNEY COMPLETED	SHELL ALONE	CHIMNEY COMPLETED
22	175	1	1	1	1
21	170	0.951	0.95	0.856	0.852
20	160	0.852	0.851	0.573	0.561
19	150	0.756	0.754	0.308	0.292
18	140	0.662	0.66	0.077	0.058
17	130	0.572	0.569	-0.111	-0.131
16	120	0.487	0.485	-0.251	-0.27
15	110	0.408	0.406	-0.342	-0.36
14	100	0.336	0.334	-0.389	-0.405
13	90	0.271	0.269	-0.398	-0.411
12	80	0.213	0.211	-0.376	-0.386
11	70	0.162	0.161	-0.332	-0.34
10	60	0.118	0.118	-0.274	-0.28
9	50	0.082	0.081	-0.21	-0.215
8	40	0.053	0.052	-0.147	-0.15
7	30	0.03	0.03	-0.09	-0.092
6	21.6	0.016	0.016	-0.051	-0.052
5	17.1	0.011	0.01	-0.034	-0.035
4	10	0.004	0.004	-0.014	-0.014
3	2.2	0.001	0.001	-0.002	-0.002
2	0	0	0	0	0

Table 4.16 gives details the outputs of the shear force and bending moment obtained from analysis of the chimney using STAAD.Pro

Table 4.16: Seismic Loads On The Chimney

Levels (m)	SHELL ALONE		CHIMNEY COMPLETED	
	Shear Force (kN)	Bending Moment ($kN \cdot m$)	Shear Force (kN)	Bending Moment ($kN \cdot m$)
175	64.9	0	97.28	0
170	224.38	324.49	262.22	486.39
160	339.96	2555.71	367.89	3104.77
150	405.53	5886.54	424.74	6693.82
140	439.88	9708.99	457.99	10636.52
130	453.94	13652.01	472.63	14599.4
120	462.84	17439.09	484.44	18373.15
110	478.68	20890.15	504	21800.04
100	515.21	23926.74	545.63	24821.95
90	581.13	26584.33	613.06	27431.52
80	674.62	29046.29	705.27	29880.93
70	791.52	31662.6	820.4	32507.52
60	923.94	34913.53	959.31	35775.5
50	1060.77	39331.13	1098.21	40200.81
40	1193.17	45338.37	1247.49	46262.44
30	1298.23	53128.39	1381.94	54191.51
21.6	1352.68	61008.03	1469.78	62342.27
17.1	1391.7	65671.23	1554.21	67249.62
10	1415.62	73567.45	1584.06	75749.16
2.2	1417.9	82822.78	1586.95	85858.59
0	1418.14	85512.33	1587.25	88815.62
-2.05	1418.14	88044.27	1587.25	91605.18

Figure 4.3 shows the variation in the magnitudes of earthquake induced shear forces along the height of the chimney. The values of shear forces induced in case of chimney complete condition are slightly higher than that in case of shell alone condition.

Figure 4.4 shows the variation in the magnitudes of seismic moments along the height of the chimney. The values of bending moments induced in case of chimney complete condition are slightly higher than that in case of chimney complete condition due to increased masses along the height of the chimney because of presence of lining, platforms and other accessories.

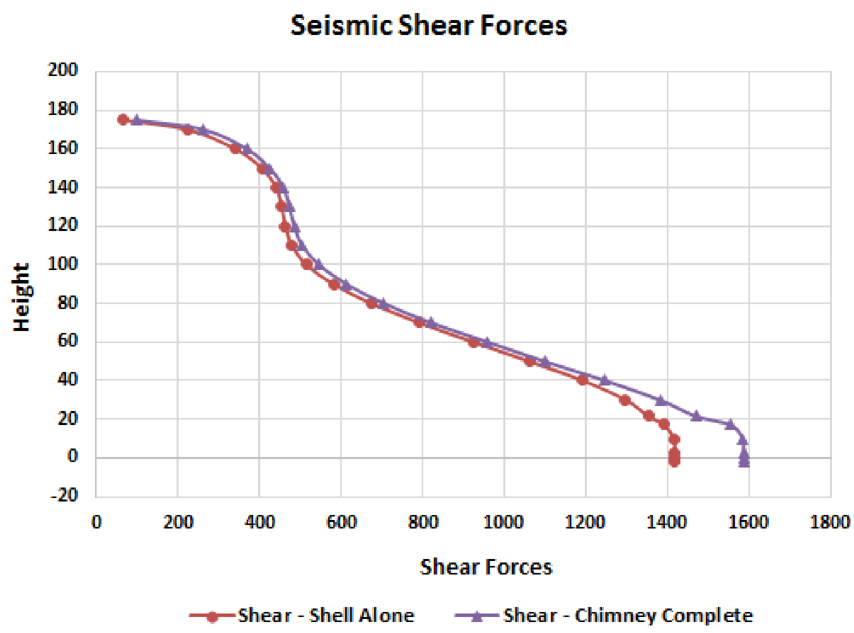

Figure 4.3: Earthquake Induced Shear Forces

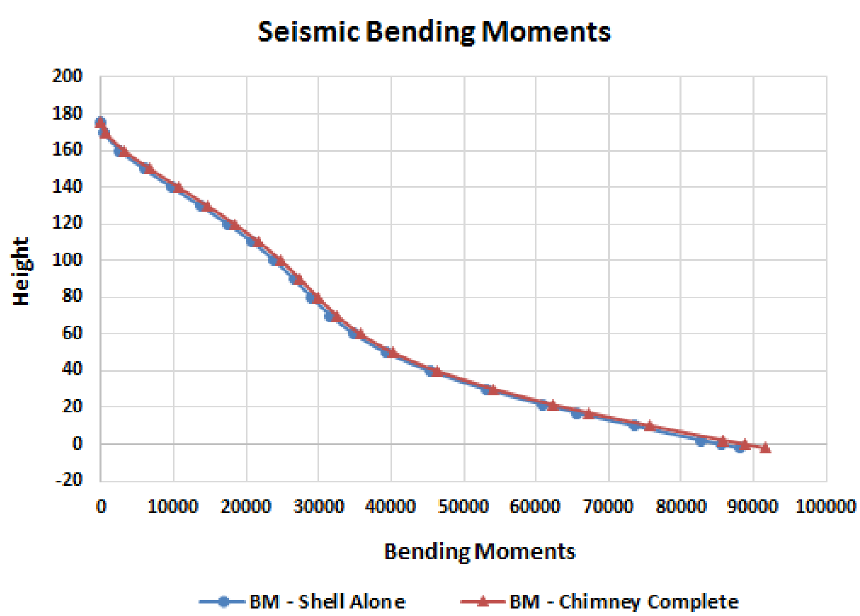

Figure 4.4: Earthquake Induced Bending Moments

From the seismic analysis results it is evident that the magnitudes of shear forces show considerably variation on the higher side in chimney complete condition as compared to the small variation visible in the values of bending moments.

4.7 Wind Load Analysis

Two methods of estimating wind loads are given in clause A-4 and A-5 of Annex A of IS: 4998 (Part - 1) 1992. The along and across wind analysis is done as per the procedure prescribed therein.

4.7.1 Basic wind data

The following basic details of the structure are deemed necessary for wind load calculations.

PARAMETER	DESCRIPTION	
Location:	Bharuch, Gujarat	
Terrain category: (As per IS : 875 (Part - 3) 1987 Pg. 8 Clause 5.3.2.1)	2	
Class of the structure: (As per IS : 875 (Part - 3) 1987 Pg. 11	C	
Basic wind speed V_b (m/s): (As per IS : 875 (Part - 3) 1987 Pg. 53 Appendix A)	44	
Assumed design life of the structure : (As per IS : 875 (Part - 3) Pg. 11 Table 1)	SHELL ALONE:	25 years
Assumed design life of the structure : (As per IS : 875 (Part - 3) Pg. 11 Table 1)	CHIMNEY COM-PLETE	100 years

4.7.2 Along wind analysis

Along wind loads are calculated as per the “Simplified Method” and “Random Response Method” for both Shell Alone (SA) as well as Chimney Complete (CC) condition.

4.7.2.1 Simplified method for along wind loads

The along wind loads are calculated as per IS : 4998 (Part - 1) 1992 Pg. 5 Clause A-4 (Annexe - A).

A sample calculation of force estimation at level EL (+) 100.00 m for shell alone condition is detailed as follows. The following data is considered for the wind analysis of the chimney.

Basic wind speed V_b : 44 m/s

Risk coefficient k_1(As per IS : 875 (Part - 3) 1987 Pg. 11 Table 1) : 0.91 and Terrain factor $k_2$at EL (+) 100.00 m (Refer Table 5.18): 1.17

Topography factor k_3 (As per IS : 875 (Part - 3) 1987 Pg.12 Clause 5.4.3.1): 1

Terrain Category : 2, Class of the structure: C, Grade of concrete : M35

The terrain factor k_2 for Class C Structures varying along the height of the structure has been listed in the excel spreadsheets.

SAMPLE CALCULATION AT EL (+) 100.00 m (SHELL ALONE CONDITION)

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

$F_z = p_z \cdot C_D \cdot d_z$

p_z= design wind pressure obtained in accordance with IS : 875 (Part - 3) 1987 Pg. 12 Clause 5.4

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

d_z = external diameter of the chimney at height z = 8.812 m (Refer Table 5.18)

V_Z = design wind velocity in m/s at height z calculated in accordance with IS : 875 (Part - 3) 1987 Pg. 8 Clause 5.3

The additional or secondary moments induced due to the deflection of the chimney (P-δ effect) has also been considered in the calculation.

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3 = 44 \times 0.91 \times 1.17 \times 1 = 46.847\ m/s$$

$$p_z = 0.6 \times V_z^2 = 0.6 \times (46.487)^2 = 1316.77\ N/m^2$$

$$F_Z = (1316.80/1000) \times 0.8 \times 8.812 = 9.28\ kN/m$$

$$F_Z \text{ at } 110.0m = 8.87\ kN/m \text{ (Refer Table 5.18)}$$

$$\text{Height of the segment} = 110 - 100 = 10\ m$$

$$\text{Force CG wrt level } 100.0\ m = \frac{(110 - 100) \times (9.28 + 2 \times 8.87)}{3 \times (9.28 + 8.87)} = 4.9623 \text{ m (Refer Fig. 4.5)}$$

$$\text{Shear force at } 100.0\ m = (110 - 100) \times \left(\frac{9.28 + 8.87}{2}\right) = 90.76\ kN$$

$$\text{Cumulative force at } 110.0\ m = 479.99\ kN \text{ (Refer Table 5.18)}$$

$$\text{Cumulative force at } 100.0\ m = 479.99 + 90.76 = 570.74\ kN$$

$$\text{Cumulative moment at } 110.0\ m = 14512.68\ kN \cdot m$$

$$\text{Net Bending Moment at } 100.0\ m = 14512.68 + (90.76 \times 4.9623) + (479.99 \times 10) = 19762.85 kN \cdot m$$

Deflection at 110.0 m	$= 0.0577\ m$
Deflection at 100.0 m	$= 0.0481\ m$
Differential deflection	$= 0.0577 - 0.0481 = 0.0096\ m$ (Refer Fig. 4.6)
Axial load at 110.0 m	$= 9726.8\ kN$
Secondary moment at 110.0 m	$= 252.38\ kN \cdot m$
Secondary moment at 100.0 m	$= 252.38 + (9726.8 \times 0.0096) = 346.11\ kN \cdot m$
Net moment at 100.0 m	$= 19762.85 + 346.11 = 20108.96\ kN \cdot m$

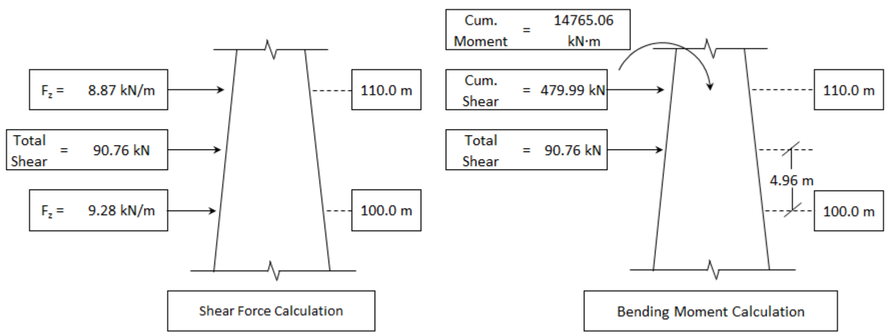

Figure 4.5: Simplified Method - Along Wind Load - Shear Force And Bending Moment Calculation

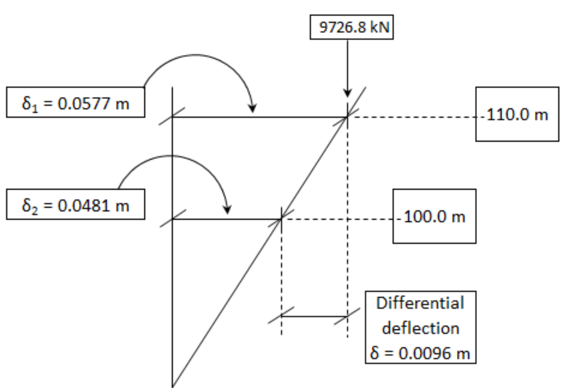

Figure 4.6: Simplified Method - Along Wind Load - Secondary Moment Calculation

Table 4.17 and Table 4.18 give details regarding the along wind analysis and the corresponding values of shear force and bending moment at various lumped mass levels of the chimney for shell alone and chimney complete condition respectively.

Table 4.17: Summary Of Along Wind Forces : Simplified Method - Shell Alone Condition

Levels (m)	k_2	V_Z (m/s)	p_z (N/m^2)	Ext. Diameter (d_z)	F_Z (kN/m)	Shear (kN)	Cumulative Shear (kN)	Moment (kN/m)	Cumulative secondary moments	Net Moment $(kN \cdot m)$
175	1.225	49.049	1443.48	5.000	5.77	0.00	0.00	0.00	0.00	0.00
170	1.222	48.929	1436.42	5.254	6.04	29.53	29.53	73.82	0.00	73.82
160	1.216	48.689	1422.35	5.762	6.56	62.97	92.50	679.66	5.99	685.65
150	1.21	48.448	1408.35	6.271	7.07	68.11	160.61	1941.01	25.20	1966.21
140	1.202	48.128	1389.79	6.779	7.54	73.01	233.63	3908.28	58.94	3967.23
130	1.194	47.808	1371.35	7.287	7.99	77.66	311.29	6629.04	108.03	6737.07
120	1.186	47.487	1353.03	7.796	8.44	82.17	393.45	10149.06	172.66	10321.72
110	1.178	47.167	1334.84	8.304	8.87	86.53	479.99	14512.68	252.38	14765.06
100	1.17	46.847	1316.77	8.812	9.28	90.76	570.74	19762.85	346.11	20108.96
90	1.156	46.286	1285.45	9.321	9.59	94.34	665.08	25939.45	452.10	26391.55
80	1.142	45.726	1254.50	9.829	9.86	97.25	762.33	33074.19	567.94	33642.13
70	1.128	45.165	1223.93	10.337	10.12	99.93	862.26	41195.02	690.54	41885.56
60	1.114	44.605	1193.74	10.846	10.36	102.40	964.66	50327.68	816.18	51143.86
50	1.1	44.044	1163.92	11.354	10.57	104.65	1069.31	60495.75	940.43	61436.18
40	1.07	42.843	1101.30	11.862	10.45	105.12	1174.43	71715.46	1058.24	72773.70
30	1.04	41.642	1040.41	12.371	10.30	103.74	1278.17	83979.74	1163.88	85143.62
21.6	1.00	40.344	976.60	12.798	10.00	85.24	1363.41	95076.12	1239.23	96315.34
17.1	0.98	39.343	928.74	13.027	9.68	44.27	1407.68	101311.61	1273.41	102585.02
10	0.93	37.237	831.97	14.387	8.91	65.99	1473.67	111543.65	1314.70	112858.35
2.2	0.93	37.237	831.97	13.784	9.17	70.53	1544.20	123312.03	1340.25	124652.29
0	0.93	37.237	831.97	13.896	9.25	20.27	1564.47	126731.54	1343.28	128074.82
-2.05	0.93	0.000	0.00	14.000	0.00	9.48	1573.95	129951.65	1344.21	131295.87
						1573.95	**17975.37**	**1112310**		

Table 4.18: Summary Of Along Wind Loads : Simplified Method - Chimney Complete Condition

Levels (m)	k_2	V_Z (m/s)	p_z (N/m^2)	Ext. Diameter (d_z)	F_Z (kN/m)	Shear (kN)	Cumulative Shear (kN)	Moment (kN/m)	Cumulative secondary moments	Net Moment ($kN \cdot m$)
175	1.225	57.673	1995.70	5.000	7.98	0.00	0.00	0.00	0.00	0.00
170	1.222	57.532	1985.94	5.254	8.35	40.83	40.83	102.06	1.04	103.10
160	1.216	57.249	1966.49	5.762	9.07	87.07	127.89	939.67	12.31	951.98
150	1.21	56.967	1947.13	6.271	9.77	94.17	222.06	2683.57	42.10	2725.66
140	1.202	56.590	1921.47	6.779	10.42	100.94	323.00	5403.44	92.18	5495.62
130	1.194	56.214	1895.98	7.287	11.05	107.37	430.37	9165.06	165.01	9330.07
120	1.186	55.837	1870.65	7.796	11.67	113.60	543.98	14031.71	259.33	14291.04
110	1.178	55.460	1845.50	8.304	12.26	119.63	663.61	20064.69	374.47	20439.16
100	1.17	55.084	1820.52	8.812	12.83	125.47	789.08	27324.38	508.85	27832.22
90	1.156	54.424	1777.21	9.321	13.25	130.43	919.52	35862.91	661.56	36524.48
80	1.142	53.765	1734.43	9.829	13.64	134.45	1053.97	45727.14	827.73	46554.86
70	1.128	53.106	1692.16	10.337	13.99	138.16	1192.13	56954.69	1002.96	57957.65
60	1.114	52.447	1650.42	10.846	14.32	141.57	1333.70	69581.16	1181.97	70763.14
50	1.1	51.788	1609.20	11.354	14.62	144.68	1478.39	83639.16	1359.68	84998.83
40	1.07	50.376	1522.62	11.862	14.45	145.33	1623.72	99151.11	1527.66	100678.76
30	1.04	48.963	1438.44	12.371	14.24	143.43	1767.15	116107.24	1679.67	117786.91
21.6	1.00	47.438	1350.21	12.798	13.82	117.85	1885.00	131448.67	1789.86	133238.53
17.1	0.98	46.261	1284.04	13.027	14.38	61.21	1946.21	140069.63	1841.06	141910.69
10	0.93	43.784	1150.24	14.387	12.32	91.24	2037.45	154216.07	1905.74	156121.81
2.2	0.93	43.784	1150.24	13.784	12.68	97.51	2134.96	170486.59	1945.41	172432.00
0	0.93	43.784	1150.24	13.896	12.79	28.02	2162.97	175214.27	1950.06	177164.33
-2.05	0.93	0.000	0.00	14.000	0.00	13.11	2176.08	179666.28	1951.49	181617.78
						2176.1	**24852.08**	**1537838**		

4.7.2.2 Random response method for along wind loads

The along wind loads are calculated as per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A-5 (Annexe - A). The along wind load is calculated by the Gust Factor Method. For the computation of forces and moments the frequency of the chimney is taken from the modal analysis performed using STAAD.Pro.

A sample calculation of force estimation at level EL (+) 100.00 m for shell alone condition is detailed as follows. The following data is considered for the wind analysis of the chimney.

SHELL ALONE CONDITION	
Basic wind speed V_b (m/s) :	44
Risk coefficient k_1: (As per IS : 875 (Part - 3) 1987 Pg. 11 Table 1)	0.91
Terrain factor $\bar{k}_2$ at 100.00 m (Refer Table 5.18)	0.92
Topography factor k_3: (As per IS : 875 (Part - 3) 1987 Pg.12 Clause 5.4.3.1)	1
z = height in m of the section of the chimney at 100.0 m measured from the top of the foundation	102.05
d_z = external diameter of the chimney at 100.0 m	8.812
Fundamental frequency $f_1(Hz)$	0.43
Height of the chimney above the top of the foundation:	177.05

The along wind load per unit height at any height z on a chimney shall be calculated using the procedure detailed in IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 5 (Exurban - A) and explained step by step as follows:

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

$$F_{zm} = \text{wind load in } N/m \text{ height due to Hourly Mean Wind at height } z$$

$$= \bar{p_z} \cdot C_D \cdot d_z$$

$$\bar{p_z} = \text{design pressure at height } z\text{, due to HMW is given by}$$

$$= 0.6 \times \bar{V}_z^2$$

$$\bar{V}_z = 44 \times 0.91 \times 0.92 \times 1 = 36.837\ m/s$$

$$\bar{p_z} = 0.6 \times (36.837)^2 = 814.17\ N/m^2$$

$$F_{zm} = \left(\frac{814.2}{1000}\right) \times 0.8 \times 8.812 = 5.74\ kN/m$$

$$B = \text{background factor indicating the slowly varying component of wind load fluctuation}$$

$$= \left[1 + \left(\frac{H}{265}\right)^{0.63}\right]^{-0.88} = \left[1 + \left(\frac{177.05}{265}\right)^{0.63}\right]^{-0.88} = 0.603$$

$$E = \text{measure of the available energy in wind at the natural frequency of the chimney}$$

$$= \frac{123 \cdot \left(\frac{f_1}{\bar{V}_{10}}\right) \cdot H^{0.21}}{\left[1 + \left(\frac{330 \cdot f_1}{\bar{V}_{10}}\right)^2 \times H^{0.42}\right]^{0.83}}$$

$$S = \text{size reduction factor}$$

$$= \left[1 + 5.78 \cdot \left(\frac{f_1}{\bar{V}_{10}}\right)^{1.14} \cdot H^{0.98}\right]^{-0.88}$$

$\bar{V}_{10}$ = hourly mean wind speed in m/sec at 10 m above the ground level

= $V_b \cdot \bar{k}_2$ where V_b and $\bar{k}_2$ are as defined in IS : 875 (Part - 3) 1987

f_1 = natural frequency of the chimney in the first mode of vibration in Hz

V_b = 44 m/s

F_{zf} = wind load in N/m due to fluctuating component of wind at height z

$$= \frac{3 \cdot (G-1)}{H^2} \times \left(\frac{Z}{H}\right) \cdot \int F_{zm} \cdot z \cdot d_z$$

G = Gust factor which is given by the equation

$$= 1 + g_f \cdot r \cdot \left(\sqrt{B + \frac{SE}{\beta}}\right)$$

g_f = peak factor = ratio of the expected peak value to RMS value of the fluctuating load

$$= \left(\sqrt{2 \cdot log_e vT}\right) + \frac{0.577}{\sqrt{2 \cdot log_e vT}}$$

$$vT = \frac{3600 \cdot f_1}{\sqrt{1 + \frac{B\beta}{SE}}}$$

r = twice the turbulence intensity = $0.622 - 0.178 \times log_{10}H$

$= 0.622 - 0.178 \times log_{10}177.05 = 0.222$

$f_1 = 0.43\ Hz$

$\bar{k}_2 = 0.92$

$\bar{V}_{10} = 44 \times 0.92 = 29.48\ m/s$

$$\left(\frac{f_1}{\bar{V}_{10}}\right) = \left(\frac{0.43}{29.48}\right) = 0.0146$$

$$S = [1 + (5.78 \times 0.0146^{1.14}) \times 177.05^{0.98}]^{-0.88} = 0.153$$

$$E = \frac{123 \times 0.0146 \times 177.05^{0.21}}{\left[1 + (330 \times 0.0146)^2 \times 177.05^{0.42}\right]^{0.83}} = 0.064$$

$\beta = 0.016$

$$vT = \frac{3600 \times 0.043}{\sqrt{1 + \frac{0.603 \times 0.016}{0.153 \times 0.064}}} = 1099.3$$

$$g_f = \left(\sqrt{2 \cdot log_e 1099.3}\right) + \frac{0.577}{\sqrt{2 \cdot log_e 1099.3}} = 3.90$$

$$G = 1 + 3.90 \times 0.222 \times \left(\sqrt{0.603 + \frac{0.153 \times 0.064}{0.016}}\right) = 1.954$$

$$\int F_{zm} \cdot z \cdot d_z = 80135.88 \text{ (Refer Table 5.20)}$$

$$F_{zf} = \frac{3 \cdot (1.954 - 1)}{(177.05)^2} \times \left(\frac{102.05}{177.05}\right) \times 80135.88 = 4.216 \ kN/m$$

Total load $= 5.74 + 4.216 = 9.956 \ kN/m$

Load at 110.0 m $= 10.1319 \ kN$

Shear Force at 100.0 m $= \left(\frac{9.956 + 10.131}{2}\right) \times 10 = 100.4395 \ kN$

Force CG wrt level 100.0 m $= \frac{(110 - 100) \times (9.956 + 2 \times 10.1319)}{3 \times (9.956 + 10.1319)} = 5.0146$ m

Cumulative force at 110.0 m $= 689.606 kN$

Cumulative force at 100.0 m $= 689.606 + 100.44 = 790.046 \ kN$

Cumulative moment at 110.0 m $= 22721.35 \ kN \cdot m$

Net Bending Moment at 100.0 m $= 22721.35 + (689.606 \times 10) + (100.44 \times 5.0146) = 30121.07 kN \cdot m$

Deflection at 110.0 m $= 0.0637 \ m$

Deflection at 100.0 m $= 0.0527 \ m$

Differential deflection $= 0.011 \ m$

Axial load at 110.0 m $= 9726.8 \ kN$

Secondary moment at 110.0 m $= 295.99 \ kN \cdot m$

Secondary moment at 100.0 m $= 295.99 + (9726.8 \times 0.011) = 402.9848 \ kN \cdot m$

Net moment at 100.0 m $= 30121.07 + 402.9848 = 30524.0548 \ kN \cdot m$

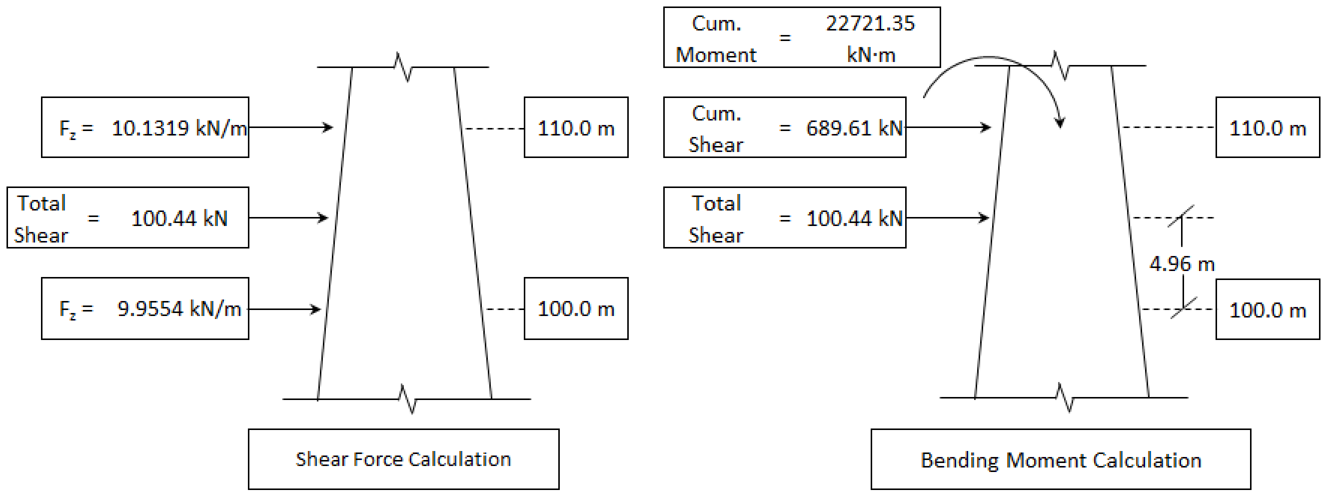

Figure 4.7: Random Response Method - Along Wind Load - Shear Force And Bending Moment Calculation

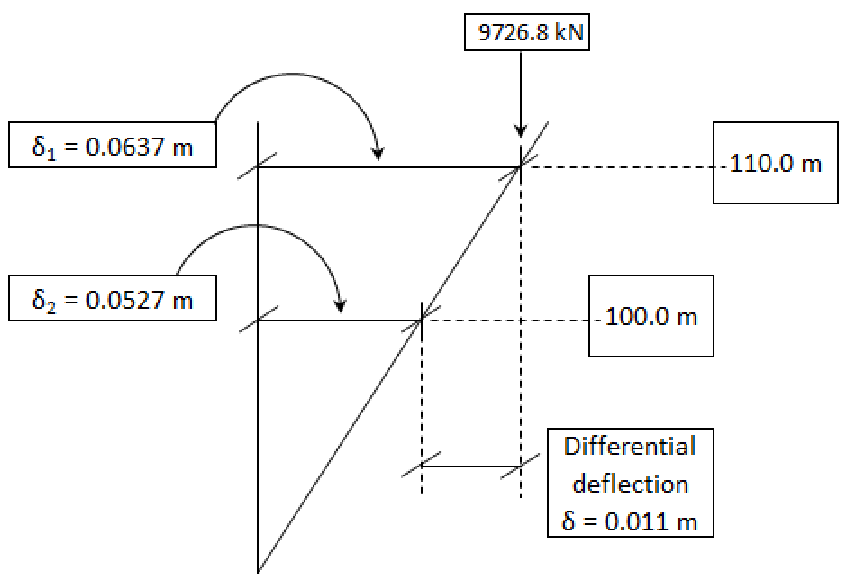

Figure 4.8: Random Response Method - Along Wind Load - Secondary Moment Calculation

ALONG WIND LOADS : RANDOM RESPONSE METHOD - As per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A-5 (Annexe - A)

DESCRIPTION	SA	CC
Probability factor k_1 :	0.91	1.07
Fundamental frequency $f_1(Hz)$	0.43	0.419
β	0.016	0.016
$\bar{V}_{10}$ (m/s)	29.48	29.48
S	0.153	0.156
E	0.064	0.065
vT	1099.3	1081.7
g_f	3.90	3.89
G	1.954	1.962

Table 4.19 give details in case of shell alone, of the loads F_{zm} and F_{zf} which sum up to give the total along wind load acting at any level of the chimney under consideration and Table 4.20 gives details of the shear force and bending moment at levels assumed for lumped mass modeling.

Table 4.21 give details in case of chimney complete condition, of the loads F_{zm} and F_{zf} which sum up to give the total along wind load acting at any level of the chimney under consideration and Table 4.22 gives details of the shear force and bending moment at levels assumed for lumped mass modeling.

Table 4.19: Summary Of Along Wind Loads : Random Response Method - Shell Alone Condition

Levels (m)	k_2	V_z (m/s)	P_z (N/m^2)	Ext. Diameter (d_z)	F_{zm} (kN/m)	z (m)	$F_1(kN)$	$F_{zm} \cdot z \cdot d_z$	F_{zf} (kN/m)	Total Load (kN/m)
175	0.98	39.239	923.83	5.000	3.695	177.05	0.000	0.00	7.314	11.0090
170	0.976	39.079	916.30	5.254	3.852	172.05	18.867	3292.93	7.107	10.9587
160	0.968	38.759	901.34	5.762	4.155	162.05	40.034	6685.08	6.694	10.8493
150	0.96	38.438	886.51	6.271	4.447	152.05	43.012	6752.67	6.281	10.7283
140	0.952	38.118	871.79	6.779	4.728	142.05	45.877	6743.81	5.868	10.5959
130	0.944	37.798	857.20	7.287	4.997	132.05	48.627	6662.15	5.455	10.4523
120	0.936	37.477	842.74	7.796	5.256	122.05	51.267	6511.28	5.042	10.2976
110	0.928	37.157	828.39	8.304	5.503	112.05	53.796	6294.71	4.629	10.1319
100	0.92	36.837	814.17	8.812	5.740	102.05	56.216	6015.93	4.216	9.9554
90	0.906	36.276	789.58	9.321	5.888	92.05	58.138	5641.02	3.802	9.6901
80	0.892	35.716	765.37	9.829	6.018	82.05	59.530	5180.97	4.389	9.4077
70	0.878	35.155	741.53	10.337	6.132	72.05	60.754	4680.12	2.976	9.1087
60	0.864	34.595	718.07	10.846	6.230	62.05	61.814	4143.84	2.563	8.7936
50	0.85	34.034	694.99	11.354	6.313	52.05	62.716	3577.27	2.150	8.4629
40	0.82	32.833	646.80	11.862	6.138	42.05	62.254	2930.52	1.737	7.8751
30	0.79	31.632	600.33	12.371	5.941	32.05	60.397	2239.34	1.324	7.2652
21.6	0.757	30.334	552.10	12.798	5.653	23.65	48.694	1357.83	0.977	6.6295
17.1	0.732	29.333	516.27	13.027	5.380	19.15	24.824	531.68	0.791	6.1712
10	0.67	26.827	431.81	14.387	4.625	12.05	35.517	557.24	0.498	5.1224
2.2	0.67	26.827	431.81	13.784	4.762	4.25	36.606	297.65	0.176	4.9372
0	0.67	26.827	431.81	13.896	4.800	2.05	10.518	33.12	0.085	4.8849
-2.05	0.67	0.000	0.00	14.000	0.000	0	4.920	6.72	0.000	0.0000
					110.254			80135.88		

Table 4.20: Summary Of Along Wind Loads : Random Response Method - Shell Alone Condition (Contd.)

Levels (m)	Shear (kN)	Cumulative Shear (kN)	Moment ($kN \cdot m$)	Cumulative secondary moments ($kN \cdot m$)	Resultant Moment ($kN \cdot m$)
175	0.000	0.000	0.000	0.000	0.00
170	54.919	54.919	137.40	0.000	137.40
160	109.04	163.959	1232.71	7.178	1239.89
150	107.89	271.847	3412.75	30.129	3442.88
140	106.62	378.468	6665.43	70.240	6735.67
130	105.24	483.709	10977.51	128.149	11105.66
120	103.75	587.459	16334.65	203.706	16538.35
110	102.15	689.606	22721.35	295.986	23017.34
100	100.44	790.043	30121.07	404.313	30524.39
90	98.228	888.271	38514.86	524.369	39038.22
80	95.489	983.760	47877.36	653.080	48530.44
70	92.582	1076.342	58180.36	788.813	58969.18
60	89.512	1165.854	69393.97	926.320	70320.29
50	86.283	1252.137	81486.68	1060.789	82547.47
40	81.690	1333.827	94421.40	1186.867	95608.27
30	75.702	1409.529	108143.26	1298.688	109441.95
21.6	58.358	1467.887	120232.14	1377.651	121609.79
17.1	28.802	1496.688	126903.21	1413.227	128316.43
10	40.092	1536.780	137676.43	1455.948	139132.37
2.2	39.232	1576.013	149817.26	1482.200	151299.46
0	10.804	1586.817	153296.39	1485.287	154781.68
-2.05	5.007	1591.824	156556.21	1486.243	158042.45

Table 4.21: Summary Of Along Wind Loads : Random Response Method : Chimney Complete Condition

Levels (m)	k_2	V_z (m/s)	P_z (N/m^2)	Ext. Diameter (d_z)	F_{zm} (kN/m)	z (m)	$F_1(kN)$	$F_{zm} \cdot z \cdot d_z$	F_{zf} (kN/m)	Total Load (kN/m)
175	0.98	46.138	1277.25	5.000	5.109	177.05	0.000	0.00	10.204	15.3127
170	0.97	45.950	1266.85	5.254	5.325	172.05	26.085	4552.68	9.916	15.2405
160	0.96	45.573	1246.16	5.762	5.745	162.05	55.349	9242.54	9.339	15.0841
150	0.96	45.197	1225.65	6.271	6.149	152.05	59.467	9335.99	8.763	14.9116
140	0.95	44.820	1205.31	6.779	6.537	142.05	63.427	9323.75	8.187	14.7234
130	0.94	44.444	1185.14	7.287	6.909	132.05	67.231	9210.84	7.610	14.5196
120	0.93	44.067	1165.13	7.796	7.267	122.05	70.879	9002.25	7.034	14.3005
110	0.92	43.690	1145.30	8.304	7.609	112.05	74.376	8702.83	6.458	14.0663
100	0.92	44.314	1125.64	8.812	7.936	102.05	77.722	8317.39	5.881	13.8171
90	0.90	42.654	1091.64	9.321	8.140	92.05	80.379	7799.06	5.305	13.4450
80	0.89	41.995	1058.17	9.829	8.321	82.05	82.303	7163.01	4.729	13.0494
70	0.87	41.336	1025.21	10.337	8.478	72.05	83.996	6470.56	4.152	12.6309
60	0.86	40.677	992.78	10.846	8.614	62.05	85.462	5729.11	3.576	12.1900
50	0.85	40.018	960.86	11.354	8.728	52.05	86.709	4945.80	3.000	11.7276
40	0.82	38.606	894.24	11.862	8.486	42.05	86.070	4051.63	2.423	10.9097
30	0.79	37.193	830.00	12.371	8.214	32.05	83.502	3096.03	1.847	10.0613
21.6	0.75	35.668	764.32	12.798	7.815	23.65	67.323	1877.29	1.363	9.1780
17.1	0.73	34.491	713.77	13.027	7.438	19.15	34.320	735.09	1.104	8.5420
10	0.67	31.544	597.00	14.387	6.394	12.05	49.104	770.42	0.694	7.0883
2.2	0.67	31.544	597.00	13.784	6.583	4.25	50.611	411.52	0.245	6.8281
0	0.67	31.544	597.00	13.896	6.637	2.05	14.542	45.79	0.118	6.7548
-2.05	0.67	0.000	0.00	14.000	0.000	0	6.803	9.30	0.000	0.0000
					152.433			110792.86		

Table 4.22: Summary Of Along Wind Loads : Random Response Method - Chimney Complete Condition (Contd.)

Levels (m)	Shear (kN)	Cumulative Shear (kN)	Moment ($kN \cdot m$)	Cumulative secondary moments ($kN \cdot m$)	Resultant Moment ($kN \cdot m$)
175	0.00	0.00	0.00	0.00	0.00
170	76.38	76.40	191.11	1.24	192.35
160	151.62	228.10	1714.53	14.83	1729.36
150	149.98	378.10	4746.86	50.61	4797.47
140	148.17	526.30	9270.30	110.46	9380.76
130	146.22	672.60	15266.07	196.84	15462.91
120	144.10	816.80	22714.40	307.71	23022.11
110	141.83	958.70	31593.52	441.69	32035.21
100	139.42	1098.20	41879.68	596.39	42476.07
90	136.31	1234.60	53546.34	770.26	54316.60
80	132.47	1367.10	66557.99	957.29	67515.29
70	128.40	1495.60	80874.49	1152.29	82026.78
60	124.10	1619.80	96454.68	1349.23	97803.92
50	119.59	1739.40	113254.48	1542.52	114797.00
40	113.19	1852.60	131221.22	1723.19	132944.42
30	104.86	1957.50	150278.57	1884.91	152163.48
21.6	80.81	2038.40	167066.14	2000.96	169067.11
17.1	39.87	2078.30	176329.73	2054.51	178384.24
10	55.49	2133.80	191288.74	2121.76	193410.51
2.2	54.27	2188.10	208145.37	2162.71	210308.09
0	14.94	2203.10	212975.66	2167.49	215143.14
-2.05	6.92	2210.10	217501.47	2168.96	219670.43
	2208.95				

4.7.3 Across wind analysis

Across wind loads are calculated as per the "Simplified Method" and "Random Response Method" for both shell alone as well as chimney complete condition.

The critical wind speed for vortex shedding for the i^{th}mode of vibration is calculated as per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 4.3 (Annexe - A). And as per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 4.4 (Annex - A), only those modes which can be excited up to wind speeds 10 % above the maximum expected wind speed at the height of the effective diameter shall be considered for analysis. If the critical wind speed for any mode of oscillation exceeds the limits specified earlier, it is permissible to assume that problem of vortex excited resonance will not be a design criterion for that and the higher modes. In such cases across-wind analysis can be ignored.

BASIC WIND DATA

PARAMETER	SHELL ALONE CONDITION	CHIMNEY COMPLETE CONDITION
Elevation at chimney top (m)	175	175
External diameter at top (m)	5	5
Elevation at 1/3 height of the chimney (m)	116.666	116.666
External diameter at 1/3 height of the chimney (m)	7.965	7.965
Effective diameter i.e. average diameter over the top 1/3 height of the chimney, d (m)	6.482	6.482
Strouhal number S_n :	0.2	0.2
k_{2max} :	1.225	1.225
Maximum expected wind speed V_{max} (m/s)	$= 40.04 \times 1.225 =$ 49.049	$= 47.08 \times 1.225 =$ 57.673
V_{max} increased by 10 % (m/s)	$= 1.10 \times 49.049 =$ 53.95	$= 1.10 \times 57.673 =$ 63.44

CRITICAL WIND SPEED CALCULATION AND CHECK FOR THE REQUIREMENT OF ACROSS WIND ANALYSIS

As per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 4.3 (Exurban - 4) $V_{cri} = \dfrac{f_i \cdot d}{S_n}$

V_{cri}= Critical wind speed for vortex shedding for i^{th}mode of vibration

f_i= natural frequency of the chimney in Hz in the i^{th}mode of vibration

d = effective diameter i.e. average diameter over the top 1/3 height of the chimney in m

S_n= Strouhal number to be taken as 0.2

SHELL ALONE CONDITION				CHIMNEY COMPLETE CONDITION			
Mode	Frequency (Hz)	V_{cr} (m/s)	Requirement	Mode	Frequency (Hz)	V_{cr} (m/s)	Requirement
1	0.43	13.938	Yes	1	0.419	13.581	Yes
2	1.624	52.639	Yes	2	1.575	51.051	Yes
3	3.878	125.698	No	3	3.718	120.512	No
4	7.214	233.829	No	4	6.842	221.771	No
5	11.644	377.419	No	5	11.007	356.772	No
6	17.162	556.275	No	6	16.238	526.325	No

4.7.3.1 Basic wind speed calculation for co-existing along wind calculation

The co-existing along wind load is combined with the across wind loads as per IS : 4998 (Part - 1) 1992 Pg. 3 Note 1 after Clause 5.3

Elevation at 1/3 height of the chimney : 116.666 m

k_{2c} =value of terrain and height factor at elevation EL (+) 116.666 m as per IS : 875 (Part - 3) 1987 Pg. 49 Table - 33

k_{2c} =0.93336

$$V_b' = \frac{V_{cri}}{k_1 \cdot k_{2c} \cdot k_3}$$

For Shell Alone (Mode - 1) $V_b' = \dfrac{13.938}{0.91 \times 0.933 \times 1} = 16.4096\ m/s$

VARIABLE	SHELL ALONE		CHIMNEY COMPLETE	
	MODE 1	MODE 2	MODE 1	MODE 2
k_1	0.91	0.91	1.07	1.07
k_3	1	1	1	1
V_{cri} (m/s)	13.938	52.639	13.581	51.051
V_b' (m/s)	= 16.4096	= 61.975	= 13.599	= 51.119

4.7.3.2 SIMPLIFIED METHOD FOR ACROSS WIND LOAD

The across wind loads are calculated as per IS : 4998 (Part - 1) 1992 Pg. 6 Clause A - 4.2 (Annexe - A)

SAMPLE CALCULATION AT LEVEL EL (+) 100.0 m (SHELL ALONE CONDITION : MODE - 1)

The following data has been considered for analysis of the chimney.

C_L =peak oscillatory lift coefficient to be taken as 0.16

S_n =Strouhal number to be taken as 0.2

β =Structural damping as a fraction of critical damping to be taken as 0.016

δ_s =Logarithmic decrement of structural damping $= 2 \cdot \pi \cdot \beta = 2 \times \pi \times 0.016 = 0.100531$

σ =mass density of air to be taken as $1.2 kg/m^3$

$$\begin{aligned}
\text{Diameter } D_z \text{at } 100.0\ m &= 8.812\ m \\
\text{Normalized mode shape } \phi_z \text{ at } 100.0\ m &= 0.3346 \\
\text{Lumped mass at } 100.0\ m &= 241.147\ kN - sec^2/m^2 \\
\text{Effective height for the lumped mass at } 100.0\ m &= \left(\frac{110-100}{2}\right) + \left(\frac{100-90}{2}\right) = 10\ m \\
\text{Lumped mass of shell per m height } (m_z) \text{ at } 100.0\ m &= \frac{241.47}{10} = 24.1147\ kN - sec^2/m \\
m_z \cdot (\phi_z)^2 &= 24.1147 \times 0.336^2 = 2.7225 \\
m_z \cdot (\phi_z)^2 \text{ at } 110.0\ m &= 3.63 \\
d_z\ (m) &= 110 \text{ - } 100 = 10 \\
m_z \cdot (\phi_z)^2 \cdot d_z \text{ at } 100.0\ m &= \left(\frac{2.72+3.63}{2}\right) \times 10 = 31.762 \\
(\phi_z)^2 \cdot d_z \text{ at } 100.0\ m &= (0.336)^2 \times 10 = 1.1290 \\
D_z \cdot \phi_z \cdot d_z \text{ at } 100.0\ m &= 8.812 \times 0.336 \times 10 = 29.610 \\
\int m_z \cdot (\phi_z)^2 \cdot d_z &= 547.6347 \\
\int (\phi_z)^2 \cdot d_z &= 36.7728 \\
\int D_z \cdot \phi_z \cdot d_z &= 431.870
\end{aligned}$$

$$m_{ei} = \frac{\int m_z \cdot (\phi_z)^2 \cdot d_z}{\int (\phi_z)^2 \cdot d_z} = \frac{547.63}{36.77} = 14.89$$

$$K_{si} = \frac{2 \cdot m_{ei} \cdot \delta_s}{\sigma \cdot (d)^2} = \frac{2 \times 14.89 \times 0.1}{0.00122 \times 6.48 \times 6.48} = 58.40244$$

$$\eta_{oi} = \frac{\int D_z \cdot \phi_z \cdot d_z}{\int (\phi_z)^2 \cdot d_z} \times \frac{C_L}{4 \cdot \pi \cdot (S_n)^2 \cdot K_{si}} = \left(\frac{431.870}{36.7728}\right) \times \left(\frac{0.16}{4 \times \pi \times (0.2)^2 \times 58.40244}\right) = 0.0640096$$

$$F_{zoi} = 4 \cdot \pi^2 \cdot (f_1)^2 \cdot \eta_{oi} \times \int m_z \cdot (\phi_z) \cdot d_z = 3.7858\ kN \cdot m$$

$$\text{Sectional shear force at } 110.0\ m = 4.1570\ kN/m$$

$$\text{Shear force at } 110.0\ m = 43.0957\ kN$$

$$\text{Shear Force at } 100.0\ m = \left(\frac{3.7858 + 4.1570}{2}\right) \times (110 - 100) = 39.7144\ kN$$

$$\text{Cumulative Shear Force at } 110.0\ m = 303.4393 kN$$

$$\text{Cumulative shear force at } 100.0\ m = 303.4393 + 39.7144 = 343.1537\ kN$$

$$\text{Cumulative bending moment at } 110.0\ m = 10017.414\ kN \cdot m$$

$$\text{Cumulative bending moment at } 100.0\ m = 13253.472\ kN \cdot m$$

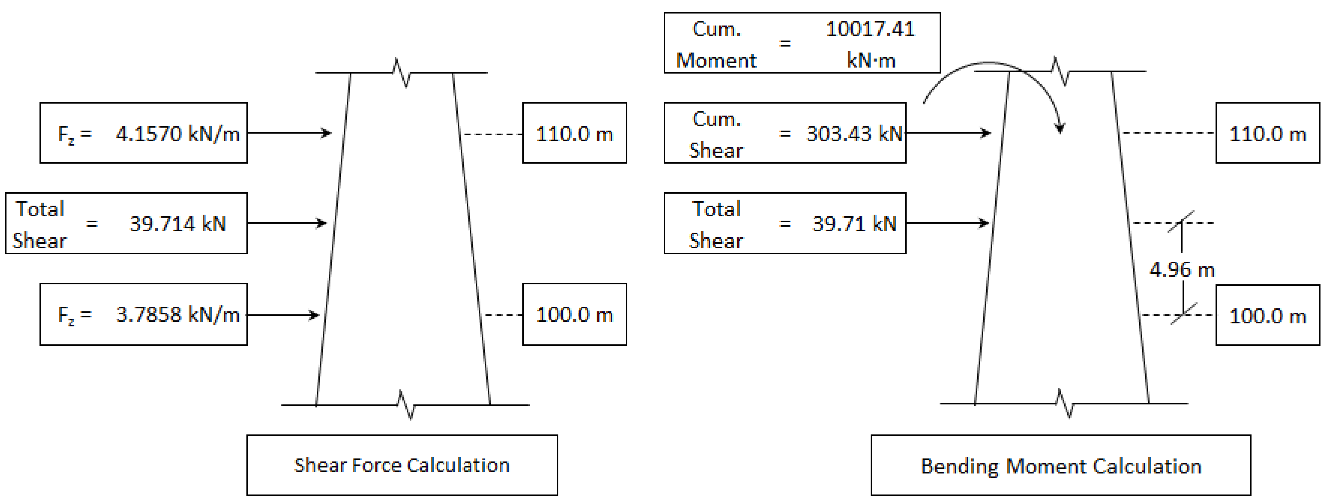

Figure 4.9: Simplified Method - Across Wind Load - Shear Force And Bending Moment Calculation

SHEAR FORCE DUE TO CO-EXISTING ALONG WIND LOADS

$$
\begin{aligned}
V_Z &= 16.410 \times 0.91 \times 0.92 \times 1 = 13.738\ m/s \\
p_z &= 0.6 \times (13.7381)^2 = 113.24\ N/m^2 \\
\text{External diameter } d_z &= 8.812\ m \\
F_Z &= \frac{113.24}{1000} \times 0.8 \times 8.812 = 0.798\ kN/m \\
F_Z \text{ at } 110.0m &= 0.765kN/m \\
\text{Height of the segment} &= \left(\frac{0.798 + 0.7650}{2}\right) \times (110 - 100) = 7.82\ kN \\
\text{Force CG wrt level } 100.0\ m &= \frac{(110 - 100)}{3} \times \left(\frac{0.798 + 2 \times 0.765}{0.798 + 0.765}\right) = 4.965\ m \\
\text{Shear force at } 100.0\ m &= \left(\frac{0.798 + 0.765}{2}\right) \times (110 - 100) = 7.82\ kN \\
\text{Cumulative shear force at } 110.0\ m &= 41.93kN \\
\text{Cumulative shear force at } 100.0\ m &= 41.93 + 7.82 = 49.75\ kN \\
\text{Cumulative moment at } 110.0\ m &= 1274.31\ kN \cdot m \\
\text{Moment due to co-existing along wind load} &= 1732.46\ kN \cdot m \\
\text{at } 100.0\ m & \\
\text{Resultant shear force at } 100.0\ m &= 343.1537 + 49.75 = 346.742\ kN \\
\text{Resultant bending moment at } 100.0\ m &= 13253.472 + 1732.46 = 13366.22\ kN \cdot m
\end{aligned}
$$

Table 4.23 to Table 4.26 summarize the values of shear force and bending moment at various levels of the chimney, calculated using the Simplified Method for across wind analysis for shell alone condition for 1^{st} and 2^{nd} mode.

Table 4.27 to Table 4.34 house the values of shear force and bending moment at various levels of the chimney, calculated using the Simplified Method for across wind analysis for chimney complete condition for 1^{st} and 2^{nd} mode.

ACROSS WIND LOADS SIMPLIFIED METHOD - As per IS : 4998 (Part - 1) Pg. 6 Clause A - 4.2 (Annexe - A)		
DESCRIPTION	SA	CC
Basic wind speed V_b (m/s) :	44	44
Assumed design life of the structure $(years)$:	25	100
Drag coefficient of the chimney C_D:	0.8	0.8
Probability factor (risk coefficient) k_1 :	0.91	1.07
Topography factor (assuming up wind slope $< 3^\circ$) k_3 :	1	1
Frequency in first mode of vibration $f_1(Hz)$	0.43	0.419
Frequency in second mode of vibration $f_2(Hz)$	1.624	1.561
H (m)	177.05	177.05
β =Structural damping as a fraction of critical damping	0.016	0.016
δ_s =Logarithmic decrement of structural damping	$= 2 \cdot \pi \cdot \beta = 0.100531$	$= 2 \cdot \pi \cdot \beta = 0.100531$
C_L =peak oscillatory lift coefficient	0.16	0.16
S_n =Strouhal number	0.2	0.2
σ =mass density of air	$1.2kg/m^3$	$1.2kg/m^3$
Co-existing along wind load calculation : V_b' (m/s) for Mode-1	16.410	13.599
Co-existing along wind load calculation : V_b' (m/s) for Mode-2	61.900	51.200
Mode 1 : Equivalent mass per unit length m_{ei}	14.8923	15.6392
Mode2 : Equivalent mass per unit length m_{ei}	18.1259	19.6052
Mode 1 : Mass damping parameter K_{si}	58.4024	61.3318
Mode 2 : Mass damping parameter K_{si}	71.3915	76.8846
Mode 1 : Peak tip deflection due to vortex shedding η_{oi}	0.0640	0.0610
Mode 2 : Peak tip deflection due to vortex shedding η_{oi}	-0.0385	-0.0378

Table 4.23: Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 1)

Levels (m)	External Diameter D_z (m)	Mode Shape (ϕ_z)	Effective height for lumped mass	Lumped mass of the shell per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	$(\phi_z)^2 \cdot d_z$	$D_z \cdot \phi_z \cdot d_z$
175	5.000	1	2.5	9.8940	9.8940	0	2.5	12.500
170	5.254	0.951	7.5	10.6938	9.6715	48.9138	6.7830	37.475
160	5.762	0.852	10	11.9409	8.6679	91.6973	7.2590	49.096
150	6.271	0.756	10	13.6906	7.8247	82.4631	5.7154	47.407
140	6.779	0.662	10	15.5520	6.8156	73.2012	4.3824	44.878
130	7.287	0.572	10	17.5250	5.7339	62.7473	3.2718	41.684
120	7.796	0.487	10	19.6096	4.6508	51.9234	2.3717	37.966
110	8.304	0.408	10	21.8063	3.6300	41.4038	1.6646	33.881
100	8.812	0.336	10	24.1147	2.7225	31.7621	1.1290	29.610
90	9.321	0.271	10	26.5347	1.9487	24.3559	0.7344	25.259
80	9.829	0.213	10	29.0668	1.3187	16.3373	0.4537	20.936
70	10.337	0.162	10	31.7105	0.8322	10.7547	0.2624	16.747
60	10.846	0.118	10	34.4659	0.4799	6.5606	0.1392	12.798
50	11.354	0.082	10	37.3328	0.2510	3.6546	0.0672	9.310
40	11.862	0.053	10	40.3114	0.1132	1.8213	0.0281	6.287
30	12.371	0.03	9.2	43.1481	0.0388	0.7603	0.0083	3.414
21.6	12.798	0.016	6.45	45.4448	0.0116	0.2120	0.0017	1.321
17.1	13.027	0.011	5.8	47.9709	0.0058	0.0392	0.0007	0.831
10	14.387	0.004	7.45	50.0284	0.0008	0.0234	0.0001	0.399
2.2	13.784	0.001	5	51.6045	0.0001	0.0033	0.0000	0.069
0	13.896	0.000	2.125	54.3022	0.0000	0.0001	0.0000	0.000
-2.05	14.000	0.000	1.025	53.6834	0.0000	0.0000	0.0000	0.000
						547.6347	**36.7728**	**431.870**

Table 4.24: Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 1) (Contd.)

Levels (m)	Sectional Shear Force F_{zoi} (kN/m)	Shear Force (kN)	Cumulative Shear Force(kN)	Cumulative Shear Force Due To Co-existing Along Wind Loads (kN)	Resultant Shear (kN)	Bending Moment ($kN.m$)	Cumulative Bending Moment Due To Co-existing Along Wind Bending Moment($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
175	4.6229	0	0	0.00	0.000	0.000	0.00	0.00
170	4.7518	23.4367	23.4367	2.62	23.583	58.323	6.52	58.69
160	4.7535	47.5266	70.9633	8.19	71.435	530.308	60.25	533.72
150	4.8360	47.9477	118.9110	14.18	119.753	1478.99	171.75	1488.93
140	4.8104	48.2323	167.1433	20.56	168.403	2909.47	345.07	2929.87
130	4.6838	47.4711	214.6143	27.32	216.346	4819.32	584.14	4854.59
120	4.4621	45.7293	260.3436	34.45	262.613	7195.95	892.69	7251.12
110	4.1570	43.0957	303.4393	41.93	306.323	10017.4	1274.31	10098.1
100	3.7858	39.7144	343.1537	49.75	346.742	13253.4	1732.46	13366.2
90	4.3599	35.7286	378.8823	57.84	383.271	16867.2	2270.24	17019.3
80	2.8928	31.2634	410.1458	66.12	415.441	20816.2	2889.86	21015.8
70	2.4003	26.4653	436.6111	74.57	442.933	25054.1	3593.16	25310.4
60	1.9003	21.5026	458.1137	83.17	465.601	29531.9	4381.71	29855.2
50	1.4304	16.6531	474.7668	91.89	483.577	34200.2	5256.89	34601.8
40	0.9983	12.1431	486.9100	100.55	497.183	39012.2	6219.27	39504.8
30	0.6048	8.0154	494.9254	108.95	506.775	43924.6	7266.98	44521.7
21.6	0.3397	3.9671	498.8925	115.72	512.138	48100.2	8210.83	48796.0
17.1	0.2466	1.3192	500.2117	119.17	514.212	50348.4	8739.41	51101.2
10	0.0935	1.2072	501.4189	124.11	516.551	53904.8	9603.52	54753.6
2.2	0.0241	0.4587	501.8776	129.21	518.242	57818.0	10591.36	58780.1
0	0.0000	0.0265	501.9041	130.67	518.635	58922.2	10877.22	59917.7
-2.05	0.0000	0.0000	501.9041	131.35	518.807	59951.1	11146.03	60978.4

Table 4.25: Summary Of Across Wind Loads : Simplified Method - Shell Alone Condition (Mode - 2)

Levels (m)	External Diameter D_z (m)	Mode Shape (ϕ_z)	Effective height for lumped mass	Lumped mass of the shell per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	$(\phi_z)^2 \cdot d_z$	$D_z \cdot \phi_z \cdot d_z$
175	5.000	1	2.5	9.8940	9.8940	0	2.5	12.500
170	5.254	0.856	7.5	10.6938	7.8358	44.3244	5.4955	33.732
160	5.762	0.573	10	11.9409	3.9205	58.7815	3.2833	33.019
150	6.271	0.308	10	13.6906	1.2987	26.0964	0.9486	19.314
140	6.779	0.077	10	15.5520	0.0922	6.9548	0.0593	5.220
130	7.287	-0.111	10	17.5250	0.2159	1.5407	0.1232	-8.089
120	7.796	-0.251	10	19.6096	1.2354	7.2567	0.6300	-19.568
110	8.304	-0.342	10	21.8063	2.5506	18.9299	1.1696	-28.400
100	8.812	-0.389	10	24.1147	3.6491	30.9981	1.5132	-34.281
90	9.321	-0.398	10	26.5347	4.2032	39.2613	1.5840	-37.097
80	9.829	-0.376	10	29.0668	4.1093	41.5627	1.4138	-36.958
70	10.337	-0.332	10	31.7105	3.4953	38.0230	1.1022	-34.320
60	10.846	-0.274	10	34.4659	2.5876	30.4141	0.7508	-29.718
50	11.354	-0.21	10	37.3328	1.6464	21.1697	0.4410	-23.844
40	11.862	-0.147	10	40.3114	0.8711	12.5873	0.2161	-17.438
30	12.371	-0.09	9.2	43.1481	0.3495	6.1029	0.0745	-10.243
21.6	12.798	-0.051	6.45	45.4448	0.1182	1.9643	0.0168	-4.210
17.1	13.027	-0.034	5.8	47.9709	0.0555	0.3907	0.0067	-2.569
10	14.387	-0.014	7.45	50.0284	0.0098	0.2317	0.0015	-1.396
2.2	13.784	-0.002	5	51.6045	0.0002	0.0390	0.0000	-0.138
0	13.896	0	2.125	54.3022	0.0000	0.0002	0.0000	0.000
-2.05	14.000	0	1.025	53.6834	0.0000	0.0000	0.0000	0.000
						386.6295	21.3302	-184.482

Table 4.26: Summary Of Across Wind Loads : Shell Alone Condition (Mode - 2) (Contd.)

Levels (m)	Sectional Shear Force F_{zoi} (kN/m)	Shear Force (kN)	Cumulative. Shear Force (kN)	Cumulative Shear Force: Co-Existing Along Wind Load (kN)	Resultant Shear Force (kN)	Bending Moment ($kN . m$)	Cumulative Bending Moment: Co-Existing Along Wind Load ($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
175	-39.725	0.000	0.000	0.00	0.00	0.000	0.000	0.00
170	-36.753	-191.19	-191.19	37.34	194.81	-484.18	92.707a	492.98
160	-27.471	-321.12	-512.32	116.57	525.42	-4079.1	857.265	4168.26
150	-16.930	-222.01	-734.33	201.70	761.53	-10400	2443.810	10683.56
140	-4.808	-108.69	-843.02	292.50	892.33	-18388	4910.162	19032.43
130	7.810	15.012	-828.01	388.74	914.73	-26848	8311.882	28105.70
120	19.762	137.86	-690.15	490.20	846.53	-34538	12702.306	36800.67
110	29.943	248.52	-441.62	596.67	742.32	-40282	18132.574	44175.63
100	37.663	338.03	-103.58	707.93	715.47	-43073	24651.658	49628.58
90	42.402	400.33	296.74	822.99	874.85	-42146	32303.813	53102.62
80	43.881	431.41	728.16	940.81	1189.68	-37034	41120.646	55339.56
70	42.270	430.75	1158.92	1061.05	1571.28	-27585	51128.039	58095.16
60	37.917	400.93	1559.85	1184.39	1957.95	-13955	62348.593	63891.34
50	31.477	346.97	1906.83	1307.51	2312.05	3431.59	74801.721	74880.39
40	23.792	276.35	2183.18	1430.72	2610.22	23945.7	88495.757	91678.23
30	15.591	196.92	2380.10	1550.25	2840.46	46830.5	103403.874	113514.1
21.6	9.305	104.57	2484.67	1646.63	2980.77	67299.5	116834.133	13483.19
17.1	6.548	35.67	2520.349	1695.76	3037.72	78565.5	124355.403	147094.5
10	2.812	33.23	2553.58	1766.05	3104.79	96593.6	136651.089	167343.5
2.2	0.414	12.58	2566.16	1838.50	3156.78	116572	150707.444	190530.7
0	0.000	0.45	2566.61	1859.31	3169.32	122219	154775.005	197212.5
-2.05	0.000	0.000	2566.61	1869.05	3175.04	127480	158599.907	203482.7

Table 4.27: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1)

Levels (m)	External Diameter D_z (m)	Mode Shape (ϕ_z)	Effective height for lumped mass	Lumped mass of the shell per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	$(\phi_z)^2 \cdot d_z$	$D_z \cdot \phi_z \cdot d_z$
175	5.000	1	2.5	9.8940	9.8940	0	2.5	12.500
170	5.254	0.95	7.5	10.6938	9.6512	48.8630	6.769	37.436
160	5.762	0.851	10	11.9409	8.6476	91.4940	7.242	49.039
150	6.271	0.754	10	13.6906	7.7833	82.1547	5.685	47.282
140	6.779	0.66	10	15.5520	6.7744	72.7889	4.356	44.742
130	7.287	0.569	10	17.5250	5.6739	62.2417	3.238	41.466
120	7.796	0.485	10	19.6096	4.6127	51.4328	2.352	37.810
110	8.304	0.406	10	21.8063	3.5945	41.0357	1.648	33.715
100	8.812	0.334	10	24.1147	2.6901	31.4230	1.116	29.434
90	9.321	0.269	10	26.5347	1.9201	23.0511	0.724	25.073
80	9.829	0.211	10	29.0668	1.2941	16.0708	0.445	20.739
70	10.337	0.161	10	31.7105	0.8220	10.5802	0.259	16.643
60	10.846	0.118	10	34.4659	0.4799	6.5094	0.139	12.798
50	11.354	0.081	10	37.3328	0.2449	3.6242	0.066	9.197
40	11.862	0.052	10	40.3114	0.1090	1.7697	0.027	6.168
30	12.371	0.03	9.2	43.1481	0.0388	0.7392	0.008	3.414
21.6	12.798	0.016	6.45	45.4448	0.0116	0.2120	0.002	1.321
17.1	13.027	0.01	5.8	47.9709	0.0048	0.0370	0.001	0.756
10	14.387	0.004	7.45	50.0284	0.0008	0.0199	0.000	0.399
2.2	13.784	0.001	5	51.6045	0.0001	0.0033	0.000	0.069
0	13.896	0	2.125	54.3022	0.0000	0.0001	0.000	0.000
-2.05	14.000	0	1.025	53.6834	0.0000	0.0000	0.000	0.000
					544.0	**544.0505**	**36.5763**	**430.001**

Table 4.28: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Effect Of Other Lumped Masses)

Other Lumped masses per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	Force (kN)
4.922	4.9215	0.000	5.203
0.743	0.6710	13.981	2.240
0.163	0.1181	3.945	0.587
0.163	0.0927	1.054	0.520
1.060	0.4618	2.773	2.959
0.163	0.0528	2.573	0.392
0.163	0.0384	0.456	0.335
0.163	0.0269	0.326	0.280
1.486	0.1657	0.963	2.099
0.382	0.0277	0.967	0.435
0.382	0.0170	0.223	0.341
0.382	0.0099	0.135	0.260
1.911	0.0266	0.183	0.954
0.382	0.0025	0.146	0.131
4.198	0.0114	0.069	0.923
8.393	0.0076	0.095	0.980
18.979	0.0049	0.052	0.828
38.413	0.0038	0.020	0.942
0.000	0.0000	0.014	0.000
0.000	0.0000	0.000	0.000
0.000	0.0000	0.000	0.000
0.000	0.0000	0.000	0.000

Table 4.29: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Contd.)

Sectional Shear Force F_{zoi} (kN/m)	Shear Force(kN)	Cumulative Shear Force (kN)	Cumulative Shear Force Due To Co-Existing Along Wind Load (kN)	Resultant Shear (kN)	Bending Moment ($kN.m$)
4.1840	0.000	0	0.00	0.000	0.00
4.2962	21.201	21.2006	2.49	21.347	53.00
4.2973	42.967	64.1678	7.78	64.638	479.84
4.3654	44.313	107.4809	13.46	108.320	1338.09
4.3407	43.530	151.0109	19.52	152.267	2630.55
4.2169	42.788	193.7988	25.94	195.527	4354.59
4.0219	41.194	234.9931	32.71	237.259	6498.55
3.7440	38.830	273.8227	39.82	276.702	9042.63
3.4061	35.750	309.5729	47.24	313.157	11959.61
3.0185	32.123	341.6958	54.92	346.081	15215.95
2.5936	28.061	369.7563	62.78	375.048	18773.21
2.1590	23.763	393.5194	70.81	399.839	22589.59
1.7199	19.394	412.9138	78.97	420.397	26621.76
1.2788	14.993	427.9072	87.25	436.712	30825.86
0.8865	10.826	438.7334	95.47	449.002	35159.07
0.5474	7.169	445.9027	103.45	457.746	39582.25
0.3075	3.591	449.4933	109.88	462.729	43342.91
0.2029	1.148	450.6416	113.16	464.632	45368.22
0.0846	1.021	451.6622	117.85	466.784	48571.39
0.0218	0.415	452.0773	122.69	468.429	52095.98
0.0000	0.024	452.1013	124.08	468.818	53090.57
0.0000	0.000	452.1013	124.73	468.990	54017.38
	452.101				

Table 4.30: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 1) (Resultant Forces)

Levels (m)	OTHER LUMPED MASSES		Total Moment ($kN \cdot m$)	Cumulative Bending Moment Due To Co-Existing Along Wind Load ($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
	Cumulative Shear Force (kN)	Bending Moment ($kN \cdot m$)			
175	5.203	0.00	0.00	0.000	0.00
170	7.443	26.02	79.02	6.187	79.26
160	8.030	100.45	580.29	57.207	583.10
150	8.550	180.75	1518.83	163.080	1527.56
140	11.509	266.25	2896.79	327.664	2915.26
130	11.902	381.34	4735.93	554.667	4768.30
120	12.236	500.35	6998.90	847.648	7050.04
110	12.516	622.71	9665.34	1210.020	9740.79
100	14.615	747.87	12707.48	1645.050	12813.51
90	15.050	894.02	16109.97	2155.692	16253.56
80	15.391	1044.52	19817.73	2744.055	20006.81
70	15.651	1198.43	23788.02	3411.867	24031.45
60	16.605	1354.94	27976.69	4160.635	28284.38
50	16.736	1520.99	32346.85	4991.654	32729.73
40	17.659	1691.80	36850.87	5905.482	37321.06
30	18.638	1864.94	41447.18	6900.328	42017.66
21.6	19.467	2021.50	45364.41	7796.553	46029.52
17.1	20.409	2109.10	47477.32	8298.461	48197.10
10	20.409	2254.01	50825.40	9118.975	51636.97
2.2	20.409	2413.20	54509.18	10056.981	55429.17
0	20.409	2458.10	55548.67	10328.416	56500.72
-2.05	20.409	2478.60	56495.99	10583.659	57478.78

Table 4.31: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2)

Levels (m)	External Diameter D_z (m)	Mode Shape (ϕ_z)	Effective height for lumped mass	Lumped mass of the shell per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	$(\phi_z)^2 \cdot d_z$	$D_z \cdot \phi_z \cdot d_z$
175	5.000	1	2.5	9.8940	9.8940	0	2.5	12.500
170	5.254	0.852	7.5	10.6938	7.7627	44.1417	5.444	33.574
160	5.762	0.561	10	11.9409	3.7580	57.6038	3.147	32.328
150	6.271	0.292	10	13.6906	1.1673	24.6268	0.853	18.311
140	6.779	0.058	10	15.5520	0.0523	6.0982	0.034	3.932
130	7.287	-0.131	10	17.5250	0.3007	1.7653	0.172	-9.547
120	7.796	-0.27	10	19.6096	1.4295	8.6514	0.729	-21.049
110	8.304	-0.36	10	21.8063	2.8261	21.2782	1.296	-29.895
100	8.812	-0.405	10	24.1147	3.9554	33.9075	1.640	-35.691
90	9.321	-0.411	10	26.5347	4.4823	42.1884	1.689	-38.309
80	9.829	-0.386	10	29.0668	4.3308	44.0655	1.490	-37.940
70	10.337	-0.34	10	31.7105	3.6657	39.9828	1.156	-35.147
60	10.846	-0.28	10	34.4659	2.7021	31.8393	0.784	-30.368
50	11.354	-0.215	10	37.3328	1.7257	22.1392	0.462	-24.411
40	11.862	-0.15	10	40.3114	0.9070	13.1636	0.225	-17.794
30	12.371	-0.092	9.2	43.1481	0.3652	6.3611	0.078	-10.471
21.6	12.798	-0.052	6.45	45.4448	0.1229	2.0500	0.017	-4.292
17.1	13.027	-0.035	5.8	47.9709	0.0588	0.4087	0.007	-2.644
10	14.387	-0.014	7.45	50.0284	0.0098	0.2434	0.001	-1.396
2.2	13.784	-0.002	5	51.6045	0.0002	0.0390	0.000	-0.138
0	13.896	0	2.125	54.3022	0.0000	0.0002	0.000	0.000
-2.05	14.000	0	1.025	53.6834	0.0000	0.0000	0.000	0.000
						400.5541	21.7249	-198.448

Table 4.32: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Effect Of Other Lumped Masses)

Other Lumped masses per m (m_z)	$m_z \cdot (\phi_z)^2$	$m_z \cdot (\phi_z)^2 \cdot d_z$	Force (kN)
4.922	4.9215	0.000	-45.568
0.743	0.5397	13.653	-17.594
0.163	0.0513	2.955	-4.389
0.163	0.0139	0.326	-1.764
1.060	0.0036	0.087	-2.277
0.163	0.0028	0.032	0.791
0.163	0.0119	0.073	1.631
0.163	0.0211	0.165	2.175
1.486	0.2437	1.324	22.285
0.382	0.0646	1.541	5.819
0.382	0.0570	0.608	5.465
0.382	0.0442	0.506	4.813
1.911	0.1498	0.970	19.820
0.382	0.0177	0.838	3.044
4.198	0.0944	0.561	24.320
8.393	0.0710	0.827	26.310
18.979	0.0513	0.514	23.576
38.413	0.0471	0.221	28.879
0.000	0.0000	0.167	0.000
0.000	0.0000	0.000	0.000
0.000	0.0000	0.000	0.000
0.000	0.0000	0.000	0.000
		25.369	

Table 4.33: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Contd.)

Sectional Shear Force F_{zoi} (kN/m)	Shear Force(kN)	Cumulative Shear Force (kN)	Cumulative Shear Force Due To Co-Existing Along Wind Load (kN)	Resultant Shear (kN)	Bending Moment $(kN.m)$
-36.6429	0.000	0	0.00	0.000	0.00
-33.7437	-175.966	-175.9665	35.32	179.476	-445.96
-24.8095	-292.766	-468.7323	110.27	481.527	-3743.90
-14.8056	-198.075	-666.8076	190.79	693.565	-9504.97
-4.3407	-90.731	-757.5387	276.67	806.481	-16722.24
8.5025	25.809	-731.7294	367.70	818.923	-24267.27
19.6088	140.557	-591.1729	463.68	751.321	-30974.34
29.0739	243.414	-347.7593	564.39	662.925	-35747.87
36.1706	326.222	-21.5369	669.63	669.973	-37653.49
40.3900	382.803	361.2661	778.46	858.206	-35990.01
41.5530	409.715	770.9814	889.91	1177.432	-30338.46
39.9301	407.416	1178.3972	1003.64	1547.874	-20578.05
35.7409	378.355	1556.7525	1119.36	1917.406	-6867.39
29.7268	327.339	1884.0911	1236.77	2253.752	10386.95
22.3943	260.606	2144.6967	1354.31	2535.977	30591.99
14.7017	185.480	2330.1769	1466.38	2753.179	53030.46
8.7520	98.506	2428.6825	1557.54	2885.207	73052.66
6.2182	33.683	2462.3654	1604.01	2938.722	84061.79
2.5940	31.283	2493.6486	1670.50	3001.474	101670.87
0.3822	11.607	2505.2558	1739.03	3049.676	121177.81
0.0000	0.420	2505.6762	1758.72	3061.291	126689.99
0.0000	0.000	2505.6762	1767.93	3066.592	131826.62

Table 4.34: Summary Of Across Wind Loads : Simplified Method - Chimney Complete Condition (Mode - 2) (Resultant Forces)

Levels (m)	OTHER LUMPED MASSES		Total Moment ($kN \cdot m$)	Cumulative Bending Moment Due To Co-Existing Along Wind Load ($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
	Cumulative Shear Force (kN)	Bending Moment ($kN \cdot m$)			
175	-45.568	0.00	0.00	0.000	0.00
170	-63.162	-227.84	-673.79	87.692	679.48
160	-66.551	-859.46	-4604.36	810.883	4674.23
150	-68.315	-1524.97	-11029.94	2311.590	11269.56
140	-70.592	-2208.12	-18930.36	4644.502	19491.79
130	-69.801	-2914.04	-27181.31	7862.176	28295.54
120	-68.170	-3612.05	-34586.39	12015.061	36613.93
110	-65.995	-4293.75	-40041.62	17151.530	43560.38
100	-43.710	-4953.70	-42607.19	23317.905	48570.54
90	-37.891	-5390.80	-41380.81	30556.048	51439.71
80	-32.427	-5769.71	-36108.17	38895.855	53072.48
70	-27.613	-6093.97	-26672.02	48361.808	55229.17
60	-7.793	-6370.10	-13237.49	58975.286	60442.66
50	-4.749	-6448.03	3938.92	70754.649	70864.20
40	18.571	-6495.52	24096.47	83707.783	87107.02
30	44.881	-6309.81	46720.65	97809.313	108395.02
21.6	68.456	-5932.81	67119.85	110512.941	129298.82
17.1	97.336	-5624.75	78437.04	117627.280	141380.85
10	97.336	-4933.67	96737.20	129257.720	161448.58
2.2	97.336	-4174.45	117004.36	142553.570	184421.55
0	97.336	-3960.31	122729.68	146401.060	191038.86
-2.05	97.336	-3573.94	128252.68	150019.020	197368.83

4.7.3.3 Random response method for across wind analysis

The across wind loads are calculated on the chimney as per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 5.3 (Annexe - A)

The calculation is made by first calculating the peak response amplitude at the specified mode of vibration (usually the first or second).

SAMPLE CALCULATION AT EL (+) 40.0 m (CHIMNEY COMPLETE CONDITION : MODE - 1)

$$\text{Peak Response Amplitude, } \eta_{oi} = \frac{\left(\frac{1.25 \times \bar{C}_L \times d \times \phi_{Hi}}{(\pi)^2 \times (S_n)^2}\right) \times \left(\frac{\sigma \times d^2 \times \sqrt{\frac{\sqrt{\pi} \cdot L}{2 \cdot (\cap + 2)}}}{m_{ei}}\right)}{\left(\left[\frac{1}{H} \int (\phi)^2 \cdot d_z\right]^{0.5} \times \sqrt{\beta - \frac{K_a \cdot \sigma \cdot d^2}{m_{ei}}}\right)}$$

Sectional shear force $F_{zoi} = 4 \cdot \pi^2 \cdot (f_1)^2 \cdot \eta_{oi} \times \int m_z \cdot (\phi_z) \cdot d_z$

Elevation at half height of the chimney	$= 87.5\ m$
External diameter at half height of the chimney	$= 9.448\ m$
Average outer diameter over the top 1/2 chimney d_{av}	$= 7.276\ m$
Taper:	$= 2 \times \left(\frac{d_{av} - d_{top}}{H}\right) = 0.0257$
Equivalent aspect ratio $\bigcap$	$= \left(\frac{H}{d}\right) = 27.3114$
Aerodynamic damping coefficient K_a	$= 0.5$
Correlation length in diameters L	$= 1$
RMS Lift coefficient $\bar{C}_L$	$= 0.12$
Peak Response Amplitude η_{oi}	$= 0.025777$
Sectional shear force F_{zoi}	$= 0.3745\ kN/m$
Sectional shear force F_{zoi} at 50.0 m	$= 0.5403$
Segment height $h\ m$	$= 50 - 40 = 10$
Shear force at 40.0 m	$= \left(\frac{0.3745 + 0.544}{2}\right) \times 10 = 4.574\ kN$
From Fig. 4.10 CG of shear force at 40.0 m	$= \left(\frac{10}{3}\right) \times \left(\frac{0.3745 + 2 \times 0.544}{0.3745 + 0.544}\right) = 5.3075\ m$
Cumulative shear at 50.0 m	$= 180.78\ kN$
Cumulative shear at 40.0 m	$= 180.78 + 4.574 = 185.3553\ kN$
Co-existing along wind shear force at 40.0 m	$= 95.47\ kN$
Resultant shear force at 40.0 m	$= \sqrt{(185.36)^2 + (95.47)^2} = 208.50\ kN$

$$
\begin{aligned}
\text{Cumulative moment } 50.0\ m &= 13023.26\ kN\cdot m\\
\text{Moment due to cumulative shear at } 50.0\ m &= 180.78\times 10 = 1807.8\ kN\cdot m\\
\text{Moment due to shear force at } 40.0\ m &= 4.574\times 5.301 = 24.2467\ kN\cdot m\\
\text{Bending moment at } 40.0\ m &= 13023.26 + 1807.8 + 24.24 = 14855.3\ kN\cdot m\\
\text{Moment due to other lumped mass} &= 713.25\ kN\cdot m\\
\text{Total bending moment} &= 14855.3 + 713.25 = 15568.55\ kN\cdot m\\
\text{Co-existing along wind moment at } 40.0\ m &= 5905.482\ kN\cdot m\\
\text{Resultant bending moment at } 40.0\ m &= \sqrt{(15568.55)^2 + (5905.482)^2} = 16650.96\ kN\cdot m
\end{aligned}
$$

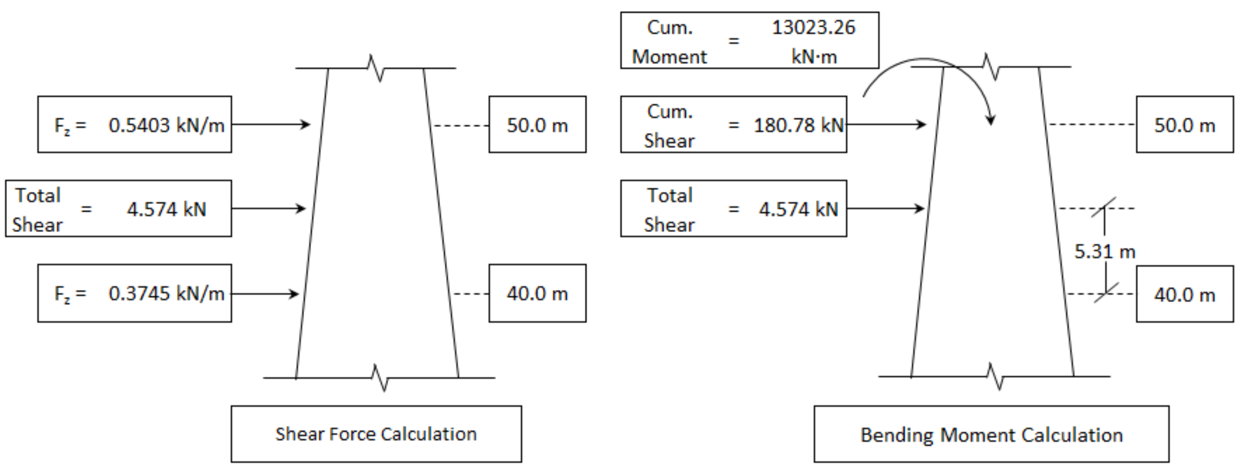

Figure 4.10: Random Response Method - Across Wind Loads - Shear Force & Bending Moment Calculation

ACROSS WIND LOADS : RANDOM RESPONSE METHOD - As per IS : 4998 (Part - 1) 1992 Pg. 7 Clause A - 5.3 (Annexe - A)

DESCRIPTION	SA	CC
Mode 1 : Peak tip deflection due to vortex shedding η_{oi}	0.0270	0.0257
Mode 2 : Peak tip deflection due to vortex shedding η_{oi}	0.0288	0.0263

Table 4.35 and Table 4.36 house the values of shear force and bending moment for 1^{st} and 2^{nd} mode respectively, acting at various levels for shell alone condition.

Table 4.37 to Table 4.40 detail the value of shear force and bending moment for 1^{st} and 2^{nd} mode in case of chimney complete condition. The contribution of lumped masses other then the RCC shell have also been tabulated in detail and considered in calculation.

Table 4.35: Summary Of Across Wind Loads : Random Response Method - Shell Alone Condition (Mode - 1)

Levels (m)	Sectional Shear Force F_{zoi} (kN/m)	Shear Force (kN)	Cumulative Shear Force (kN)	Cumulative Shear Force Due To Co-Existing Along Wind Load (kN)	Resultant Shear (kN)	Bending Moment ($kN . m$)	Cumulative Bending Moment Due To Co-Existing Along Wind Load ($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
175	1.9554	0	0	0.00	0.000	0.000	0.000	0.00
170	2.0100	9.9135	9.9135	2.62	10.255	24.784	6.515	25.63
160	2.0107	20.1033	30.0168	8.19	31.115	224.435	60.247	232.38
150	2.0456	20.2815	50.2983	14.18	52.258	626.011	171.745	649.14
140	2.0348	20.4018	70.7001	20.56	73.628	1231.004	345.075	1278.45
130	1.9812	20.0798	90.7800	27.32	94.802	2038.404	584.139	2120.45
120	1.8874	19.3431	110.1231	34.45	115.386	3042.920	892.688	3171.16
110	1.7584	18.2291	128.3522	41.93	135.028	4235.296	1274.315	4422.85
100	1.6014	16.7988	145.1510	49.75	153.441	5602.812	1732.461	5864.55
90	1.4212	15.1129	160.2639	57.84	170.381	7129.887	2270.236	7482.60
80	1.2236	13.2242	173.4881	66.12	185.660	8798.647	2889.862	9261.07
70	1.0153	11.1946	184.6827	74.57	199.168	10589.501	3593.158	11182.50
60	0.8038	9.0954	193.7781	83.17	210.871	12481.805	4381.712	13228.56
50	0.6050	7.0441	200.8222	91.89	220.846	14454.807	5256.889	15381.04
40	0.4223	5.1364	205.9587	100.55	229.192	16488.712	6219.273	17622.63
30	0.2558	4.3904	209.3491	108.95	236.002	18565.251	7266.981	19936.84
21.6	0.1437	1.6781	211.0272	115.72	240.674	20330.831	8210.828	21926.25
17.1	0.1043	0.5580	211.5852	119.17	242.839	21281.709	8739.405	23006.27
10	0.0396	0.5106	212.0958	124.11	245.741	22785.777	9603.517	24726.89
2.2	0.0102	0.1940	212.2898	129.21	248.518	24440.881	10591.364	26637.07
0	0.0000	0.0112	212.3011	130.67	249.291	24907.931	10877.223	27179.39
-2.05	0.0000	0.0000	212.3011	131.35	249.650	25343.148	11146.028	27685.90
					3594.744			

Table 4.36: Summary Of Across Wind Loads : Random Response Method - Shell Alone Condition (Mode - 2)

Levels (m)	Sectional Shear Force F_{zoi} (kN/m)	Shear Force (kN)	Cumulative Shear Force (kN)	Cumulative Shear Force Due To Co-Existing Along Wind Load (kN)	Resultant Shear (kN)	Bending Moment ($kN.m$)	Cumulative Bending Moment Due To Co-Existing Along Wind Load ($kN \cdot m$)	Resultant Bending Moment ($kN \cdot m$)
175	29.7707	0.00	0.00	0.00	0.00	0.00	0.00	0.00
170	27.5439	143.29	143.29	37.34	148.07	358.22	92.71	370.02
160	20.5877	240.66	383.94	116.57	401.25	2994.37	857.26	3114.67
150	12.6879	166.38	550.32	201.70	586.12	7665.71	2443.81	8045.82
140	3.6032	81.46	631.78	292.50	696.20	13576.21	4910.16	14436.87
130	-5.8533	-11.25	620.53	388.74	732.24	19837.75	8311.88	21508.69
120	-14.8101	-104.32	517.21	490.20	712.60	25526.45	12702.31	28512.25
110	-22.4402	-186.25	330.96	596.67	682.31	29767.31	18132.57	34855.17
100	-28.2259	-254.33	77.63	707.93	712.17	31810.25	24651.66	40244.21
90	-31.7771	-300.02	-222.39	822.99	852.51	31086.47	32303.81	44831.97
80	-32.8853	-324.31	-545.70	940.81	1087.61	27246.06	41120.65	49328.04
70	-31.6781	-322.82	-868.51	1061.05	1371.18	20175.00	51128.04	54964.60
60	-28.4156	-300.47	-1168.98	1184.39	1663.41	9987.52	62348.59	63143.47
50	-23.5900	-260.03	-1429.01	1307.51	1936.92	-3002.45	74801.72	74861.95
40	-17.8305	-207.10	-1636.11	1430.72	2173.44	-18328.06	88495.76	90373.76
30	-11.6848	-147.58	-1783.69	1550.25	2363.23	-35427.07	103403.87	109304.34
21.6	-6.9738	-78.37	-1862.06	1646.63	2485.68	-50739.20	116834.13	127376.14
17.1	-4.9077	-26.73	-1888.79	1695.76	2538.33	-59178.60	124355.40	137718.45
10	-2.1075	-24.90	-1913.69	1766.05	2604.06	-72677.40	136651.09	154775.73
2.2	-0.3106	-9.43	-1923.12	1838.50	2660.54	-87640.98	150707.44	174337.82
0	0.0000	-0.34	-1923.46	1859.31	2675.21	-91872.23	154775.01	179988.36
-2.05	0.0000	0.00	-1923.46	1869.05	2681.99	-95815.33	158599.91	185295.73
		-1923.46			31765.08			

Table 4.37: Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 1)

Levels (m)	Sectional Shear ForceF_{zoi} (kN/m)	Shear Force (kN)	Cumulative Shear Force (kN)	Cumulative SF: Co-Existing Along Wind Load (kN)	Resultant SF (kN)	BM ($kN \cdot m$)
175	1.7677	0.000	0	0.00	0.00	0.00
170	1.8150	8.957	8.95679	2.49	9.30	22.39
160	1.8155	18.153	27.10950	7.78	28.20	202.72
150	1.8443	18.299	45.40834	13.46	47.36	565.31
140	1.8338	18.391	63.79885	19.52	66.72	1111.35
130	1.7816	18.077	81.87579	25.94	85.89	1839.72
120	1.6992	17.404	99.27948	32.71	104.53	2745.50
110	1.5818	16.405	115.68415	39.82	122.34	3820.32
100	1.4390	15.104	130.78786	47.24	139.06	5052.68
90	1.2753	13.571	144.35907	54.92	154.45	6428.41
80	1.0957	11.855	156.21404	62.78	168.36	7931.28
70	0.9121	10.039	166.25343	70.81	180.70	9543.61
60	0.7266	8.194	174.44715	78.97	191.49	11247.12
50	0.5403	6.334	180.78151	87.25	200.74	13023.26
40	0.3745	4.574	185.35537	95.47	208.50	14853.94
30	0.2313	3.029	188.38424	103.45	214.92	16722.64
21.6	0.1299	1.517	189.90117	109.88	219.40	18311.44
17.1	0.0857	0.485	190.38630	113.16	221.48	19167.09
10	0.0358	0.431	190.81748	117.85	224.28	20520.36
2.2	0.0092	0.175	190.99287	122.69	227.00	22009.42
0	0.0000	0.010	191.00301	124.08	227.76	22429.62
-2.05	0.0000	0.000	191.00301	124.73	228.12	22821.17

Table 4.38: Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 1) (Resultant Forces & Moments)

OTHER LUMPED MASSES		Total Bending Moment $(kN \cdot m)$	Cumulative Bending Moment Due To Co-Existing Along Wind Load $(kN \cdot m)$	Resultant Bending Moment $(kN \cdot m)$
Cumulative force (kN)	Bending Moment $(kN \cdot m)$			
2.198	0.00	0.00	0.000	0.00
3.145	10.99	34.38	6.187	33.95
4.393	42.43	245.15	57.207	251.74
3.612	76.35	641.66	163.080	662.06
4.862	112.47	1223.82	327.664	1266.92
5.028	161.09	2000.81	554.667	2076.27
5.169	211.37	2956.87	847.648	3075.97
5.288	263.06	4084.38	1210.020	4258.89
6.174	315.93	5368.61	1645.050	5614.99
6.358	377.67	6806.08	2155.692	7139.31
6.502	441.25	8372.53	2744.055	8810.73
6.612	506.27	10049.88	3411.867	10613.25
7.015	572.39	11819.51	4160.635	12530.43
7.070	642.54	13665.80	4991.654	14548.91
7.460	713.24	15567.18	5905.482	16649.68
7.874	781.58	17504.22	6900.328	18815.22
8.224	853.98	19165.42	7796.553	20690.57
8.622	884.01	20051.10	8298.461	21700.48
8.622	952.21	21472.57	9118.975	23328.67
8.622	1019.46	23028.88	10056.981	25129.11
8.622	1038.43	23468.04	10328.416	25640.31
8.622	1047.09	23868.26	10583.659	26109.53

Table 4.39: Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 2)

Levels (m)	Sectional Shear ForceF_{zoi} (kN/m)	Shear Force (kN)	Cumulative Shear Force (kN)	Cumulative SF: Co-Existing Along Wind Load (kN)	Resultant SF (kN)	BM ($kN.m$)
175	25.5588	0.00	0	0.00	0.00	0.00
170	23.5366	122	122.73	35.32	127.72	306.85
160	17.3049	204	326.94	110.27	345.04	2555.2
150	10.3270	138	465.10	190.79	502.72	6515.5
140	2.3301	63.2	528.39	276.67	596.44	11483
130	-5.9306	-18.0	510.38	367.70	629.05	16676
120	-13.677	-98.0	412.34	463.68	620.51	21290
110	-20.279	-169	242.56	564.39	614.31	24565
100	-25.229	-227.5	15.02	669.63	669.79	25853
90	-28.172	-267	-251.98	778.46	818.23	24668
80	-28.983	-285	-537.76	889.91	1039.77	20719
70	-27.851	-284	-821.94	1003.64	1297.26	13920
60	-24.929	-263	-1085.85	1119.36	1559.50	4381.
50	-20.734	-228	-1314.17	1236.77	1804.62	-7618.
40	-15.620	-181	-1495.94	1354.31	2017.25	-21668
30	-10.254	-129	-1625.32	1466.38	2189.05	-37275
21.6	-6.1046	-68.7	-1694.03	1557.54	2301.23	-51216
17.1	-4.3373	-23.4	-1717.52	1604.01	2350.05	-58892
10	-1.8093	-21.8	-1739.34	1670.50	2411.62	-71164
2.2	-0.2666	-8.09	-1747.44	1739.03	2465.31	-84762
0	0.0000	-0.29	-1747.73	1758.72	2479.45	-88607
-2.05	0.0000	0.00	-1747.73	1767.93	2485.99	-92190
		-1822				

Table 4.40: Summary Of Across Wind Loads : Random Response Method - Chimney Complete Condition (Mode - 2) (Resultant

OTHER LUMPED MASSES		Total Bending Moment $(kN \cdot m)$	Cumulative Bending Moment Due To Co-Existing Along Wind Load $(kN \cdot m)$	Resultant Bending Moment $(kN \cdot m)$
Cumulative force (kN)	Bending Moment $(kN \cdot m)$			
31.784	0.00	0.00	0.000	0.00
44.056	158.92	465.77	87.692	473.95
46.420	599.48	3154.75	810.883	3257.29
47.650	1063.68	7579.20	2311.590	7923.87
49.239	1540.18	13023.18	4644.502	13826.59
48.687	2032.56	18709.46	7862.176	20294.28
47.549	2519.42	23810.01	12015.061	26669.80
46.032	2994.90	27560.06	17151.530	32461.24
30.488	3455.21	29308.31	23317.905	37452.66
26.430	3760.08	28428.36	30556.048	41735.40
22.618	4024.36	24743.87	38895.855	46099.31
19.261	4250.52	18171.47	48361.808	51663.01
5.436	4443.11	8825.09	58975.286	59631.92
4.313	4497.45	-3120.69	70754.649	70823.44
-12.953	4530.56	-17138.19	83707.783	85444.20
-31.305	4303.45	-32971.65	97809.313	103217.20
-47.749	4138.03	-47078.35	110512.941	120122.78
-67.893	3824.07	-55068.31	117627.280	129879.54
-67.893	3441.10	-67723.18	129257.720	145924.59
-67.893	2911.52	-81851.23	142553.570	164381.09
-67.893	2762.15	-85845.29	146401.060	169713.54
-67.893	2492.65	-89697.65	150019.020	174789.52

4.8 Summary of results

This chapter contains the summary of axial forces, shear forces and bending moments acting at various levels considered across the height of the chimney. The values for shell alone as well as chimney complete conditions have been tabulated. Table 4.41 gives details of the axial loads, Table 4.42 gives the details of the shear forces and Table 4.43 gives the details of the bending moments. Figure 4.11 and 4.12 show the variation in the magnitudes of shear force along the height of the chimney. Figure 4.13 and 4.14 show the variation in the magnitudes of bending moment along the height of the chimney. The results obtained by various methods of analysis recommended by IS : 4998 (Part - 1) 1992 have been compiled in the following table and the maximum of the same shall be considered for the design of the RCC shell. A magnification factor or 1.1 has been applied to the governing forces to consider the fluctuations the amplitude of transverse oscillations in the case of rare load combinations. The following things are evident from the plots:

- From the graphs shown in Fig. 4.11 and Fig. 4.12 it is evident that the shear forces induced in the chimney owing to the seismic forces show a consistently uniform increment along the height of the chimney, whereas the shear forces induced due to wind loads show a sharp variation over a particular range of height in which the wind achieves its critical wind speed.
- The values of shear force and bending moment calculated using the random response method for along wind loads are higher than those obtained using simplified method both in presence as well as absence of lining.
- Across wind load analysis done for the 2^{nd} produces the governing values of shear force and bending moments may it be shell alone or chimney completed condition.
- Nature of variation in magnitudes of shear force and bending moment along the height of the chimney remains more or less the same in both the cases namely shell alone and chimney complete, except the values being higher in case of chimney complete condition.

Table 4.41: Summary Of Axial Loads

Levels (m)	AXIAL LOADS (CUMULATIVE)	
	Shell Alone Case	Chimney Completed Case
175	0	120.70
170	485.3	660.70
160	1573.6	1765.00
150	2828.1	3035.50
140	4259.7	4571.10
130	5879.4	6206.80
120	7698.1	8041.50
110	9726.8	10086.20
100	11976.5	12481.65
90	14458.1	15000.75
80	17182.6	17762.75
70	20161	20778.65
60	23404.2	24209.35
50	26923.2	27765.85
40	30728.9	31984.35
30	34832.3	36844.25
21.6	38517.3	41730.16
17.1	40584.3	45981.75
10	43976.2	49374.65
2.2	47895.9	53294.35
0	49038.6	54437.05
-2.05	50118.2	55516.65

Table 4.42: Summary Of Shear Forces (Shell Alone Condition)

Levels (m)	Seismic Shear Forces (kN)	ALONG WIND SHEAR FORCES (kN)		ACROSS WIND SHEAR FORCES (RESULTANT SHEAR) (m)				Magnification Factor	Governing Shear Forces ((kN)
		Simplified Method (cumulative)	Random Response Method (cumulative)	FIRST MODE		SECOND MODE			
				Simplified Method	Random Response Method	Simplified Method	Random Response Method		
175	64.9	0.00	0.00	0.00	0.00	0.00	0.00	1.1	71.39
170	224.38	29.53	54.92	23.58	10.25	194.81	148.07	1.1	245.72
160	339.96	92.50	163.96	71.43	31.11	525.42	401.25	1.1	577.96
150	405.53	160.61	271.85	119.75	52.26	761.53	586.12	1.1	837.69
140	439.88	233.63	378.47	168.40	73.63	892.33	696.20	1.1	981.56
130	453.94	311.29	483.71	216.35	94.80	914.73	732.24	1.1	1006.20
120	462.84	393.45	587.46	262.61	115.39	846.53	712.60	1.1	931.18
110	478.68	479.99	689.61	306.32	135.03	742.32	682.31	1.1	816.56
100	515.21	570.74	790.04	346.74	153.44	715.47	712.17	1.1	869.05
90	581.13	665.08	888.27	383.27	170.38	874.85	852.51	1.1	977.10
80	674.62	762.33	983.76	415.44	185.66	1189.68	1087.61	1.1	1308.65
70	791.52	862.26	1076.34	442.93	199.17	1571.28	1371.18	1.1	1728.41
60	923.94	964.66	1165.85	465.60	210.87	1957.95	1663.41	1.1	2153.74
50	1060.77	1069.31	1252.14	483.58	220.85	2312.05	1936.92	1.1	2543.26
40	1193.17	1174.43	1333.83	497.18	229.19	2610.22	2173.44	1.1	2871.24
30	1298.23	1278.17	1409.53	506.77	236.00	2840.46	2363.23	1.1	3124.50
21.6	1352.68	1363.41	1467.89	512.14	240.67	2980.77	2485.68	1.1	3278.85
17.1	1391.7	1407.68	1496.69	514.21	242.84	3037.72	2538.33	1.1	3341.49
10	1415.62	1473.67	1536.78	516.55	245.74	3104.79	2604.06	1.1	3415.27
2.2	1417.9	1544.20	1576.01	518.24	248.52	3156.78	2660.54	1.1	3472.46
0	1418.14	1564.47	1586.82	518.63	249.29	3169.32	2675.21	1.1	3486.25
-2.05	1418.14	1573.95	1591.82	518.81	249.65	3175.04	2681.99	1.1	3492.55

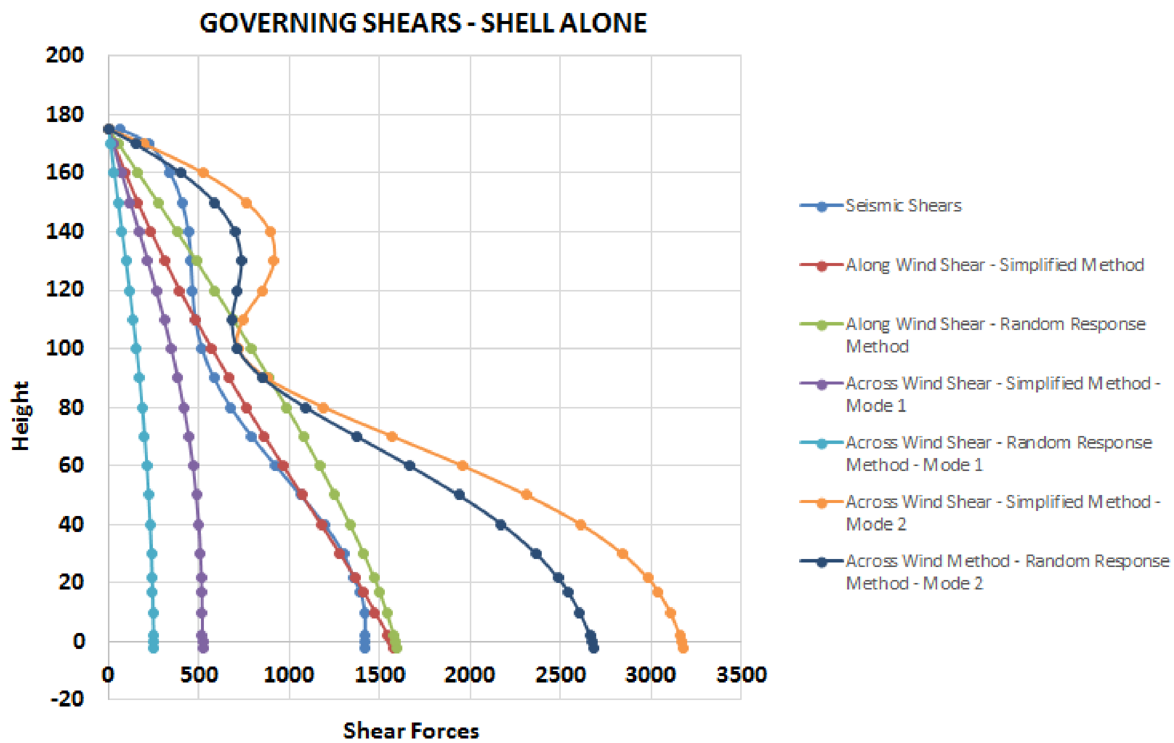

Figure 4.11: Summary Of Magnified Shear Forces (Shell Alone Condition)

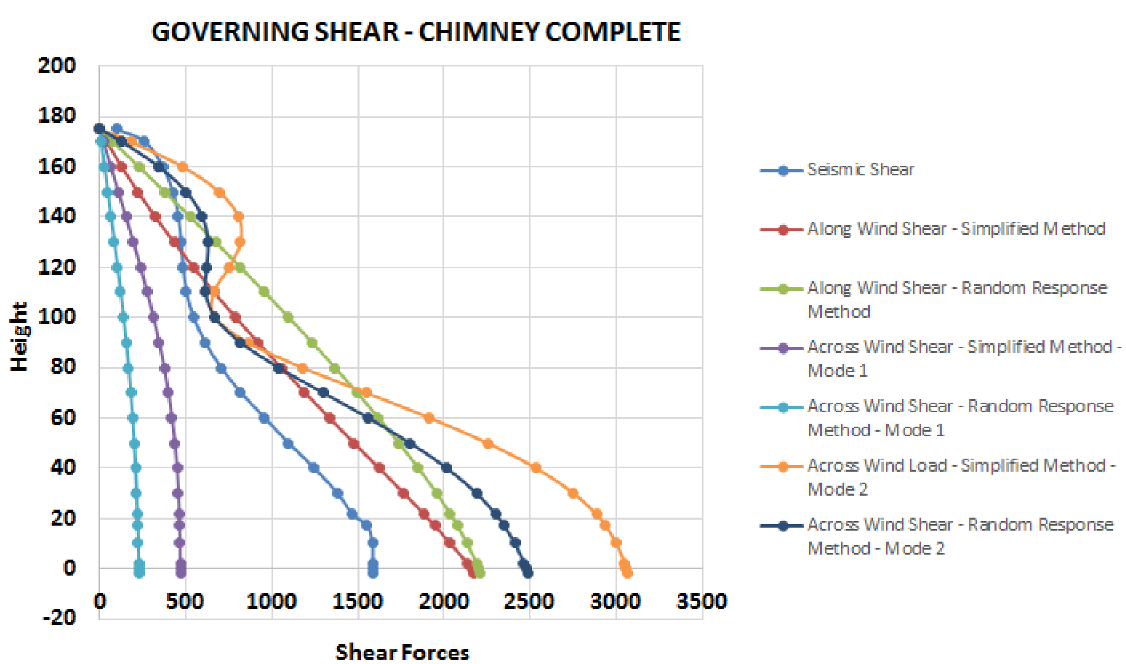

Figure 4.12: Summary Of Magnified Shear Forces (Chimney Complete Condition)

Table 4.43: Summary Of Shear Forces (Chimney Completed Case)

Levels (m)	Seismic Shear Forces (kN)	ALONG WIND SHEAR FORCES (kN)		ACROSS WIND SHEAR FORCES (RESULTANT SHEAR) (m)				Magnification Factor	Governing Shear Forces ((kN)
				FIRST MODE		SECOND MODE			
		Simplified Method (cumulative)	Random Response Method (cumulative)	Simplified Method	Random Response Method	Simplified Method	Random Response Method		
175	97.28	0.00	0	0.00	0.00	0.00	0.00	1.1	107.01
170	262.22	40.83	76.4	21.35	9.30	179.48	127.72	1.1	288.44
160	367.89	127.89	228.1	64.64	28.20	481.53	345.04	1.1	529.68
150	424.74	222.06	378.1	108.32	47.36	693.56	502.72	1.1	762.92
140	457.99	323.00	526.3	152.27	66.72	806.48	596.44	1.1	887.13
130	472.63	430.37	672.6	195.53	85.89	818.92	629.05	1.1	900.82
120	484.44	543.98	816.8	237.26	104.53	751.32	620.51	1.1	898.48
110	504	663.61	958.7	276.70	122.34	662.92	614.31	1.1	1054.57
100	545.63	789.08	1098.2	313.16	139.06	669.97	669.79	1.1	1208.02
90	613.06	919.52	1234.6	346.08	154.45	858.21	818.23	1.1	1358.06
80	705.27	1053.97	1367.1	375.05	168.36	1177.43	1039.77	1.1	1503.81
70	820.4	1192.13	1495.6	399.84	180.70	1547.87	1297.26	1.1	1702.66
60	959.31	1333.70	1619.8	420.40	191.49	1917.41	1559.50	1.1	2109.15
50	1098.21	1478.39	1739.4	436.71	200.74	2253.75	1804.62	1.1	2479.13
40	1247.49	1623.72	1852.6	449.00	208.50	2535.98	2017.25	1.1	2789.57
30	1381.94	1767.15	1957.5	457.75	214.92	2753.18	2189.05	1.1	3028.50
21.6	1469.78	1885.00	2038.4	462.73	219.40	2885.21	2301.23	1.1	3173.73
17.1	1554.21	1946.21	2078.3	464.63	221.48	2938.72	2350.05	1.1	3232.59
10	1584.06	2037.45	2133.8	466.78	224.28	3001.47	2411.62	1.1	3301.62
2.2	1586.95	2134.96	2188.1	468.43	227.00	3049.68	2465.31	1.1	3354.64
0	1587.25	2162.97	2203.1	468.82	227.76	3061.29	2479.45	1.1	3367.42
-2.05	1587.25	2176.08	2210.1	468.99	228.12	3066.59	2485.99	1.1	3373.25

Table 4.44: Summary Of Bending Moments (Shell Alone Condition)

Levels (m)	Seismic Bending Moment ($kN \cdot m$)	ALONG WIND MOMENTS ($kN \cdot m$)		ACROSS WIND LOAD MOMENTS ($kN \cdot m$)				Magnification Factor	Governing Moments ($kN \cdot m$)
				FIRST MODE		SECOND MODE			
		Simplified Method	Random Response Method (cumulative)	Simplified Method	Random Response Method	Simplified Method	Random Response Method		
175	0	0.00	0.00	0.00	0.00	0.00	0.00	1.1	0.00
170	324.49	73.82	137.40	58.69	25.63	492.98	370.02	1.1	542.28
160	2555.71	685.65	1239.89	533.72	232.38	4168.26	3114.67	1.1	4585.08
150	5886.54	1966.21	3442.88	1488.93	649.14	10683.56	8045.82	1.1	11751.91
140	9708.99	3967.23	6735.67	2929.87	1278.45	19032.43	14436.87	1.1	20935.67
130	13652.01	6737.07	11105.66	4854.59	2120.45	28105.70	21508.69	1.1	30916.27
120	17439.09	10321.72	16538.35	7251.12	3171.16	36800.67	28512.25	1.1	40480.73
110	20890.15	14765.06	23017.34	10098.14	4422.85	44175.63	34855.17	1.1	48593.19
100	23926.74	20108.96	30524.39	13366.22	5864.55	49628.58	40244.21	1.1	54591.43
90	26584.33	26391.55	39038.22	17019.30	7482.60	53102.62	44831.97	1.1	58412.88
80	29046.29	33642.13	48530.44	21015.87	9261.07	55339.56	49328.04	1.1	60873.51
70	31662.6	41885.56	58969.18	25310.47	11182.50	58095.16	54964.60	1.1	64866.09
60	34913.53	51143.86	70320.29	29855.21	13228.56	63891.34	63143.47	1.1	77352.32
50	39331.13	61436.18	82547.47	34601.89	15381.04	74880.39	74861.95	1.1	90802.22
40	45338.37	72773.70	95608.27	39504.84	17622.63	91678.23	90373.76	1.1	105169.09
30	53128.39	85143.62	109441.95	44521.75	19936.84	113514.14	109304.34	1.1	124865.56
21.6	61008.03	96315.34	121609.79	48796.04	21926.25	134831.19	127376.14	1.1	148314.31
17.1	65671.23	102585.02	128316.43	51101.27	23006.27	147094.57	137718.45	1.1	161804.03
10	73567.45	112858.35	139132.37	54753.62	24726.89	167343.55	154775.73	1.1	184077.90
2.2	82822.78	124652.29	151299.46	58780.13	26637.07	190530.74	174337.82	1.1	209583.82
0	85512.33	128074.82	154781.68	59917.79	27179.39	197212.59	179988.36	1.1	216933.85
-2.05	88044.27	131295.87	158042.45	60978.44	27685.90	203482.79	185295.73	1.1	223831.07

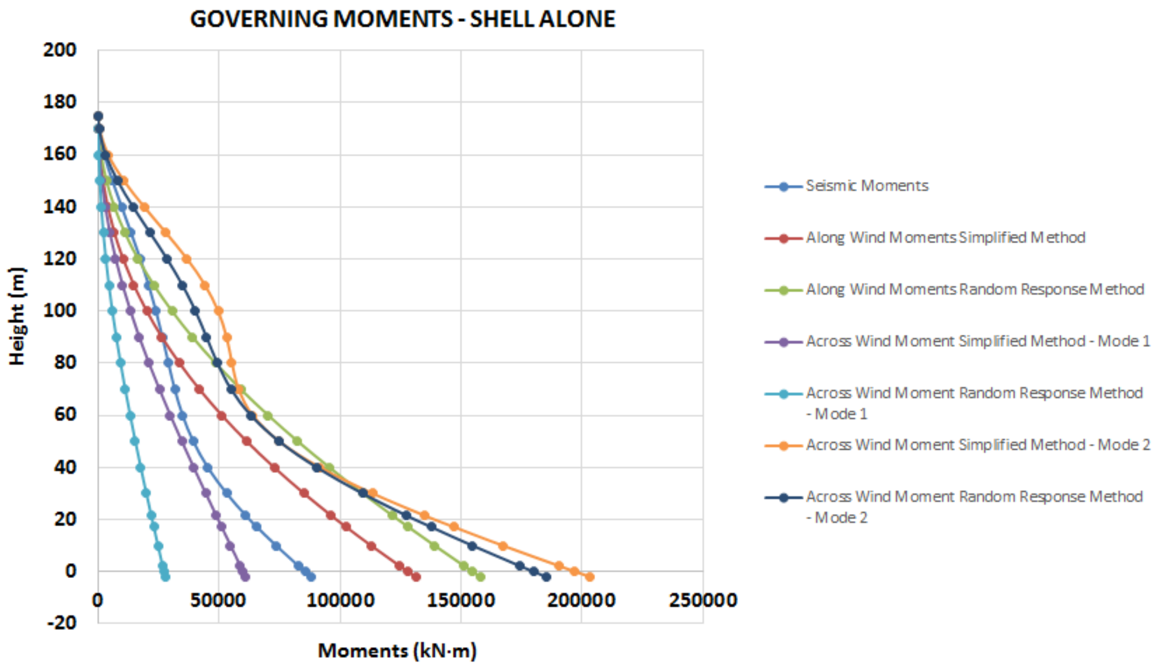

Figure 4.13: Summary Of Magnified Bending Moments - Shell Alone Condition

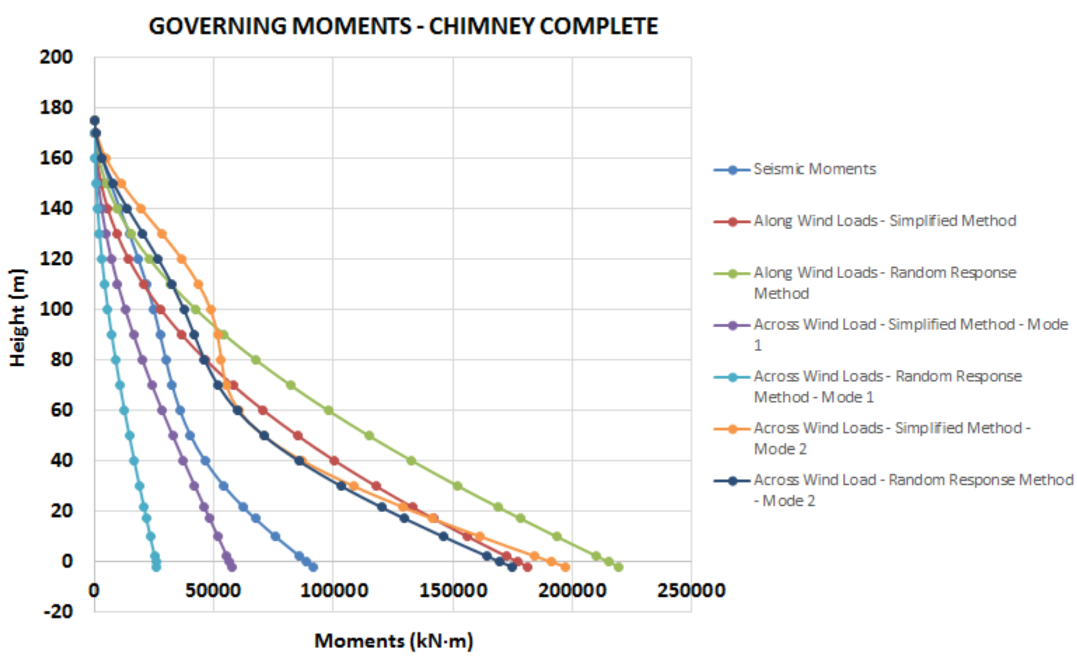

Figure 4.14: Summary Of Magnified Bending Moments - Chimney Complete Condition

Table 4.45: Summary Of Bending Moments (Chimney Complete Condition)

Levels (m)	Seismic Bending Moment ($kN \cdot m$)	ALONG WIND MOMENTS ($kN \cdot m$)		ACROSS WIND LOAD MOMENTS ($kN \cdot m$)				Magnification Factor	Governing Moments ($kN \cdot m$)
				FIRST MODE		SECOND MODE			
		Simplified Method	Random Response Method (cumulative)	Simplified Method	Random Response Method	Simplified Method	Random Response Method		
175	0	0.00	0.00	0.00	0.00	0.00	0.00	1.1	0.00
170	486.39	103.10	192.35	79.26	33.95	679.48	473.95	1.1	747.42
160	3104.77	951.98	1729.36	583.10	251.74	4674.23	3257.29	1.1	5141.66
150	6693.82	2725.66	4797.47	1527.56	662.06	11269.56	7923.87	1.1	12396.52
140	10636.52	5495.62	9380.76	2915.26	1266.92	19491.79	13826.59	1.1	21440.97
130	14599.4	9330.07	15462.91	4768.30	2076.27	28295.54	20294.28	1.1	31125.09
120	18373.15	14291.04	23022.11	7050.04	3075.97	36613.93	26669.80	1.1	40275.32
110	21800.04	20439.16	32035.21	9740.79	4258.89	43560.38	32461.24	1.1	47916.42
100	24821.95	27832.22	42476.07	12813.51	5614.99	48570.54	37452.66	1.1	53427.60
90	27431.52	36524.48	54316.60	16253.56	7139.31	51439.71	41735.40	1.1	59748.26
80	29880.93	46554.86	67515.29	20006.81	8810.73	53072.48	46099.31	1.1	74266.82
70	32507.52	57957.65	82026.78	24031.45	10613.25	55229.17	51663.01	1.1	90229.46
60	35775.5	70763.14	97803.92	28284.38	12530.43	60442.66	59631.92	1.1	107584.31
50	40200.81	84998.83	114797.00	32729.73	14548.91	70864.20	70823.44	1.1	126276.70
40	46262.44	100678.76	132944.42	37321.06	16649.68	87107.02	85444.20	1.1	146238.86
30	54191.51	117786.91	152163.48	42017.66	18815.22	108395.02	103217.20	1.1	167379.83
21.6	62342.27	133238.53	169067.11	46029.52	20690.57	129298.82	120122.78	1.1	185973.82
17.1	67249.62	141910.69	178384.24	48197.10	21700.48	141380.85	129879.54	1.1	196222.66
10	75749.16	156121.81	193410.51	51636.97	23328.67	161448.58	145924.59	1.1	212751.56
2.2	85858.59	172432.00	210308.09	55429.17	25129.11	184421.55	164381.09	1.1	231338.89
0	88815.62	177164.33	215143.14	56500.72	25640.31	191038.86	169713.54	1.1	236657.46
-2.05	91605.18	181617.78	219670.43	57478.78	26109.53	197368.83	174789.52	1.1	241637.48

Chapter 5

Design Of RCC Shell

5.1 Introduction

This chapter houses the details of the RCC wind shield design. RCC wind shield is designed as per working stress method given in IS : 4998 (Part - 1) 1975. The calculations of stresses at important or controlling sections are given for both Shell Alone (SA) and Chimney Complete (CC) conditions.

The following load combinations have been considered for design of the RCC shell:

- Dead Load + Governing Moments
- Dead Load + Temperature
- Dead Load + Governing Mom9ents + Temperature
- Circumferential Loads
  - Due to wind
  - Due to temperature
  - Due to wind + temperature

5.2 Calculation of stresses in RCC shell due to DL

Grade of concrete used for shell construction = M35

Permissible stress in concrete in bending compression : σ_{cbc} = 11.5 (N/mm^2)

$$\text{Modular ratio } m = \frac{280}{3 \cdot \sigma_{cbc}} = 8.1159$$

Plenum size = 4.5 m×4.5 m

Access door size = 2.2 m×2.5 m

SAMPLE CALCULATION OF STRESSES IN RCC SHELL AT EL (+) 30.0 m (SHELL ALONE CONDITION)

Thickness of the shell = 0.455 m

Internal diameter of shell = 11.46 m

Axial load (kN) = 34832.3 kN

Modular ratio m = 8.12

Area of the shell = 17.024 m^2

$$\text{Stress in the shell } \sigma'_{cv} \ (N/mm^2) = \frac{34832.3 \times 10^3}{17.024 \times 10^6} = 2.047$$

Allowable stress as per IS : 456 - 2000 Pg. 81 Table 21 = 9 N/mm^2

The area of plenums, access doors etc has been deducted from the actual shell area for stress calculations.

Table 5.1details the stresses induced in the RCC shell (Shell Alone Condition) under the effect of dead loads individually.

Table 5.1: Stress In RCC Shell Due To Dead Loads (DL) : Shell Alone Condition

Levels (m)	Internal diameter of shell (m)	Thickness of shell (m)	Axial load (kN)	Area (m^2)	σ'_{cv} (N/mm^2)	Allowable σ_{cv} (N/mm^2)	Check
175	4.50	0.250	0	3.731	0.000	9	Safe
170	4.74	0.257	485.3	4.036	0.120	9	Safe
160	5.22	0.271	1573.6	4.678	0.336	9	Safe
150	5.70	0.285	2828.1	5.365	0.527	9	Safe
140	6.18	0.299	4259.7	6.095	0.699	9	Safe
130	6.66	0.314	5879.4	6.869	0.856	9	Safe
120	7.14	0.328	7698.1	7.688	1.001	9	Safe
110	7.62	0.342	9726.8	8.550	1.138	9	Safe
100	8.10	0.356	11976.5	9.455	1.267	9	Safe
90	8.58	0.370	14458.1	10.405	1.390	9	Safe
80	9.06	0.384	17182.6	11.398	1.507	9	Safe
70	9.54	0.398	20161	12.436	1.621	9	Safe
60	10.02	0.412	23404.2	13.517	1.731	9	Safe
50	10.50	0.427	26923.2	14.642	1.839	9	Safe
40	10.98	0.441	30728.9	15.811	1.944	9	Safe
30	11.46	0.455	34832.3	17.024	2.046	9	Safe
21.6	11.86	0.467	38517.3	13.800	2.791	9	Safe
17.1	12.08	0.473	40584.3	14.400	2.818	9	Safe
10	12.42	0.483	43976.2	19.581	2.246	9	Safe
2.2	12.80	0.494	47895.9	19.550	2.450	9	Safe
0	12.90	0.497	49038.6	19.320	2.538	9	Safe
-2.05	13.00	0.500	50118.2	21.206	2.363	9	Safe

Table 5.2 houses the stresses induced in the RCC shell (Chimney Complete Condition) due to dead loads individually.

Table 5.2: Stresses In RCC Shell Due To Dead Loads (DL): Chimney Complete Condition

Levels (m)	Internal diameter of shell (m)	Thickness of shell (m)	Axial load (kN)	Area (m^2)	σ'_{cv} (N/mm^2)	Check
175	4.50	0.250	120.70	3.731	0.032	Safe
170	4.74	0.257	660.70	4.036	0.164	Safe
160	5.22	0.271	1765.00	4.678	0.377	Safe
150	5.70	0.285	3035.50	5.365	0.566	Safe
140	6.18	0.299	4571.10	6.095	0.750	Safe
130	6.66	0.314	6206.80	6.869	0.904	Safe
120	7.14	0.328	8041.50	7.688	1.046	Safe
110	7.62	0.342	10086.20	8.550	1.180	Safe
100	8.10	0.356	12481.65	9.455	1.320	Safe
90	8.58	0.370	15000.75	10.405	1.442	Safe
80	9.06	0.384	17762.75	11.398	1.558	Safe
70	9.54	0.398	20778.65	12.436	1.671	Safe
60	10.02	0.412	24209.35	13.517	1.791	Safe
50	10.50	0.427	27765.85	14.642	1.896	Safe
40	10.98	0.441	31984.35	15.811	2.023	Safe
30	11.46	0.455	36844.25	17.024	2.164	Safe
21.6	11.86	0.467	41730.16	13.800	3.024	Safe
17.1	12.08	0.473	45981.75	14.400	3.193	Safe
10	12.42	0.483	49374.65	19.581	2.522	Safe
2.2	12.80	0.494	53294.35	19.550	2.726	Safe
0	12.90	0.497	54437.05	19.320	2.818	Safe
-2.05	13.00	0.500	55516.65	21.206	2.618	Safe

5.3 Calculation of stresses in the shell under DL + WL combination (Governing Moments)

(A) Annular section without opening:

SAMPLE CALCULATION OF STRESSES AT EL (+) 30.0 m (CHIMNEY COMPLETE CONDITION)

$$\begin{aligned}
\text{Axial load} &= 36844.25\ kN \\
\text{Bending Moment} &= 167379.83\ kN\cdot m \\
\text{Thickness of shell } t &= 0.455\ m \\
\text{Internal diameter of the shell } I_d &= 11.461\ m \\
\text{Mean radius of the shell } r &= \frac{11.461+0.455}{2} = 5.96\ m \\
\text{Grade of concrete} &= \text{M35} \\
\text{Grade of steel} &= \text{Fe500} \\
\text{Modular ratio } m &= 8.12 \\
\text{Total steel ratio } p &= 0.005 \\
\text{Eccentricity } e = \left(\frac{M}{W}\right) &= 4.4853 \\
\left(\frac{e}{r}\right) &= \frac{4.4853}{5.96} = 0.7525
\end{aligned}$$

α = position of neutral axis and its value needs to be such that the ratio $\left(\frac{e}{r}\right) = \left(\frac{A}{B}\right)$.

$$A = \frac{1}{2}\cdot[(1-p)\cdot(\alpha - sin\alpha\cdot cos\alpha) + (mp)\cdot\pi]$$

$$A = 1.069$$

$$B = (1-p)\cdot(sin\alpha - \alpha cos\alpha) - (mp)\cdot\pi\cdot cos\alpha$$

$$B = 1.404$$

$$\left(\frac{A}{B}\right) = \left(\frac{1.069}{1.404}\right) = 0.7612$$

$$\sigma'_{cv} = \frac{W \cdot (1 - cos\alpha)}{2 \cdot r \cdot t \cdot B}$$

$$\sigma'_{cv} = 5.94 \ N/mm^2$$

$$\sigma_{cv} = \sigma'_{cv} \cdot \left[1 + \frac{t}{2 \cdot r \cdot (1 - cos\alpha)}\right]$$

$$\sigma_{cv} = 6.12 \ N/mm^2$$

Allowable $\sigma_{cv} N/mm^2$ as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (a)

Allowable $\sigma_{cv} = 0.38 \times \sigma_{cu} = 0.38 \times 35 = 14.3 \ N/mm^2 > 6.12 \ N/mm^2$.... Hence Safe.

$$\sigma_{sv} = m \cdot \sigma'_{cv} \cdot \left[\frac{1 + cos\alpha}{1 - cos\alpha}\right]$$

$$\sigma_{sv} = 39.280 \ N/mm^2$$

Allowable $\sigma_{sv} \ N/mm^2$as per Is : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (a)

Allowable $\sigma_{sv} = 0.57 \times f_y = 0.57 \times 500 = 285 \ N/mm^2 > 39.280 \ N/mm^2$.... Hence Safe.

ϕ = angle between the direction of wind and the center line of the opening.

In our case the openings are located such that its value remains zero in all the cases.

Figure 5.1 shows the details of the openings at EL (+) 21.9 and even defines β and α and shows the calculations for the same.

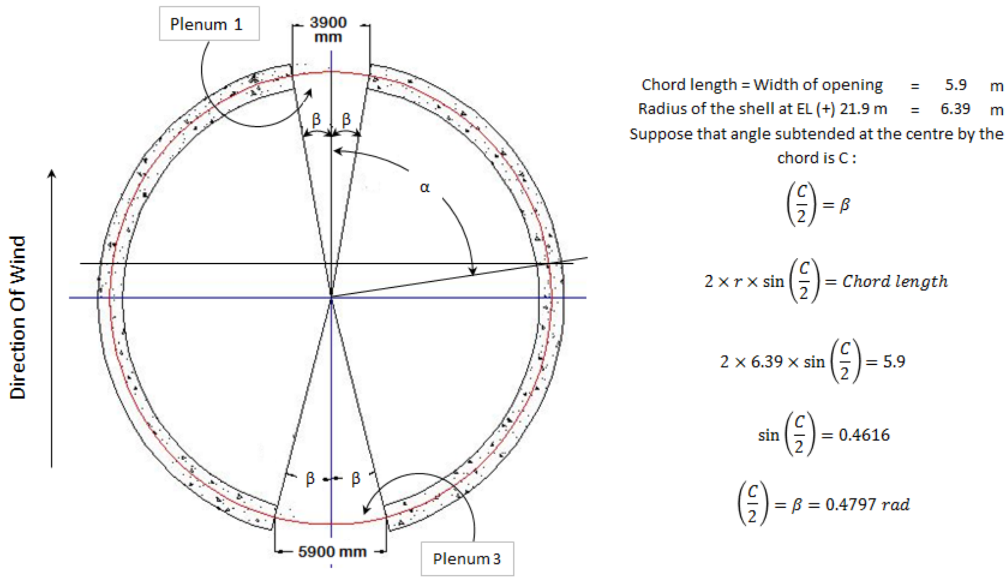

Figure 5.1: Details Of Opening At EL (+) 21.9 m

Table 5.3 to Table 5.5 house the magnitude of the stresses induced in the RCC shell (Shell Alone Condition) under the combination of DL and WL. The details regarding the definition of ϕ, β and α are as mentioned in the text and figure 4.1.

Table 5.3: Stresses In RCC Shell Due To DL + WL (Shell Alone Condition)

Elevation (m)	Axial Load (kN)	Governing Moment ($kN.m$)	Eccentricity e = M/W	Radius r (m)	Section Property	$\phi(radian)$	$\beta(radian)$
175	0.00	0.00	0.000	2.38	Annular	0	0.00
170	485.30	542.28	1.117	2.50	Annular	0	0.00
160	1573.60	4585.08	2.914	2.75	Annular	0	0.00
150	2828.10	11751.91	4.155	2.99	Annular	0	0.00
140	4259.70	20935.67	4.915	3.24	Annular	0	0.00
130	5879.40	30916.27	5.258	3.49	Annular	0	0.00
120	7698.10	40480.73	5.259	3.73	Annular	0	0.00
110	9726.80	48593.19	4.996	3.98	Annular	0	0.00
100	11976.50	54591.43	4.558	4.23	Annular	0	0.00
90	14458.10	58412.88	4.040	4.48	Annular	0	0.00
80	17182.60	60873.51	3.543	4.72	Annular	0	0.00
70	20161.00	64866.09	3.217	4.97	Annular	0	0.00
60	23404.20	77352.32	4.305	5.22	Annular	0	0.00
50	26923.20	90802.22	4.373	5.46	Annular	0	0.00
40	30728.90	105169.09	3.422	5.71	Annular	0	0.00
30	34832.30	124865.56	3.585	5.96	Annular	0	0.00
21.6	38517.30	148314.31	3.851	6.17	2 open.	0	0.50
17.1	40584.30	161804.03	3.987	6.28	1 open.	0	0.10
10	43976.20	184077.90	4.186	6.45	Annular	0	0.00
2.2	47895.90	209583.82	4.376	6.64	Annular	0	0.00
0	49038.60	216933.85	4.424	6.70	1 open.	0	0.09
-2.05	50118.20	223831.07	4.466	6.75	Annular	0	0.00

Following expressions for eccentricity ratio and stresses in concrete and steel have been used for the typical cases of annular cross-sections of the chimney shell:

$$Eccentricity\ Ratio\ \left(\frac{e}{r}\right) = \left(\frac{A}{B}\right)$$

(B) Annular section with single opening: (Sample Calculation At EL (+) 17.1 m)

$$\begin{aligned}
\text{Axial load} &= 45981.75\ kN \\
\text{Governing moment} &= 196222.06\ kN \cdot m \\
\text{Thickness of the shell} &= 0.473\ m \\
\text{Internal diameter of the shell} &= 12.081\ m \\
\text{Mean radius } r &= \left(\frac{12.081 + 0.473}{2}\right) = 6.277\ m \\
\text{Total steel ratio } p &= 0.0045 \\
\text{Eccentricity } e &= \left(\frac{M}{W}\right) = \left(\frac{196222.06}{4581.75}\right) = 4.2673 \\
\left(\frac{e}{r}\right) &= \left(\frac{4.2673}{6.277}\right) = 0.6798
\end{aligned}$$

$$A = \frac{1}{2} \cdot [(1-p) \cdot (\alpha - sin\alpha \cdot cos\alpha) - (1-p+mp) \cdot (\beta + sin\beta \cdot cos\beta - 2 \cdot cos\alpha \cdot sin\beta) + (mp) \cdot \pi]$$

$$A = 1.101$$

$$B = (1-p) \cdot (sin\alpha - \alpha \cdot cos\alpha) - (1-p+mp) \cdot (sin\beta - \beta cos\alpha) - (m \cdot p \cdot \pi \cdot cos\alpha)$$

$$B = 1.641$$

$$\left(\frac{A}{B}\right) = \left(\frac{1.101}{1.641}\right) = 0.6709$$

$$\sigma'_{cv} = \left[\frac{W \cdot (cos\beta - cos\alpha)}{2 \cdot r \cdot t \cdot \beta}\right]$$

$$\sigma'_{cv} = 6.66\ N/mm^2$$

$$\sigma_{cv} = \sigma'_{cv} \cdot \left[1 + \frac{t}{2 \cdot r \cdot cos\beta \cdot (cos\beta - cos\alpha)}\right]$$

$$\sigma_{cv} = 6.84\ N/mm^2$$

Allowable $\sigma_{cv} N/mm^2$ as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (a)

Allowable $\sigma_{cv} = 0.38 \times \sigma_{cu} = 0.38 \times 35 = 14.3\ N/mm^2 > 6.84\ N/mm^2$.... Hence Safe.

$$\sigma_{sv} = m \cdot \sigma'_{cv} \cdot \left[\frac{1 + cos\alpha}{(cos\beta - cos\alpha)}\right]$$

$$\sigma_{sv} = 38.110\ N/mm^2$$

Allowable $\sigma_{sv}\ N/mm^2$as per Is : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (a)

Allowable $\sigma_{sv} = 0.57 \times f_y = 0.57 \times 500 = 285\ N/mm^2 > 38.110\ N/mm^2$.... Hence Safe.

(C) Annular section with two diametrically opposite equal openings: (Sample calculation at EL (+) 21.6 m)

$$\begin{aligned}
\text{Axial load} &= 41730.16\ kN \\
\text{Governing moment} &= 185973.82\ kN \cdot m \\
\text{Thickness of the shell} &= 0.467\ m \\
\text{Internal diameter of the shell} &= 11.865\ m \\
\text{Mean radius } r &= \left(\frac{11.865 + 0.467}{2}\right) = 6.166\ m \\
\text{Total steel ratio } p &= 0.0050 \\
\text{Eccentricity } e &= \left(\frac{M}{W}\right) = \left(\frac{185973.82}{41730.16}\right) = 4.4565 \\
\left(\frac{e}{r}\right) &= \left(\frac{4.4565}{6.166}\right) = 0.723
\end{aligned}$$

$$A = \frac{1}{2}\left[(1-p) \cdot (\alpha - \beta - sin\alpha \cdot cos\alpha - sin\beta \cdot cos\beta + 2 \cdot cos\alpha \cdot sin\beta) + mp \cdot (\pi - 2\beta - sin2\beta)\right]$$

$$A \quad = 0.407$$

$$B = (1-p)\cdot(sin\alpha - \alpha cos\alpha - sin\beta + \beta cos\alpha) - (\pi - 2\beta)\cdot mp\cdot cos\alpha$$

$$B \quad = 0.564$$

$$\left(\frac{A}{B}\right) \quad = \left(\frac{0.407}{0.564}\right) = 0.7216$$

$$\sigma_{cv}^{'} = \left[\frac{W\cdot(cos\beta - cos\alpha)}{2\cdot r\cdot t\cdot\beta}\right]$$

$$\sigma_{cv}^{'} \quad = 12.68\ N/mm^2$$

$$\sigma_{cv} = \sigma_{cv}^{'}\cdot\left[1 + \frac{t}{2\cdot r\cdot cos\beta\cdot(cos\beta - cos\alpha)}\right]$$

$$\sigma_{cv} \quad = 13.23\ N/mm^2$$

Allowable $\sigma_{cv} N/mm^2$ as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (a)

Allowable $\sigma_{cv} = 0.38\times\sigma_{cu} = 0.38\times35 = 14.3\ N/mm^2 > 13.23\ N/mm^2$.... Hence Safe.

$$\sigma_{sv} = m\cdot\sigma_{cv}^{'}\cdot\left[\frac{(cos\beta + cos\alpha)}{(cos\beta - cos\alpha)}\right]$$

$$\sigma_{sv} \quad = 78.990\ N/mm^2$$

Allowable $\sigma_{sv}\ N/mm^2$as per Is : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (a)

Allowable $\sigma_{sv} = 0.57\times f_y = 0.57\times500 = 285\ N/mm^2 > 78.990\ N/mm^2$.... Hence Safe.

Table 5.4: Stresses In RCC Shell Due To DL + WL (Shell Alone Condition - Contd.)

Elevation (m)	e/r	e/r (req)	Nature Of Stress	Area (m^2)	p	Area of steel req. (mm^2)	. ($radian$)	. ($degrees$)	A	B	A/B
175	0.00	0.5	Compressive	3.731	0.0065	2.425	0	0	—-	—-	—-
170	0.45	0.5	Compressive	4.036	0.006	2.421	0	0	—-	—-	—-
160	1.06	0.5	Tensile	4.678	0.005	2.339	1.24	71	0.527	0.498	1.057
150	1.39	0.5	Tensile	5.365	0.0045	2.414	1.00	57	0.328	0.237	1.382
140	1.52	0.5	Tensile	6.095	0.008	4.876	1.10	63	0.445	0.294	1.513
130	1.51	0.5	Tensile	6.869	0.007	4.809	1.07	61	0.408	0.270	1.507
120	1.41	0.5	Tensile	7.688	0.0065	4.997	1.08	62	0.414	0.294	1.406
110	1.25	0.5	Tensile	8.550	0.0055	4.702	1.11	64	0.424	0.338	1.254
100	1.08	0.5	Tensile	9.455	0.005	4.728	1.22	70	0.510	0.473	1.077
90	0.90	0.5	Tensile	10.405	0.0065	6.763	1.52	87	0.812	0.907	0.895
80	0.75	0.5	Tensile	11.398	0.006	6.839	1.85	106	1.127	1.504	0.749
70	0.65	0.5	Tensile	12.436	0.0055	6.840	2.20	126	1.400	2.174	0.644
60	0.63	0.5	Tensile	13.517	0.005	6.758	2.25	129	1.426	2.260	0.630
50	0.62	0.5	Tensile	14.642	0.0045	6.589	2.34	134	1.470	2.415	0.608
40	0.60	0.5	Tensile	15.811	0.0045	7.115	2.42	139	1.508	2.552	0.591
30	0.60	0.5	Tensile	17.024	0.005	8.512	3.65	209	1.668	2.799	0.595
21.6	0.62	0.35	Tensile	18.076	0.005	9.038	1.85	106	0.490	0.774	0.632
17.1	0.64	0.44	Tensile	18.653	0.0045	8.394	2.10	120	1.171	1.824	0.642
10	0.65	0.5	Tensile	19.581	0.0045	8.811	2.20	126	1.389	2.161	0.642
2.2	0.66	0.5	Tensile	20.625	0.0045	9.281	2.17	124	1.365	2.095	0.651
0	0.66	0.44	Tensile	20.925	0.0045	9.416	2.04	117	1.139	1.723	0.660
-2.05	0.66	0.5	Tensile	21.206	0.0045	9.543	2.13	122	1.341	2.029	0.660

Table 5.5: Stresses In RCC Shell Due To DL + WL (Shell Alone Condition - Contd.)

Elevation (m)	STRESSES						
	σ'_{cv} (N/mm^2)	$\sigma_{cv}(N/mm^2)$	Allowable σ_{cv}	Check	σ_{sv} (N/mm^2)	Allowable σ_{sv}	Check
175	0	0	14.3	Safe	0	285	Safe
170	0	0.23	14.3	Safe	0	285	Safe
160	1.41	1.52	14.3	Safe	16.755	285	Safe
150	3.17	3.49	14.3	Safe	55.424	285	Safe
140	4.04	4.39	14.3	Safe	60.079	285	Safe
130	5.08	5.52	14.3	Safe	79.287	285	Safe
120	5.57	6.03	14.3	Safe	84.157	285	Safe
110	5.78	6.22	14.3	Safe	83.172	285	Safe
100	5.45	5.79	14.3	Safe	66.437	285	Safe
90	4.57	4.77	14.3	Safe	39.056	285	Safe
80	4.02	4.14	14.3	Safe	25.548	285	Safe
70	3.72	3.82	14.3	Safe	19.012	285	Safe
60	3.85	3.95	14.3	Safe	18.773	285	Safe
50	4.06	4.15	14.3	Safe	19.411	285	Safe
40	4.19	4.28	14.3	Safe	19.415	285	Safe
30	4.30	4.39	14.3	Safe	18.636	285	Safe
21.6	9.97	10.34	14.3	Safe	51.734	285	Safe
17.1	5.62	5.76	14.3	Safe	30.272	285	Safe
10	5.51	5.64	14.3	Safe	28.141	285	Safe
2.2	5.75	5.89	14.3	Safe	29.911	285	Safe
0	6.50	6.67	14.3	Safe	36.287	285	Safe
-2.05	6.35	6.51	14.3	Safe	33.691	285	Safe

Table 5.6 to Table 5.8 house the stresses induced in the RC shell due to DL + WL in case of Chimney Complete Condition.

Table 5.6: Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition)

Elevation (m)	Axial Load (kN)	Governing Moment ($kN \cdot m$)	Eccentricity e = M/W	Radius r (m)	Section Property	ϕ ($radian$)	β ($radian$)
175	120.70	0.00	0.000	2.38	Annular	0	0.00
170	660.70	747.42	1.131	2.50	Annular	0	0.00
160	1765.00	5141.66	2.913	2.75	Annular	0	0.00
150	3035.50	12396.52	4.084	2.99	Annular	0	0.00
140	4571.10	21440.97	4.691	3.24	Annular	0	0.00
130	6206.80	31125.09	5.015	3.49	Annular	0	0.00
120	8041.50	40275.32	5.008	3.73	Annular	0	0.00
110	10086.20	47916.42	4.751	3.98	Annular	0	0.00
100	12481.65	53427.60	4.280	4.23	Annular	0	0.00
90	15000.75	59748.26	3.983	4.48	Annular	0	0.00
80	17762.75	74266.82	4.181	4.72	Annular	0	0.00
70	20778.65	90229.46	4.342	4.97	Annular	0	0.00
60	24209.35	107584.31	4.444	5.22	Annular	0	0.00
50	27765.85	126276.70	4.548	5.46	Annular	0	0.00
40	31984.35	146238.86	4.572	5.71	Annular	0	0.00
30	36844.25	167379.83	4.543	5.96	Annular	0	0.00
21.6	41730.16	185973.82	4.457	6.17	2 open.	0	0.50
17.1	45981.75	196222.66	4.267	6.28	1 open.	0	0.10
10	49374.65	212751.56	4.309	6.45	Annular	0	0.00
2.2	53294.35	231338.89	4.341	6.64	Annular	0	0.00
0	54437.05	236657.46	4.347	6.70	1 open.	0	0.09
-2.05	55516.65	241637.48	4.353	6.75	Annular	0	0.00

Table 5.7: Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition - Contd.)

Elevation (m)	e/r	e/r (req)	Nature Of Stress	Area (m^2)	p	Area of steel req. (mm^2)	. ($radian$)	. ($degrees$)	A	B	A/B
175	0.00	0.5	Compressive	3.731	0.0065	2.425	0	0	—	—	—
170	0.45	0.5	Compressive	4.036	0.006	2.421	0	0	—	—	—
160	1.06	0.5	Tensile	4.678	0.005	2.339	1.24	71	0.527	0.498	1.057
150	1.36	0.5	Tensile	5.365	0.0045	2.414	1.01	58	0.335	0.247	1.358
140	1.45	0.5	Tensile	6.095	0.008	4.876	1.12	64	0.462	0.319	1.447
130	1.44	0.5	Tensile	6.869	0.007	4.809	1.09	62	0.426	0.297	1.435
120	1.34	0.5	Tensile	7.688	0.0065	4.997	1.11	64	0.436	0.325	1.339
110	1.19	0.5	Tensile	8.550	0.0055	4.702	1.15	66	0.456	0.383	1.191
100	1.01	0.5	Tensile	9.455	0.005	4.728	1.30	74	0.582	0.578	1.006
90	0.89	0.5	Tensile	10.405	0.0065	6.763	1.53	88	0.822	0.923	0.890
80	0.89	0.5	Tensile	11.398	0.006	6.839	1.53	88	0.816	0.924	0.882
70	0.87	0.5	Tensile	12.436	0.0055	6.840	1.54	88	0.820	0.942	0.870
60	0.85	0.5	Tensile	13.517	0.005	6.758	1.57	90	0.844	0.993	0.849
50	0.83	0.5	Tensile	14.642	0.0045	6.589	1.61	92	0.878	1.062	0.826
40	0.80	0.5	Tensile	15.811	0.0045	7.115	1.70	97	0.967	1.220	0.792
30	0.76	0.5	Tensile	17.024	0.005	8.512	1.80	103	1.069	1.404	0.761
21.6	0.72	0.35	Tensile	18.076	0.005	9.038	1.68	96	0.407	0.564	0.720
17.1	0.68	0.44	Tensile	18.653	0.0045	8.394	2.00	115	1.101	1.641	0.671
10	0.67	0.5	Tensile	19.581	0.0045	8.811	2.13	122	1.341	2.029	0.660
2.2	0.65	0.5	Tensile	20.625	0.0045	9.281	2.19	125	1.382	2.142	0.645
0	0.65	0.44	Tensile	20.925	0.0045	9.416	2.11	121	1.187	1.851	0.641
-2.05	0.64	0.5	Tensile	21.206	0.0045	9.543	2.20	126	1.389	2.161	0.642

Table 5.8: Stresses In RCC Shell Due To DL + WL (Chimney Complete Condition - Contd.)

Elevation (m)	STRESSES						
	$\sigma_{cv}^{'}$ (N/mm^2)	σ_{cv}(N/mm^2)	Allowable σ_{cv}	Check	σ_{sv} (N/mm^2)	Allowable σ_{sv}	Check
175	0	0.03	14.3	Safe	0	285	Safe
170	0	0.31	14.3	Safe	0	285	Safe
160	1.60	1.72	14.3	Safe	19.281	285	Safe
150	4.37	3.71	14.3	Safe	58.352	285	Safe
140	4.16	4.50	14.3	Safe	59.760	285	Safe
130	5.13	5.56	14.3	Safe	77.490	285	Safe
120	5.60	6.04	14.3	Safe	81.858	285	Safe
110	5.72	6.13	14.3	Safe	78.479	285	Safe
100	5.25	5.55	14.3	Safe	58.168	285	Safe
90	4.70	4.90	13.3	Safe	39.786	285	Safe
80	5.08	5.29	13.3	Safe	42.959	285	Safe
70	5.40	5.62	13.3	Safe	45.199	285	Safe
60	5.66	5.88	13.3	Safe	45.958	285	Safe
50	5.83	6.05	13.3	Safe	45.526	285	Safe
40	5.88	6.08	13.3	Safe	42.275	285	Safe
30	5.94	6.12	13.3	Safe	39.280	285	Safe
21.6	12.68	13.23	13.3	Safe	78.990	285	Safe
17.1	6.66	6.84	13.3	Safe	38.110	285	Safe
10	6.34	6.50	13.3	Safe	33.645	285	Safe
2.2	6.34	6.49	13.3	Safe	32.554	285	Safe
0	7.00	7.18	13.3	Safe	37.499	285	Safe
-2.05	6.86	7.02	13.3	Safe	35.047	285	Safe

5.4 Calculation of temperature drop in RCC shell

Temperature drop T_x across the shell for the lined chimneys with unventilated air space between the lining and shell is calculated as per IS : 4998 (Part - 1) 1975 Pg. 29 Clause D - 2.2.3 (c) - Annexe D:

$$T_x = \frac{t \cdot D_{bi}}{C_c \cdot D_c} \times \left[\frac{T - T_o}{\frac{1}{K_1} + \frac{t_b \cdot D_{bi}}{C_b \cdot D_b} + \frac{D_{bi}}{K_r \cdot D_s} + \frac{t \cdot D_{bi}}{C_c \cdot D_c} + \frac{D_{bi}}{K_2 \cdot D_{co}}} \right]$$

SAMPLE CALCULATION AT EL (+) 30.0 m IS DETAILED AS FOLLOWS

Internal diameter of the shell, D_{ci}	$= 11.46\ m$
Thickness of the concrete shell, t	$= 0.455\ m$
Thickness of the air space, t_s	$= 0\ m$
Thickness of lining, t_b	$= 0.075\ m$
Co-eff. of thermal conductivity of concrete, C_c	$= 1.488\ KCal/m/hr/^0C$
Coeff. of thermal conductivity of lining, C_b	$= 1.25\ KCal/m/hr/^0C$
Internal diameter of the lining, D_{bi}	$= 11.31\ m$
Mean diameter of the concrete shell, D_c	$= 11.46 + 0.455 = 11.9147m$

CALCULATION OF GAS FLUE FILM COEFFICIENT $K_1 = K_{1c} + K_{1r}$

Temperature of flue gas	$= 45\ ^0C$
K_{1r}	$= 0$
Exit velocity of flue gas through line	$= 100\ km/hr$
K_{1c}	$= 50\ KCal/m/hr/^0C$
K_1	$= 50\ KCal/m/hr/^0C$
Max. temp. of flue gas, T	$= 45.00^0C$
Min. ambient temp. T_o	$= 15.00^0C$
$K_r = 0.0732T + 1.3$	$= 4.594$
K_2	$= 58.59$

$$\frac{t \cdot D_{bi}}{C_c \cdot D_c} = \left[\frac{0.455 \times 11.31}{1.488 \times 11.916}\right] = 0.290$$

$$\frac{1}{K_1} = 0.020$$

$$\frac{t_b \cdot D_{bi}}{C_b \cdot D_b} = \left(\frac{0.075 \times 11.31}{1.25 \times 11.386}\right) = 0.06$$

$$\frac{D_{bi}}{K_r \cdot D_s} = \left(\frac{11.311}{4.594 \times 11.461}\right) = 0.215$$

$$\frac{D_{bi}}{K_2 \cdot D_{co}} = \left(\frac{11.31}{58.59 \times 12.371}\right) = 0.016$$

$$\text{Hence, } T_x = 0.290 \times \left[\frac{30}{0.020 + 0.06 + 0.215 + 0.290 + 0.016}\right] = 14.5\ ^0C$$

SAMPLE CALCULATION AT EL (+) 60.0 m IS AS DETAILED

Temperature drop T_x across the shell for unlined chimneys is calculated as per IS : 4998 (Part - 1) 1975 Pg. 29 Clause D - 2.2.3 (c) - Annexe D:

$$T_x = \frac{t \cdot D_{ci}}{C_c \cdot D_c} \times \left[\frac{T - T_o}{\frac{1}{K_1} + \frac{t \cdot D_{ci}}{C_c \cdot D_c} + \frac{D_{ci}}{K_2 \cdot D_{co}}}\right]$$

Thickness of concrete shell, t = 0.412 m

Inside diameter of the concrete shell, D_{ci} = 10.02 m

Outside diameter of the concrete shell, D_{co} = 10.85 m

Mean diameter of the concrete shell, D_c = 10.43 m

$C_c$as per IS 4998 (Part - 1) 1975 Pg. 30 (Notes) = 1.488 $KCal/m/hr/^0C$

Velocity of gas through the liner =100 km/hr

K_2 = Coefficient of heat transmission from outside surface of the chimney to the surrounding area as per IS 4998 (Part - 1) 1975 Pg. 30 (Notes) = 58.6 $KCal/m/hr/^0C$

K_1=Coefficient of heat transmission from gas to inner surface of the the chimney shell (As per IS : 4998 (Part - 1) 1975 Pg. 31 Fig. 3 = 50 $KCal/m^2/hr/^0C$

Hence, T_x= 26.45 ^0C

Table 5.9 and Table 5.10 house the details temperature drop at various levels across the height of the chimney. A sharp decrement in the values of temperature drop can be observed along the height of the chimney where lining is present, the values being uniform in that particular height range.

Table 5.9: Temperature Drop Across The Shell

Levels (m)	Int. diameter of shell D_{ci} (m)	Ext. diameter of shell D_{co} (m)	Avg. diameter of shell D_c (m)	Avg. Lining thickness t_b (m)	Internal diameter of lining D_{bi} (m)	Mean diameter of lining D_b (m)	Mean diameter of space between lining and shell D_s (m)	$\frac{t \cdot D_{bi}}{C_c \cdot D_c}$	$\frac{t_b \cdot D_{bi}}{C_b \cdot D_b}$	$\frac{D_{bi}}{K_r \cdot D_s}$	$\frac{D_{bi}}{K_2 \cdot D_{co}}$
175	4.500	5.000	4.750	-	-	-	-	-	-	-	-
170	4.740	5.254	4.997	-	-	-	-	-	-	-	-
160	5.220	5.762	5.491	-	-	-	-	-	-	-	-
150	5.700	6.271	5.986	-	-	-	-	-	-	-	-
140	6.180	6.779	6.480	-	-	-	-	-	-	-	-
130	6.660	7.287	6.974	-	-	-	-	-	-	-	-
120	7.140	7.796	7.468	-	-	-	-	-	-	-	-
110	7.621	8.304	7.962	-	-	-	-	-	-	-	-
100	8.101	8.812	8.457	-	-	-	-	-	-	-	-
90	8.581	9.321	8.951	-	-	-	-	-	-	-	-
80	9.061	9.829	9.445	-	-	-	-	-	-	-	-
70	9.541	10.337	9.939	-	-	-	-	-	-	-	-
60	10.021	10.846	10.433	-	-	-	-	-	-	-	-
50	10.501	11.354	10.928	-	-	-	-	-	-	-	-
40	10.981	11.862	11.422	0.075	10.831	10.906	10.981	0.2808	0.0595	0.2161	0.0155
30	11.461	12.371	11.916	0.075	11.311	11.386	11.461	0.2900	0.0596	0.2162	0.0156
21.6	11.865	12.798	12.331	0.075	11.715	11.790	11.865	0.2978	0.0596	0.2162	0.0156
17.1	12.081	13.027	12.554	0.075	11.931	12.006	12.081	0.3020	0.0596	0.2163	0.0156
10	12.421	13.387	12.904	-	-	-	-	-	-	-	-
2.2	12.796	13.784	13.290	-	-	-	-	-	-	-	-
0	12.902	13.896	13.399	-	-	-	-	-	-	-	-
-2.05	13.000	14.000	13.500	-	-	-	-	-	-	-	-

Table 5.10: Temperature Drop Across The Shell Contd.

Levels (m)	Shell thickness t (m)	$\frac{t \cdot D_{ci}}{C_c \cdot D_c}$	$\frac{t \cdot D_{ci}}{C_c \cdot D_c}$	T_x	Z	p	K	$\sigma_c \cdot T_v$	Permissible Stresses	$\sigma_s \cdot T_v$	Permissible Stresses	Check
175	0.250	0.159	0.015	24.55	0.80	0.003	0.16	1.29	11.55	36.232	275	Safe
170	0.257	0.164	0.015	24.67	0.81	0.003	0.16	1.30	11.55	36.693	275	Safe
160	0.271	0.173	0.015	24.90	0.82	0.003	0.16	1.32	11.55	37.556	275	Safe
150	0.285	0.183	0.016	25.12	0.82	0.003	0.16	1.34	11.55	38.347	275	Safe
140	0.299	0.192	0.016	25.31	0.83	0.003	0.16	1.36	11.55	39.075	275	Safe
130	0.314	0.201	0.016	25.49	0.84	0.003	0.17	1.37	11.55	39.748	275	Safe
120	0.328	0.211	0.016	25.66	0.85	0.003	0.17	1.39	11.55	40.371	275	Safe
110	0.342	0.220	0.016	25.81	0.85	0.003	0.17	1.40	11.55	40.950	275	Safe
100	0.356	0.229	0.016	25.96	0.86	0.003	0.17	1.42	11.55	41.489	275	Safe
90	0.370	0.238	0.016	26.09	0.86	0.003	0.17	1.43	11.55	41.992	275	Safe
80	0.384	0.248	0.016	26.22	0.87	0.003	0.17	1.44	11.55	42.464	275	Safe
70	0.398	0.257	0.016	26.34	0.87	0.003	0.17	1.45	11.55	42.905	275	Safe
60	0.412	0.266	0.016	26.45	0.88	0.003	0.17	1.46	11.55	43.321	275	Safe
50	0.427	0.275	0.016	26.55	0.88	0.003	0.17	1.47	11.55	43.711	275	Safe
40	0.441		-	14.23	0.89	0.003	0.17	0.79	11.55	23.531	275	Safe
30	0.455	-	-	14.47	0.89	0.003	0.17	0.80	11.55	24.036	275	Safe
21.6	0.467	-	-	14.66	0.89	0.003	0.17	0.82	11.55	24.447	275	Safe
17.1	0.473	-	-	14.77	0.89	0.003	0.17	0.82	11.55	24.664	275	Safe
10	0.483	0.312	0.016	26.91	0.90	0.003	0.17	1.50	11.55	45.070	275	Safe
2.2	0.494	0.320	0.016	26.98	0.90	0.003	0.17	1.51	11.55	45.303	275	Safe
0	0.497	0.322	0.016	26.99	0.90	0.003	0.17	1.51	11.55	45.366	275	Safe
-2.05	0.500	0.324	0.016	27.01	0.90	0.003	0.17	1.51	11.55	45.425	275	Safe

5.5 Check for stresses in shell under DL + Temperature condition

SAMPLE CALCULATION AT EL (+) 30 m (Chimney Complete Condition)

Internal diameter of the shell	$= 11.460\ m$
Thickness of the shell	$= 0.455\ m$
Vertical compressive stress in concrete at mean diameter due to DL alone $\sigma_{cv}^{'}$	$= 2.164\ N/mm^2$
Temperature drop in the shell T_x	$= 14.52039\ ^0C$
Outside vertical steel ratio p	$= \frac{0.0025}{2} = 0.00125$
Inside vertical steel ratio C_p	$= \frac{0.0025}{2} = 0.00125$
$C = \frac{C_p}{p}$	$= 1$
Clear cover	$= 50\ mm$
Diameter of main reinforcement	$= 16\ mm$
Diameter of circumferential reinforcement	$= 12\ mm$
$Z = \frac{455 - (50 + 12 + 0.5 \times 16)}{455}$	$= 0.8461$
Modular ratio	$= 8.12$
Coefficient of linear thermal expansion of concrete and steel L:	$0.000011\ ^0C$

$$K = -mp\cdot(C+1)+\sqrt{[mp\cdot(C+1)]^2+2\cdot mp\cdot[Z+C\cdot(1-Z)]} = 0.1236$$

Vertical compressive stress in concrete due to temperature alone $\sigma_{cv}^{'} = L\cdot K\cdot T_x\cdot E_c$ $= 0.51\ N/mm^2$

For dead load alone compressive stress in concrete is $\sigma_{cw}^{'} = \dfrac{P}{A}$ (as M = 0.0 $kN\cdot m$) $= \dfrac{36843.20}{16.2012}$ =2.164 N/mm^2

$$K_c = -mp\cdot(C+1)+\sqrt{[mp\cdot(C+1)]^2+2\cdot mp\cdot(Z+C\cdot(1-Z)+2\cdot K\cdot(1+mp\cdot(C+1))\cdot\frac{\sigma_{cv}^{'}}{\sigma_c\cdot T_v}} = 1.0240$$

If $K_c > 1$, $\sigma_{cwc} = \sigma_{cw}^{'} + \left(\dfrac{\sigma_{cv}^{'}}{2K}\right)$ and If $K_c < 1$ then $\sigma_{cwc} = \left(\dfrac{K_c}{K}\right)\cdot\sigma_{cv}^{'}$ Here $K_c > 1$ hence, $=\sigma_{cwc} = 4.2297\ N/mm^2$

Allowable compressive stress in concrete due to DL + temperature as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1 (c) $= 0.33\times 35 = 11.55\ N/mm^2$

Vertical tensile stress in steel due to temperature $\sigma_{sv} = L\cdot(Z-K)\cdot T_x\cdot E_s$ $= 24.23\ N/mm^2$

Allowable tensile stresses in steel as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (c) $= 0.55\times 500 = 275\ N/mm^2$

$$K_c^{'} = -mp\cdot(C+1)+\sqrt{[mp\cdot(C+1)]^2+2\cdot mp\cdot[Z+C\cdot(1-Z)]+2\cdot mp\cdot(Z-K)\cdot(C+1)\cdot\left(\frac{\sigma_{sw}}{\sigma_{sv}}\right)},$$

For dead load alone $\sigma_{sw} = 0\ N/mm^2$ $= K_c^{'} = 0.1236$

$$\sigma_{swc} = \sigma_{sv}\times\left(\frac{Z-K_c^{'}}{Z-K}\right) = 24.2325\ N/mm^2$$

The compressive stresses in concrete as well the tensile stress in concrete are fairly within permissible limits hence the provided shell thickness is sufficient.

Table 4.11 and Table 4.12 house the details of stresses induced in the concrete and steel due to combination of DL and Temperature loading.

Table 5.11: Stresses Due To DL + Temp

Levels(m)	Internal Diameter Of Shell (m)	Shell Thickness(m)	T_x	Z	K	$\sigma_c T_v$ (N/mm^2)	$\sigma_{cv}^{'}$ (N/mm^2)	K_c	σ_{cwc} (N/mm^2)	Allowable stresses in concrete (N/mm^2)	Check
175	4.500	0.250	24.55	0.72	0.076	0.533	0.032	0.153	1.071	11.55	Safe
170	4.740	0.257	24.67	0.72	0.098	0.690	0.164	0.241	1.692	11.55	Safe
160	5.220	0.271	24.90	0.74	0.101	0.717	0.377	0.339	2.405	11.55	Safe
150	5.700	0.285	25.12	0.75	0.103	0.741	0.566	0.407	2.906	11.55	Safe
140	6.180	0.299	25.31	0.76	0.105	0.763	0.750	0.463	3.332	11.55	Safe
130	6.660	0.314	25.49	0.77	0.107	0.783	0.904	0.504	3.656	11.55	Safe
120	7.140	0.328	25.66	0.78	0.109	0.801	1.046	0.539	3.937	11.55	Safe
110	7.621	0.342	25.81	0.79	0.111	0.818	1.180	0.570	4.187	11.55	Safe
100	8.101	0.356	25.96	0.80	0.112	0.833	1.320	0.600	4.436	11.55	Safe
90	8.581	0.370	26.09	0.81	0.114	0.848	1.442	0.625	4.644	11.55	Safe
80	9.061	0.384	26.22	0.81	0.115	0.861	1.558	0.648	4.837	11.55	Safe
70	9.541	0.398	26.34	0.82	0.116	0.873	1.671	0.669	5.017	11.55	Safe
60	10.021	0.412	26.45	0.83	0.117	0.885	1.791	0.691	5.203	11.55	Safe
50	10.501	0.427	26.55	0.83	0.118	0.895	1.896	0.710	5.363	11.55	Safe
40	10.981	0.441	14.23	0.84	0.119	0.483	2.023	1.000	4.047	11.55	Safe
30	11.461	0.455	14.47	0.84	0.120	0.495	2.164	1.025	4.223	11.55	Safe
21.6	11.865	0.467	14.66	0.84	0.120	0.505	3.024	1.204	5.111	11.55	Safe
17.1	12.081	0.473	14.77	0.85	0.121	0.510	3.193	1.233	5.295	11.55	Safe
10	12.421	0.483	26.91	0.85	0.121	0.933	2.522	0.812	6.219	11.55	Safe
2.2	12.796	0.494	26.98	0.85	0.122	0.939	2.726	0.843	6.472	11.55	Safe
0	12.902	0.497	26.99	0.85	0.122	0.941	2.818	0.857	6.582	11.55	Safe
-2.05	13.000	0.500	27.01	0.86	0.122	0.942	2.618	0.826	6.347	11.55	Safe

Table 5.12: Stresses Due To DL + Temp (Contd.)

Levels (m)	σ_{sw} (N/mm^2)	$\sigma_s T_v$ (N/mm2)	$K_c^{'}$	σ_{swc} (N/mm^2)	Allowable stresses in steel (N/mm^2)	Check
175	0	36.497	0.123590419	33.818	275	Safe
170	0	35.872	0.123590419	34.427	275	Safe
160	0	36.859	0.123590419	35.567	275	Safe
150	0	37.768	0.123590419	36.611	275	Safe
140	0	38.607	0.123590419	37.572	275	Safe
130	0	39.384	0.123590419	38.460	275	Safe
120	0	40.106	0.123590419	39.282	275	Safe
110	0	40.778	0.123590419	40.045	275	Safe
100	0	41.404	0.123590419	40.756	275	Safe
90	0	41.991	0.123590419	41.420	275	Safe
80	0	42.540	0.123590419	42.041	275	Safe
70	0	43.056	0.123590419	42.623	275	Safe
60	0	43.541	0.123590419	43.171	275	Safe
50	0	43.998	0.123590419	43.686	275	Safe
40	0	23.718	0.123590419	23.580	275	Safe
30	0	24.257	0.123590419	24.145	275	Safe
21.6	0	24.698	0.123590419	24.606	275	Safe
17.1	0	24.929	0.123590419	24.848	275	Safe
10	0	45.591	0.123590419	45.475	275	Safe
2.2	0	45.863	0.123590419	45.782	275	Safe
0	0	45.938	0.123590419	45.866	275	Safe
-2.05	0	46.008	0.123590419	45.943	275	Safe

5.6 Check for stresses in shell under DL + WL + Temperature combination

SAMPLE CALCULATION AT EL (+) 30.0 m IS DETAILED BELOW (Chimney Completed Condition)

Internal diameter of the shell	= 11.461 m
Vertical compressive stress in concrete due to DL + WL, σ'_{cw}	= 5.953 N/mm^2
Temperature drop across the shell T_x	= 14.52039 ^0C
Modular ratio m	= 8.12
C	= 1

$$K_c = -mp \cdot (C+1) + \sqrt{[mp \cdot (C+1)]^2 + 2 \cdot mp \cdot [Z + C \cdot (1+Z)] + 2 \cdot K \cdot \left[1 + mp \cdot (C+1) \cdot \left(\frac{\sigma'_{cw}}{\sigma'_{cv}}\right)\right]} = 1.7006$$

$$\sigma_{cwc} = \left(\frac{\sigma'_{cv}}{K}\right) \times \sigma_c T_v = 8.019\ N/mm^2$$

Allowable stress in concrete as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (e)	$= 0.50 \times 35 = 17.5\ N/mm^2$
Tensile stress in steel due to DL + WL, σ_{sw}	= 30.704 N/mm^2
Vertical stresses in steel due to temperature alone $\sigma_{stv} = L \times (Z-K) \times T_x \times E_s$	= 24.23 N/mm^2
$\sigma_{swc} = \sigma_{stv} \times \left(\frac{Z - K'_c}{Z-K}\right)$	= 42.312 N/mm^2
Allowable tensile stresses in steel as per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (d)	$= 0.65 \times 500 = 325\ N/mm^2$...

Table 4.13 houses details of the stresses induced in the concrete and steel due to combination of DL + WL and Temperature...

Table 5.13: Stresses In RCC Shell Under DL + WL + Temperature

Levels (m)	Shell thickness t (m)	Z	K	$\sigma_{cv}(N/mm^2)$	K_c	σ_{cwc} (N/mm^2)	Allowable σ_{cwc} (N/mm^2)	Check	σ_{swc} (N/mm^2)	Allowable σ_{swc} (N/mm^2)	Check
175	0.250	0.80	0.16	0.032	0.000	0.000	17.5	Safe	31.610	325	Safe
170	0.257	0.81	0.16	0.312	0.000	0.000	17.5	Safe	32.478	325	Safe
160	0.271	0.82	0.16	1.721	0.551	4.463	17.5	Safe	34.270	325	Safe
150	0.285	0.82	0.16	3.709	0.545	4.456	17.5	Safe	35.571	325	Safe
140	0.299	0.83	0.16	4.495	0.552	4.544	17.5	Safe	32.899	325	Safe
130	0.314	0.84	0.17	5.561	0.553	4.584	17.5	Safe	34.337	325	Safe
120	0.328	0.85	0.17	6.044	0.555	4.635	17.5	Safe	35.356	325	Safe
110	0.342	0.85	0.17	6.135	0.558	4.686	17.5	Safe	36.891	325	Safe
100	0.356	0.86	0.17	5.552	0.563	4.755	17.5	Safe	37.947	325	Safe
90	0.370	0.86	0.17	4.905	0.568	4.820	17.5	Safe	36.824	325	Safe
80	0.384	0.87	0.17	5.293	0.569	4.853	17.5	Safe	37.756	325	Safe
70	0.398	0.87	0.17	5.621	0.570	4.885	17.5	Safe	38.700	325	Safe
60	0.412	0.88	0.17	5.882	0.571	4.916	17.5	Safe	39.661	325	Safe
50	0.427	0.88	0.17	6.048	0.573	4.946	17.5	Safe	40.647	325	Safe
40	0.441	0.89	0.17	6.081	0.574	2.658	17.5	Safe	21.885	325	Safe
30	0.455	0.89	0.17	6.124	0.576	2.710	17.5	Safe	22.017	325	Safe
21.6	0.467	0.89	0.17	13.231	0.573	2.733	17.5	Safe	22.397	325	Safe
17.1	0.473	0.89	0.17	6.837	0.578	2.775	17.5	Safe	22.946	325	Safe
10	0.483	0.90	0.17	6.500	0.579	5.067	17.5	Safe	41.934	325	Safe
2.2	0.494	0.90	0.17	6.488	0.579	5.085	17.5	Safe	42.154	325	Safe
0	0.497	0.90	0.17	7.175	0.579	5.086	17.5	Safe	42.155	325	Safe
-2.05	0.500	0.90	0.17	7.020	0.580	5.094	17.5	Safe	42.215	325	Safe

5.7 Circumferential Stresses

5.7.1 Circumferential stresses in concrete due to temperature alone

As per IS : 4998 (Part - 1) 1975 Pg. 32 Clause. D - 2.2.5 Maximum circumferential stress in concrete due to temperature alone is given by, $\sigma_c T_c = L \cdot K' \cdot T_x \cdot E_c$

L =Co-eff. of linear thermal expansion of concrete & steel $/^0C = 0.000011\ /^0C$ and $K' = -p'{\cdot}m + \sqrt{p' \cdot m \times (p' \cdot m + 2 \cdot Z}$

p' = ratio of the cross-sectional area of the circumferential reinforcing steel per unit of height to the cross-sectional area of the chimney shell per unit of height, and

At level EL (+) 175.0 m $\sigma_c T_c = 0.000011 \times 0.16 \times 24.55 \times 29580.39 = 1.2781\ N/mm^2$

As per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (f) Allowable $\sigma_c T_c = 0.30 \times \sigma_{cu} = 0.30 \times 35 = 10.5\ N/mm^2 > 1.2781\ N/mm^2$.... Hence Safe.

Table 5.14 houses the values of circumferential stresses induced at different levels in the RC shell.

Table 5.14: Circumferential Stresses In Concrete Due To Temperature Alone

Levels (m)	K	T_x	$\sigma_c T_c$ (N/mm^2)	Permissible $\sigma_c T_c$ N/mm^2	Check
175	0.16	24.55	1.286	10.5	Safe
170	0.16	24.67	1.298	10.5	Safe
160	0.16	24.90	1.319	10.5	Safe
150	0.16	25.12	1.338	10.5	Safe
140	0.16	25.31	1.356	10.5	Safe
130	0.17	25.49	1.373	10.5	Safe
120	0.17	25.66	1.388	10.5	Safe
110	0.17	25.81	1.402	10.5	Safe
100	0.17	25.96	1.415	10.5	Safe
90	0.17	26.09	1.428	10.5	Safe
80	0.17	26.22	1.439	10.5	Safe
70	0.17	26.34	1.450	10.5	Safe
60	0.17	26.45	1.460	10.5	Safe
50	0.17	26.55	1.469	10.5	Safe
40	0.17	14.23	0.789	10.5	Safe
30	0.17	14.47	0.804	10.5	Safe
21.6	0.17	14.66	0.817	10.5	Safe
17.1	0.17	14.77	0.823	10.5	Safe
10	0.17	26.91	1.502	10.5	Safe
2.2	0.17	26.98	1.508	10.5	Safe
0	0.17	26.99	1.509	10.5	Safe
-2.05	0.17	27.01	1.511	10.5	Safe

5.7.2 Circumferential stresses in steel due to temperature alone

As per IS : 4998 (Part - 1) 1975 Pg. 32 Clause D - 2.2.6 Maximum circumferential tensile stress in steel due to temperature alone $\sigma_s T_c = L \cdot (Z' - K') \cdot T_x \cdot E_s$

The definition of all the parameters remain same as defined earlier.

At EL (+) 175.0 m $\sigma_s T_c = 0.000011 \times (0.80 - 0.16) \times 24.55 \times 210000 = 36.2947\ N/mm^2$

As per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.2 (f) Permissible $\sigma_s T_c = 0.50 \times f_y = 0.50 \times 500 = 250\ N/mm^2$.... $>$ 36.2497 N/mm^2....Hence Safe.

Table 5.15 details the magnitudes of the tensile stresses induced in the steel at various levels across the height of the chimney.

Table 5.15: Circumferential Stresses In Shell Due To Temperature Alone

Levels (m)	Z	K	Z - K	T_x	$\sigma_s T_c$ (N/mm^2)	Permissible $\sigma_s T_c$ $(N/mm^{2)}$	Check
175	0.80	0.16	0.64	24.55	36.23	250	Safe
170	0.81	0.16	0.64	24.67	36.69	250	Safe
160	0.82	0.16	0.65	24.90	37.56	250	Safe
150	0.82	0.16	0.66	25.12	38.35	250	Safe
140	0.83	0.16	0.67	25.31	39.08	250	Safe
130	0.84	0.17	0.68	25.49	39.75	250	Safe
120	0.85	0.17	0.68	25.66	40.37	250	Safe
110	0.85	0.17	0.69	25.81	40.95	250	Safe
100	0.86	0.17	0.69	25.96	41.49	250	Safe
90	0.86	0.17	0.70	26.09	41.99	250	Safe
80	0.87	0.17	0.70	26.22	42.46	250	Safe
70	0.87	0.17	0.71	26.34	42.91	250	Safe
60	0.88	0.17	0.71	26.45	43.32	250	Safe
50	0.88	0.17	0.71	26.55	43.71	250	Safe
40	0.89	0.17	0.72	14.23	23.53	250	Safe
30	0.89	0.17	0.72	14.47	24.04	250	Safe
21.6	0.89	0.17	0.72	14.66	24.45	250	Safe
17.1	0.89	0.17	0.72	14.77	24.66	250	Safe
10	0.90	0.17	0.72	26.91	45.07	250	Safe
2.2	0.90	0.17	0.73	26.98	45.30	250	Safe
0	0.90	0.17	0.73	26.99	45.37	250	Safe
-2.05	0.90	0.17	0.73	27.01	45.43	250	Safe

5.7.3 Circumferential tensile stresses in concrete due to wind induced ring moment

As per IS : 4998 (Part - 1) 1975 Pg. 32 Clause D - 2.2.7 Maximum circumferential tensile stress in concrete due to wind induced ring moment is given by,

$\sigma_{cwct} = \dfrac{(2 \times 10^{-4}) \times W_d \times (r)^2}{(t)^2}$ .... HereW_d= Wind pressure in kg/cm^2

At level EL (+) 175.0 m $\sigma_{cwct} = \dfrac{(2 \times 10^{-4}) \times 199.57 \times (250)^2}{(25)^2} = 3.991\ kg/cm^2$

As per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (g) Permissible $\sigma_{cwct} = 0.07 \times \sigma_{cu} = 0.07 \times 35 \times 10 = 24.5\ kg/cm^2$... $>$ 3.991 kg/cm^2...Hence Safe.

Table 5.16 details the tensile stresses induced at various levels across the chimney height due to wind induced ring moment.

Table 5.16: Circumferential Tensile Stresses In Concrete Due To Wind Induced Ring Moment

Levels (m)	W_d kg/m^2	Radius r (cm)	Avg. Shell Thickness t (cm)	σ_{cwct} kg/cm^2	Permissible σ_{cwct} kg/cm^2	Check
175	199.57	250.00	25.00	3.991	24.5	Safe
170	198.59	262.50	25.71	4.142	24.5	Safe
160	196.65	288.00	27.12	4.436	24.5	Safe
150	194.71	313.50	28.53	4.702	24.5	Safe
140	192.15	339.00	29.94	4.926	24.5	Safe
130	189.60	364.50	31.35	5.125	24.5	Safe
120	187.07	390.00	32.77	5.300	24.5	Safe
110	184.55	415.00	34.18	5.442	24.5	Safe
100	182.05	440.50	35.59	5.578	24.5	Safe
90	177.72	466.00	37.00	5.637	24.5	Safe
80	173.44	491.50	38.41	5.679	24.5	Safe
70	169.22	517.00	39.83	5.703	24.5	Safe
60	165.04	542.50	41.24	5.712	24.5	Safe
50	160.92	567.50	42.65	5.698	24.5	Safe
40	152.26	593.00	44.06	5.516	24.5	Safe
30	143.84	618.50	45.47	5.322	24.5	Safe
21.6	135.02	640.00	46.66	5.080	24.5	Safe
17.1	128.40	651.50	47.30	4.873	24.5	Safe
10	115.02	669.50	48.30	4.420	24.5	Safe
2.2	115.02	689.00	49.40	4.475	24.5	Safe
0	115.02	695.00	49.71	4.497	24.5	Safe
-2.05	115.02	700.00	50.00	4.509	24.5	Safe

5.7.4 Circumferential compressive stresses in concrete due to wind induced ring moments

As per IS : 4998 (Part - 1) 1975 Pg. 32 Clause d - 2.2.8 Maximum circumferential compressive stress in concrete due to wind induced ring moment.

$\sigma_{cwct} = \dfrac{(2 \times 10^{-4}) \times W_d \times (r)^2}{(t)^2}$ .... HereW_d= Wind pressure in kg/cm^2

At level EL (+) 175.0 m $\sigma_{cwct} = \dfrac{(2 \times 10^{-4}) \times 199.57 \times (250)^2}{(25)^2} = 3.991\ kg/cm^2$

As per IS : 4998 (Part - 1) 1975 Pg. 11 Clause 7.1.1 (g) Permissible $\sigma_{cwct} = 0.07 \times \sigma_{cu} = 0.07 \times 35 \times 10 = 24.5\ kg/cm^2$... $>$ 3.991 kg/cm^2...Hence Safe.

Table 5.17 details the compressive stresses induced at various levels across the chimney height due to wind induced ring moment.

Table 5.17: Circumferential Compressive Stresses In Concrete Due To Wind Induced Ring Moment

Levels (m)	W_d (kg/m^2)	Radius r (cm)	Avg. Shell Thickness$t$ (cm)	σ_{cwcc} (kg/cm^2)	Permissible σ_{cwcc} (kg/cm^2)	Check
175	199.57	250.00	25.00	3.991	140	Safe
170	198.59	262.50	25.71	4.142	140	Safe
160	196.65	288.00	27.12	4.436	140	Safe
150	194.71	313.50	28.53	4.702	140	Safe
140	192.15	339.00	29.94	4.926	140	Safe
130	189.60	364.50	31.35	5.125	140	Safe
120	187.07	390.00	32.77	5.300	140	Safe
110	184.55	415.00	34.18	5.442	140	Safe
100	182.05	440.50	35.59	5.578	140	Safe
90	177.72	466.00	37.00	5.637	140	Safe
80	173.44	491.50	38.41	5.679	140	Safe
70	169.22	517.00	39.83	5.703	140	Safe
60	165.04	542.50	41.24	5.712	140	Safe
50	160.92	567.50	42.65	5.698	140	Safe
40	152.26	593.00	44.06	5.516	140	Safe
30	143.84	618.50	45.47	5.322	140	Safe
21.6	135.02	640.00	46.66	5.080	140	Safe
17.1	128.40	651.50	47.30	4.873	140	Safe
10	115.02	669.50	48.30	4.420	140	Safe
2.2	115.02	689.00	49.40	4.475	140	Safe
0	115.02	695.00	49.71	4.497	140	Safe
-2.05	115.02	700.00	50.00	4.509	140	Safe

5.8 Design of vertical reinforcement

As per IS : 4998 (Part - 1) 1975 Pg. 12 Clause 9.2.1.1

Minimum vertical reinforcement = 0.25% of the concrete area of the section under consideration, for HYSD bars.

As per IS : 4998 (Part - 1) 1975 Pg. 12 Clause 9.2.1.3

The minimum diameter of bars shall be 12 mm and the maximum center to center distance of reinforcement shall not exceed 300 mm when provided in a single layer and shall not exceed 600 mm in each layer and shall be staggered symmetrically when provided in two layers.

As per IS : 4998 (Part - 1) 1975 Pg. 13 Clause 9.3.2

The clear concrete cover over the reinforcement shall not be less than 5 cm.

SAMPLE CALCULATION FOR VERTICAL REINFORCEMENT AT EL (+) 30.0 m

Diameter of circumferential bars	$= 12\ mm$
Clear cover to the circumferential bars	$= 50\ mm$
Clear cover to the vertical bars	$= 50 + 12 = 62\ mm$
Diameter of vertical reinforcement	$= 16\ mm$
Internal diameter of the shell, I_d	$= 11.46\ m$
Thickness of the shell, t	$= 454.74\ mm$
Grade of concrete	= M35
Grade of steel	= Fe500
Outer diameter of the shell, O_d	$= 12.36948\ m$
Cross-Sectional area of the shell	$= 17.021\ m^2$
No. of bars in each layer based on minimum % required	$= \left(\frac{0.0025 \times 17.021 \times 10^6}{0.25 \times \pi \times 16^2} \times 0.5\right) + 1 = 107$
No. of bars in each layer base on spacing criterion	$= \left(\frac{\pi \times (11460 + 2 \times 454.74}{250}\right) + 1 = 157$
Hence, governing number of bars	= Max (107, 157) = 157
Actual number of bars provided	238
Hence spacing provided	163.29 mm $<$ 250 mm... Hence Safe

Table 5.18 and Table 5.19 house the details of the vertical reinforcement provided across the height of the chimney. More or less a uniformity has been maintained in the diameter of the bars as well as spacing of the bars for easy placement.

Table 5.18: Vertical Reinforcement Requirement

Levels (m)	Internal diameter of shell (m)	Thickness of shell (m)	Area m^2	Number of bars required per layer based on minimum % requirement	Governing Number Of Bars	% steel required	Area of steel required (mm2)	No. of bars required
175	4.500	0.250	3.73064	24.19 ≈25	64	0.65	24249.17	108
170	4.740	0.257	4.03555	26.08≈27	68	0.60	24213.32	108
160	5.220	0.271	4.67826	30.08≈31	74	0.50	23391.32	104
150	5.700	0.285	5.36482	34.35≈35	80	0.45	24141.69	107
140	6.180	0.299	6.09522	38.89≈39	86	0.80	48761.79	122
130	6.660	0.314	6.86947	43.70≈44	92	0.70	48086.31	120
120	7.140	0.328	7.68756	48.79≈50	98	0.65	49969.20	125
110	7.621	0.342	8.54951	54.15≈55	106	0.55	47022.32	117
100	8.101	0.356	9.45530	59.78≈60	112	0.50	47276.51	118
90	8.581	0.370	10.4049	65.68≈66	118	0.65	67632.10	169
80	9.061	0.384	11.3984	71.86≈72	124	0.60	68390.53	171
70	9.541	0.398	12.4357	78.31≈79	130	0.55	68396.63	171
60	10.021	0.412	13.5169	85.03≈86	138	0.50	67584.63	169
50	10.501	0.427	14.6419	92.02≈93	144	0.45	65888.77	164
40	10.981	0.441	15.8108	99.29≈100	150	0.45	71148.69	177
30	11.461	0.455	17.0235	106.83≈107	156	0.50	85117.67	212
21.6	11.865	0.467	18.0761	113.37≈114	162	0.50	90380.50	225
17.1	12.081	0.473	18.6527	116.96≈117	164	0.45	83937.16	209
10	12.421	0.483	19.5805	122.73≈123	170	0.45	88112.28	220
2.2	12.796	0.494	20.6252	129.22≈130	174	0.45	92813.69	231
0	12.902	0.497	20.9247	131.08≈132	176	0.45	94161.43	235
-2.05	13.000	0.500	21.2057	132.83≈133	176	0.45	95425.88	238

Table 5.19: Requirement Of Vertical Reinforcement (Contd.)

Levels(m)	No. of bars provided	ϕ (DIA) (mm)	Spacing based on reinforcement provided	Area of steel provided (mm^2)	Check
175	108	12	145.44	12214.51	Safe
170	108	12	152.84	12214.51	Safe
160	108	12	167.62	12214.51	Safe
150	108	12	182.41	12214.51	Safe
140	178	16	119.65	35789.02	Safe
130	178	16	128.62	35789.02	Safe
120	178	16	137.59	35789.02	Safe
110	178	16	146.56	35789.02	Safe
100	178	16	155.53	35789.02	Safe
90	178	16	164.51	35789.02	Safe
80	178	16	173.48	35789.02	Safe
70	178	16	182.45	35789.02	Safe
60	178	16	191.42	35789.02	Safe
50	178	16	200.39	35789.02	Safe
40	178	16	209.37	35789.02	Safe
30	238	16	163.29	47852.74	Safe
21.6	238	16	168.93	47852.74	Safe
17.1	238	16	171.95	47852.74	Safe
10	238	16	176.71	47852.74	Safe
2.2	238	16	181.95	47852.74	Safe
0	238	16	183.42	47852.74	Safe
-2.05	238	16	184.80	47852.74	Safe

5.9 Design of circumferential reinforcement

As per IS : 4998 (Part - 1) 1975 Pg. 12 Clause 9.2.2.1

The circumferential reinforcement shall not be less than 0.2% , when deformed bars are used, of the concrete area in vertical section under consideration subject to minimum of 400 mm^2per m height of the stack. When mild steel bars are used the percentage shall be 0.25%.

If the vertical reinforcement is provided in two layers, then the circumferential reinforcement shall be provided in two layers and the minimum reinforcement specified above shall be divided equally in each layer. the spacing of the bars shall not exceed minimum of 300 mm or shell thickness whichever is smaller.

SAMPLE CALCULATION : CIRCUMFERENTIAL STEEL AT EL (+) 30.0 m

$$\begin{aligned}
\text{Internal diameter of the shell} &= 11.46\ m \\
\text{Shell thickness} &= 454.74\ mm \\
\text{Grade of concrete} &= \text{M35} \\
\text{Grade of steel} &= \text{Fe500} \\
\text{Minimum \% of steel required in one layer} &= 0.20\ \% \\
\text{Number of bars required in one layer} &= \left(\frac{0.20 \times 454.74 \times 1000 \times 4}{2 \times 100 \times \pi \times (12)^2}\right) = 4.021 \\
\text{Required spacing} &= \left(\frac{1000}{4.021}\right) = 248.5\ mm \\
\text{Maximum allowable spacing} &= 250\ mm \\
\text{Steel provided} &= \phi\ 12\ mm \text{ at } 1500\ mm\ c/c \\
\text{Area of steel provided} &= 754\ mm^2 > 400\ mm^2 \text{....Hence Safe.}
\end{aligned}$$

Table 5.20 houses the details of the circumferential reinforcement provided in two layers across the height of the stack.

Table 5.20: Details Of Circumferential Reinforcement

Levels (m)	% of steel reqd. based on wind moments and temperature	Shell thickness (mm)	Provided bar diameter	Total number of bars required based on % reqd.	Reqd. spacing	Provided spacing	Area of steel provided	Check
175	0.2	250.00	12.00	6	166.67	150	753.98	Safe
170	0.2	257.06	12.00	6	166.67	150	753.98	Safe
160	0.2	271.18	12.00	6	166.67	150	753.98	Safe
150	0.2	285.30	12.00	6	166.67	150	753.98	Safe
140	0.2	299.42	16.00	4	250.00	150	1340.41	Safe
130	0.2	313.54	16.00	4	250.00	150	1340.41	Safe
120	0.2	327.66	16.00	4	250.00	150	1340.41	Safe
110	0.2	341.78	16.00	4	250.00	150	1340.41	Safe
100	0.2	355.90	16.00	4	250.00	150	1340.41	Safe
90	0.2	370.02	16.00	4	250.00	150	1340.41	Safe
80	0.2	384.14	16.00	4	250.00	150	1340.41	Safe
70	0.2	398.26	16.00	4	250.00	150	1340.41	Safe
60	0.2	412.38	16.00	6	166.67	150	1340.41	Safe
50	0.2	426.50	16.00	6	166.67	150	1340.41	Safe
40	0.2	440.62	16.00	6	166.67	150	1340.41	Safe
30	0.2	454.74	16.00	6	166.67	150	1340.41	Safe
21.6	0.2	466.61	16.00	6	166.67	150	1340.41	Safe
17.1	0.2	472.96	16.00	6	166.67	150	1340.41	Safe
10	0.2	482.99	16.00	6	166.67	150	1340.41	Safe
2.2	0.2	494.00	16.00	6	166.67	150	1340.41	Safe
0	0.2	497.11	16.00	6	166.67	150	1340.41	Safe
-2.05	0.2	500.00	16.00	6	166.67	150	1340.41	Safe

5.10 Design of extra reinforcement around openings

VERTICAL REINFORCEMENT AROUND PLENUM OPENING AT EL (+) 21.6 m

Size of opening	$= 4.5\ m \times 4.5\ m$
Width of opening, W (m)	$= 4.5\ m$
Height of opening, H (m)	$= 4.5\ m$
Thickness of the shell at EL (+) 21.6 m	$= 467\ mm$
Spacing provided at EL (+) 21.6 m	$= 168\ mm$
Number of bars in the width of opening	$= \left(\frac{4500}{168} + 1\right) \times 2 \approx 56$
Bar diameter	$= 16\ mm$
Total area of steel required	$= \pi \times 16^2 \times 0.25 \times 56 = 11259.46\ mm^2$
Extra reinforcement required on either side	$= 0.5 \times 11259.46 = 5629.73\ mm^2$
Diameter of bars to be used as extra reinforcement	$= 32\ mm$
No. of bars required	$= \left(\frac{5629.73}{\pi \times 32^2 \times 0.25}\right) = 6.99 \approx 8$
Area of extra steel provided on each side of the opening	$= 8 \times \pi \times 32^2 \times 0.25 = 6433.98\ mm^2$

CIRCUM. REINFORCEMENT AROUND PLENUM OPENING AT EL (+) 21.6 m

Size of opening	$= 4.5\ m \times 4.5\ m$
Width of opening, W (m)	$= 4.5\ m$
Height of opening, H (m)	$= 4.5\ m$
Thickness of the shell at EL (+) 21.6 m	$= 467\ mm$
Spacing provided at EL (+) 21.6 m	$= 150\ mm$
Number of bars over the height of the opening	$= \left(\frac{4500}{150} + 1\right) \approx 31$
Number of layers	$= 2$
Area of steel required on each side of the opening	$= 32 \times \left(\frac{\pi \times 12^2}{4}\right) = 3619.11\ mm^2$
$\phi 32\ mm$ number of bars required on each side	$= \frac{3619.11}{0.25 \times \pi \times 32^2} \approx 5$
Area of extra steel provided on each side of the opening	$= 5 \times 0.25 \times \pi \times 32^2 = 4021.235\ mm^2$

DIAGONAL REINFORCEMENT AROUND PLENUM OPENING AT EL (+) 21.6 mm

$$\begin{aligned}
\text{Thickness of the shell} &= 467\ mm \\
\text{Minimum area of diagonal reinforcement in } cm^2 &= 0.5 \times 46.7 = 23.35\ cm^2 \\
\text{Assume diameter of bars as} &= 25\ mm \\
\text{No. of bars required} &= \frac{2355}{0.25 \times \pi \times 25^2} = 4.75 \approx 5 \\
\text{Providing 6 bars the area provided is} &= 6 \times \pi \times 25^2 \times 0.25 = 2945.24\ mm^2
\end{aligned}$$

Table 4.21 gives details of the extra vertical reinforcement around the openings, Table 4.22 gives details of the extra circumferential reinforcement around the openings, and Table 4.23 gives the details regarding the details of the extra diagonal reinforcement around the openings

Table 5.21: Details Of Extra Vertical Reinforcement Around Openings

Details Of Opening	Width (m)	Height (m)	Shell thickness (m)	VERTICAL REINFORCEMENT (Diameter of extra reinforcing bar : 32 mm)					
				Spacing of vertical reinforcement provided in shell	Number of bars in the opening width	Bar diameter	Area of steel to be provided at either end of the opening	Number of bars	Area of steel provided
EL (+) 21.6 Plenum inlet duct opening 1or 2	4.5	4.5	0.467	168.93	55.2763	32	5556.983	8	6433.981
EL (+) 0.0 Access door	2.2	2.5	0.497	183.42	25.9881	32	2612.612	4	3216.990

Table 5.22: Details Of Extra Circumferential Reinforcement Around Openings

Details Of Opening	Width (m)	Height (m)	Shell thickness (m)	CIRCUMFERENTIAL REINFORCEMENT (Diameter of extra reinforcing bar : 32 mm)					
				Spacing of vertical reinforcement provided in shell	Number of bars in the opening height	Bar diameter	Area of steel to be provided at either end of the opening	Number of bars	Area of steel provided
EL (+) 21.6 Plenum inlet duct opening 1or 2	4.5	4.5	0.467	150	16	32	6433.88 mm^2	10	8042.47
EL (+) 0.0 Access door	2.2	2.5	0.497	150	16	32	3619.11 mm^2	5	4021.235

Table 5.23: Details Of Diagonal Reinforcement Around Openings

Details Of Opening	Width (m)	Height (m)	Shell thickness (m)	DIAGONAL REINFORCEMENT (Diameter of extra reinforcing bar : 25 mm)		
				Minimum area of diagonal reinforcement required	Number of ϕ 25 mm bars required	Area of steel to provided
EL (+) 21.6 Plenum inlet duct opening 1or 2	4.5	4.5	0.467	$= (0.5 \times 46.7) \times 100 =$ 2355 mm^2	$= \left(\frac{2355}{\pi \times 25^2 \times 0.25}\right) \approx 5$	Providing 6 bars : $6 \times \pi \times 25^2 \times 0.25 =$ 2945.24 mm^2
EL (+) 0.0 Access door	2.2	2.5	0.497	$= (0.5 \times 49.7) \times 100 = 2485 mm^2$	$= \left(\frac{2485}{\pi \times 25^2 \times 0.25}\right) \approx 6$	Providing 8 bars : $8 \times \pi \times 25^2 \times 0.25 = 3927$ mm^2

5.11 Foundation Design

A circular RC slab foundation is designed for the chimney

Total vertical load on the base = 55516.65 kN

Net bending moment = 241637.48 $kN \cdot m$

Allowable bearing pressure = 270 kN/m^2

Self weight of the footing (assumed to be 10% of total vertical load)

$= 0.10 \times 55516.65 = 5551.665\ kN$

Total load on the soil = 55516.65 + 5551.665 = 61068.315 kN

If D is the diameter of circular footing then for no tension to develop,

$$\left(\frac{W}{A}\right) = \left(\frac{M}{Z}\right) \text{ i.e. } \left(\frac{61068.315}{\frac{\pi}{4} \times D^2}\right) = \left(\frac{241637.48}{\frac{\pi}{32} \times D^3}\right)$$

$4 \times 61068.315 \times D = 32 \times 241637.48$ Hence, $D = 31.6547 \approx 32\ m$

The loading on the base is taken as annular loading on the mean diameter. The bending moments in the base are obtained by superposing two types of loading as shown below:

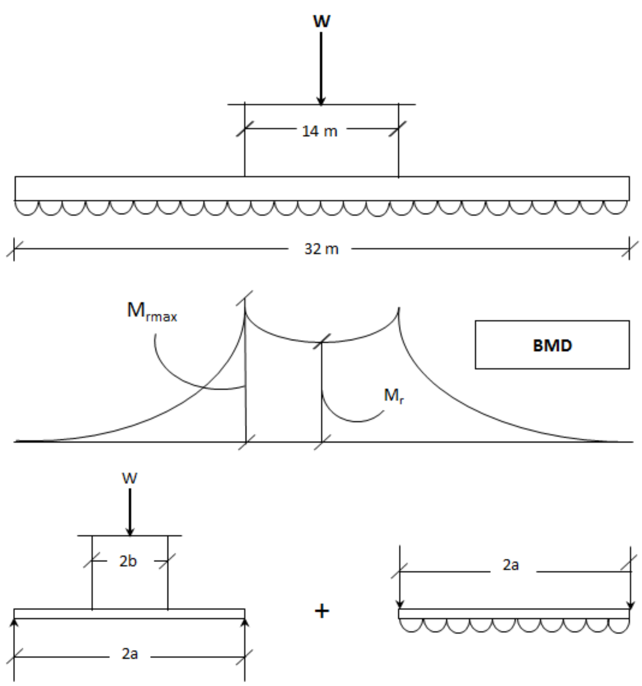

Figure 5.2: Nature Of Bending Moment Diagram For Footing

Intensity of soil pressure $w = \left[\dfrac{61068.315}{\dfrac{\pi}{4} \times (32)^2}\right] = 75.9322\ kN/m^2$

Here, $2a = 32\ m$ means $a = 16\ m$ and $2b = 14\ m$ means $b = 7\ m$

Maximum bending moment in the section is governed by the radial moment,

M_r =Bending moment at the center of the footing

$$M_r = \left(\frac{W}{8\pi}\right) \cdot \left[2log_e\left(\frac{a}{b}\right) + 1 - \left(\frac{b}{a}\right)^2\right] - \left(\frac{3}{16}\right) \cdot w \cdot a^2$$

$$M_r = \left(\frac{61068.315}{8\pi}\right) \cdot \left[2log_e\left(\frac{16}{7}\right) + 1 - \left(\frac{7}{16}\right)^2\right] - \left(\frac{3}{16}\right) \cdot (75.9322) \cdot (16)^2$$

$M_r = 2337.48\ kN \cdot m/m$

M_{rmax} =Moment at the junction of footing and chimney wall at a radius of 7 m

$$M_{rmax} = \left(\frac{W}{8\pi}\right) \cdot \left[2log_e\left(\frac{a}{b}\right) + 1 - \left(\frac{b}{a}\right)^2\right] - \left(\frac{3}{16}\right) \cdot w \cdot (a^2 - b^2)$$

$$M_{rmax} = \left(\frac{61068.315}{8\pi}\right) \cdot \left[2log_e\left(\frac{16}{7}\right) + 1 - \left(\frac{7}{16}\right)^2\right] - \left(\frac{3}{16}\right) \cdot (75.9322) \cdot (16^2 - 7^2)$$

$M_{rmax} = 3035.10\ kN \cdot m/m$

Design ultimate moment = M_u =1.5×M_{rmax}= 1.5 ×3035.10 = 4552.637 $kN \cdot m/m$

Using M30 grade concrete and Fe500 grade steel

Effective depth required, $M_{ulim} = 0.133 \cdot f_{ck} \cdot b \cdot d^2$

$3035.10 \times 10^6 = 0.133 \times 30 \times 1000 \times d^2$

$d = 872.1678\ mm$

Since the moments are very heavy, adopt a larger depth of footing to reduce the quantity of reinforcement.

Adopt an overall depth of 3000 m and assuming a cover of 100 mm the provided effective depth turns out to be 2900 mm

$$\left(\frac{M_u}{b \cdot d^2}\right) = \left(\frac{4552.637 \times 10^6}{1000 \times 2900^2}\right) = 0.60$$

As per SP : 16 Pg. 50 Table 4

$p_t = 0.15$ % Hence $A_{streq} = \left(\dfrac{0.150 \times 1000 \times 2400}{100}\right) = 3600mm^2$

Provide ϕ25 mm bars at 100 mm c/c in perpendicular direction both ways. Also provide ϕ 12 mm bars both ways at the top of the footing.

Hence A_{stpro} =4908.73 mm^2...... Hence Safe.

5.12 Check for shear

Intensity of soil pressure = 75.93 kN/m^2

Ultimate soil pressure = 1.5×75.93 = 113.895 kN/m^2

Cantilever projection = (0.5×32) − 7 = 9 m

Maximum shear force at a distance " d " from the support is given by,

V_u =113.895×(9 − 2.9) = 694.7595 kN

$$\tau_v = \left(\frac{V_u}{b \cdot d}\right) = \left(\frac{694.7595 \times 10^3}{1000 \times 2900}\right) = 0.2395\ N/mm^2$$

$$p_{tpro} = \frac{4908.73 \times 100}{1000 \times 2900} = 0.17\ \%$$

As per IS : 456 - 2000 Pg. 73 Table 19

τ_c =0.306 N/mm^2..

As per IS : 456 - 2000 Pg. 72 Clause 40.2.1.1 $k = 1$

And $k \cdot \tau_c = 1 \times 0.306 = 0.306\ N/mm^2$..... Hence the slab is safe against shear failure.

5.13 Summary

In this chapter the entire design of RCC shell and foundation has been detailed. The calculation of stresses induced due to dead load, wind load, and temperature loads individually as well as in combination have been calculated and checked for acceptance within permissible limits based on the provisions of IS : 4998 (Part - 1) 1975. The main highlight of the chapter is the stress calculation for the combination of DL + WL because it governs the reinforcement requirement of the chimney. The chapter also details the calculations for requirement of extra reinforcement around the ducts/openings and design for the same. The foundation has been checked for shear.

Chapter 6

Parametric study

6.1 Introduction

This chapter houses the details of the parametric study carried out to understand the variation in the structural behaviour and response of the reinforced concrete chimney under different intensities and combinations of wind and earthquake forces. The parametric study has been carried out for 175 m tall reinforced concrete for two different seismic zones viz. zone III and zone V and four different basic wind speeds namely 39 m/s, 44m/s, 49m/s and 50 m/s. Two different STAAD models were created for two different seismic zones. Wind load estimation was done using the procedure slated in IS : 4998 (Part - 1) 1992. The parametric study has been limited only to the study of the changes in the magnitudes of shear force and bending moment. The results of the analysis are tabulated as well as graphically represented as follows.

6.2 Details of Parametric Study

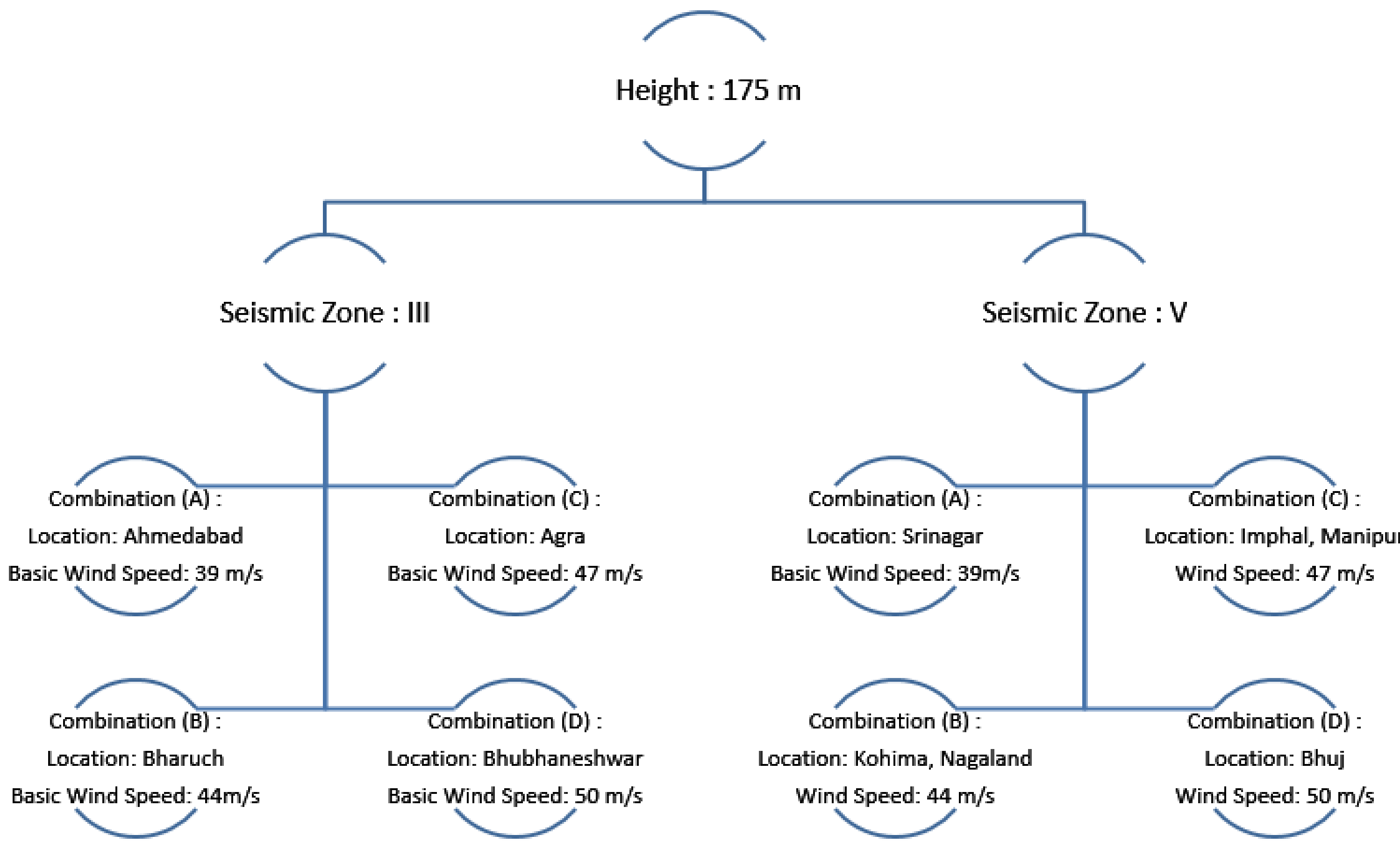

Figure 6.1: Parametric Study : Flow Chart

6.3 Parametric Study For Two Different Seismic Zones and Four Different Basic Wind Speeds

6.3.1 Combination (A)

Combination (A) houses the comparison of variation in shear force and bending moment values in case of a 175 m tall RCC chimney located in Ahmedabad and Srinagar having a similar basic wind speed of 39 m/s and seismic zones of III and V respectively. Table 6.1 houses the details of variation in shear forces due to varying parameters and on the same line Table 6.2 houses the variation in bending moments.

Table 6.1: Combination (A) - Variation Of Shear Forces

GOVERNING SHEAR FORCES								
CITY	AHMEDABAD (ZONE : III & BASIC WIND SPEED : 39 m/s)				SRINAGAR (ZONE : V & BASIC WIND SPEED : 39 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA - Seismic	SA - Wind	CC - Seismic	CC - Wind	SA - Seismic	SA - Wind	CC - Seismic	CC - Wind
175	65	0	97	0	146	0	219	0
170	223	195	262	179	503	195	590	179
160	340	525	368	482	765	525	828	482
150	406	762	425	694	912	762	956	694
140	440	892	458	806	990	892	1030	806
130	454	915	473	819	1021	915	1063	819
120	463	847	484	751	1041	847	1090	751
110	479	742	504	733	1077	742	1134	733
100	515	715	546	840	1159	715	1228	840
90	581	875	613	945	1308	875	1379	945
80	675	1190	705	1177	1518	1190	1587	1177
70	792	1571	820	1548	1781	1571	1846	1548
60	924	1958	959	1917	2079	1958	2158	1917
50	1061	2312	1098	2254	2387	2312	2471	2254
40	1193	2610	1247	2536	2685	2610	2807	2536
30	1298	2840	1382	2753	2921	2840	3109	2753
21.6	1353	2981	1470	2885	3044	2981	3307	2885
17.1	1392	3038	1554	2939	3131	3038	3497	2939
10	1416	3105	1584	3001	3185	3105	3564	3001
2.2	1418	3157	1587	3050	3190	3157	3571	3050
0	1418	3169	1587	3061	3191	3169	3571	3061
-2.05	1418	3175	1587	3067	3191	3175	3571	3067

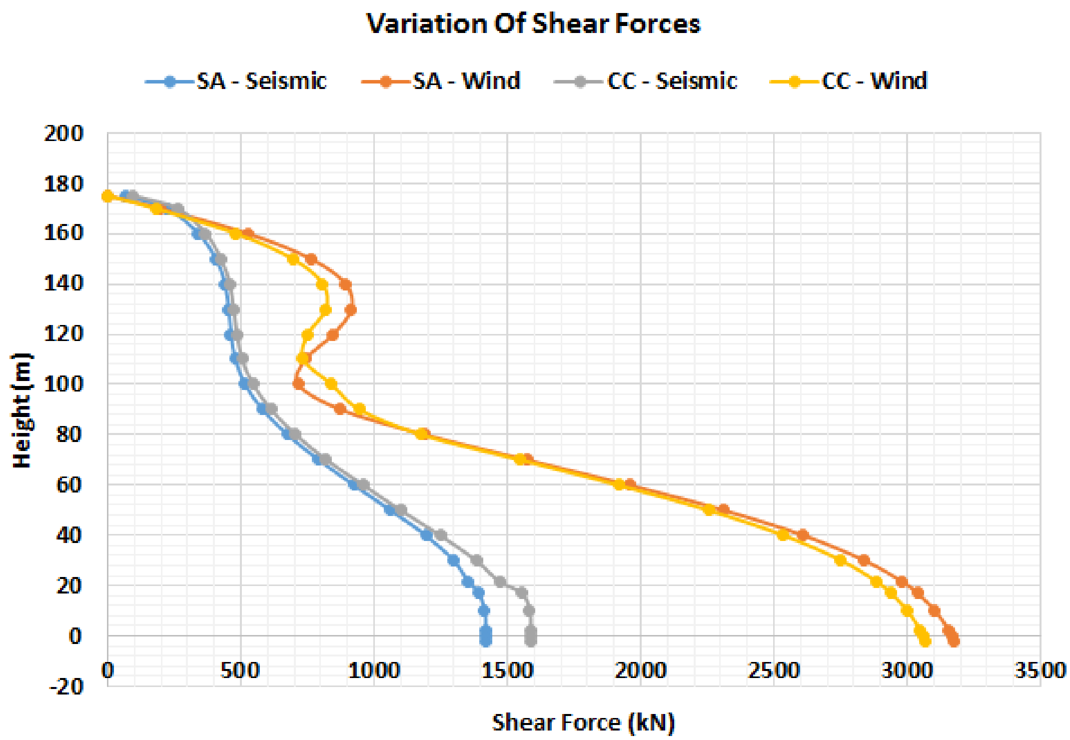

Figure 6.2: 39 - III - Variation Of Shear Forces

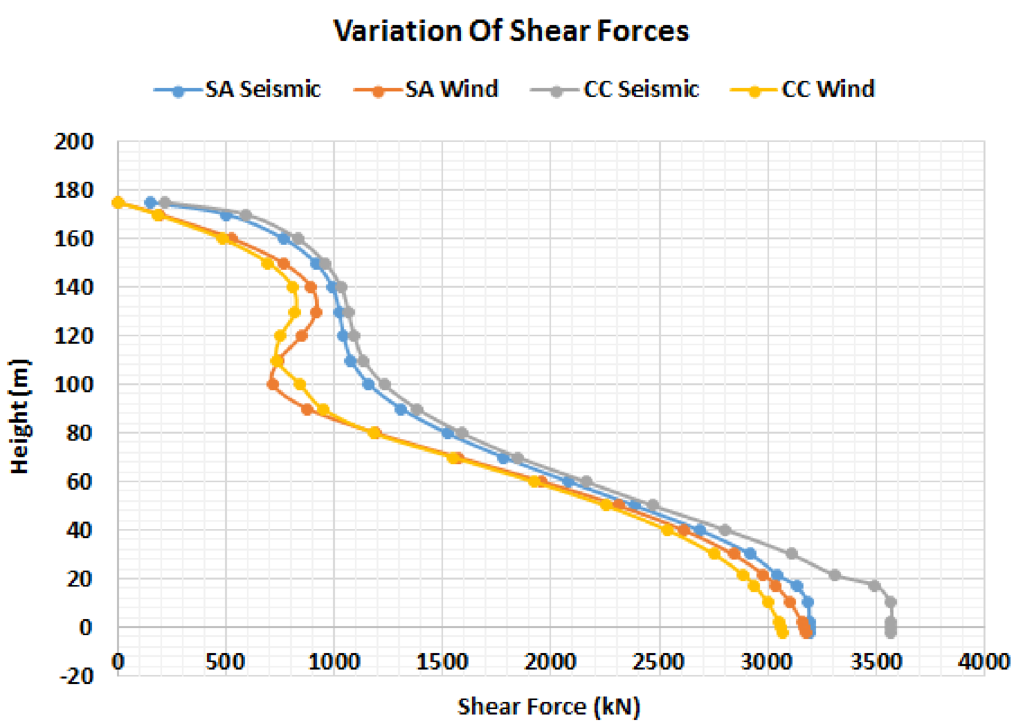

Figure 6.3: 39 - V - Variation Of Shear Forces

Table 6.2: Combination (A) - Variation Of Bending Moments

GOVERNING BENDING MOMENTS								
CITY	AHMEDABAD (ZONE : III & WIND SPEED : 39 m/s)				SRINAGAR (ZONE : V & WIND SPEED : 39 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	0	0	0	0	0	0	0	0
170	324	493	486	679	730	493	1094	679
160	2556	4168	3105	4674	5750	4168	6986	4674
150	5887	10684	6694	11270	13245	10684	15061	11270
140	9709	19032	10637	19492	21845	19032	23932	19492
130	13652	28106	14599	28296	30717	28106	32848	28296
120	17439	36801	18373	36614	39238	36801	41339	36614
110	20890	44176	21800	43560	47003	44176	49050	43560
100	23927	49629	24822	48571	53835	49629	55849	48571
90	26583	53103	27432	51440	59812	53103	61720	51440
80	29046	55340	29881	53072	65354	55340	67232	53072
70	31663	58095	32508	62745	71240	58095	73141	62745
60	34914	63891	35776	74848	78555	63891	80494	74848
50	39331	74880	40201	87892	88494	74880	90451	87892
40	45338	91678	46262	101833	102011	91678	104090	101833
30	53128	113514	54192	116609	119538	113514	121930	116609
21.6	61008	134831	62342	129611	137267	134831	140269	129611
17.1	65671	147095	67250	141381	147759	147095	151311	141381
10	73567	167344	75749	161449	165526	167344	170434	161449
2.2	82823	190531	85859	184422	186350	190531	193180	184422
0	85512	197213	88816	191039	192401	197213	199834	191039
-2.05	88044	203483	91605	197369	198098	203483	206110	197369

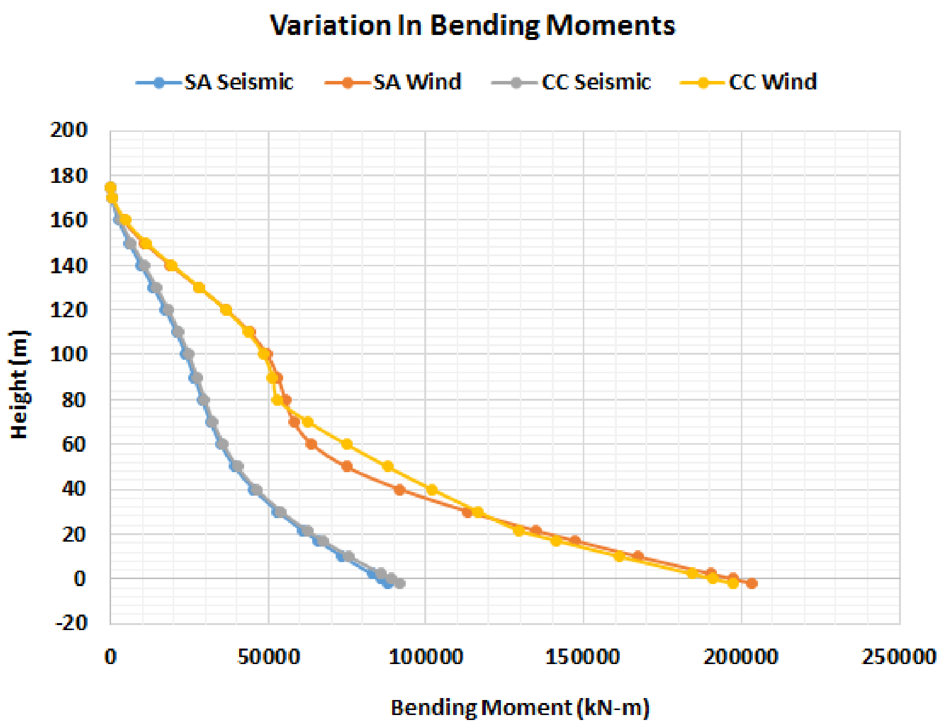

Figure 6.4: 39 - III - Variation Of Bending Moments

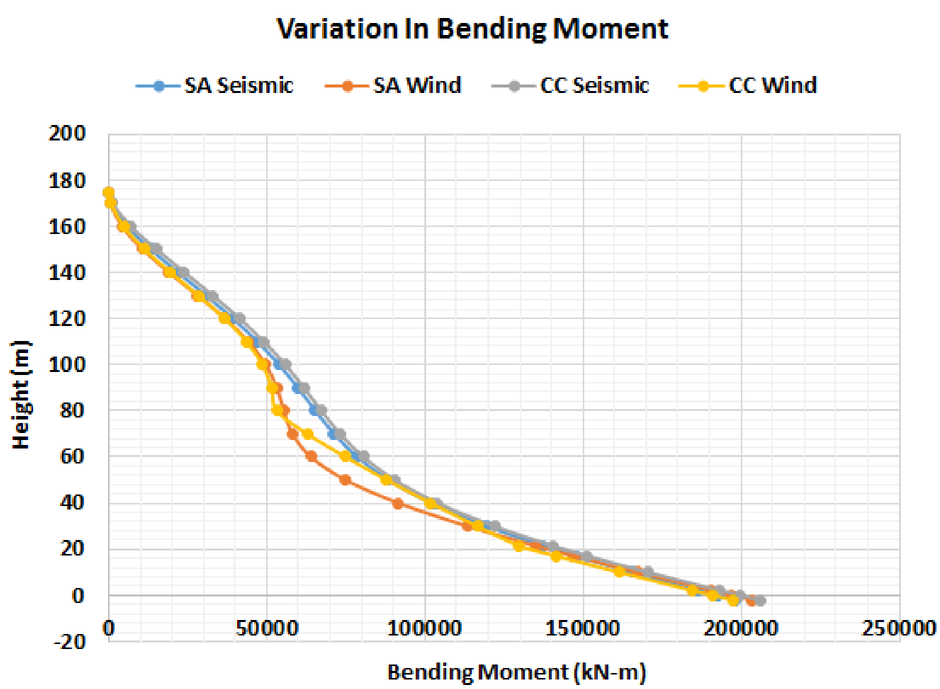

Figure 6.5: 39 - V - Variation Of Bending Moments

6.3.2 Combination (B)

Combination (B) houses the comparison of variation in shear force and bending moment values in case of a 175 m tall RCC chimney located in Bharuch and Kohima, Nagaland having a similar basic wind speed of 44 m/s and seismic zones of III and V respectively.Table 6.3 houses the details of variation in shear forces due to varying parameters and on the same line Table 6.4 houses the variation in bending moments.

Table 6.3: Combination (B) - Variation Of Shear Forces

GOVERNING SHEAR FORCES								
CITY	BHARUCH (ZONE : III & BASIC WIND SPEED : 44 m/s)				KOHIMA (ZONE : V & BASIC WIND SPEED : 44 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	65	0	97	0	146	0	219	0
170	223	195	262	179	503	195	590	179
160	340	525	368	482	765	525	828	482
150	406	762	425	694	912	762	956	694
140	440	892	458	806	990	892	1030	806
130	454	915	473	819	1021	915	1063	819
120	463	847	484	817	1041	847	1090	817
110	479	742	504	959	1077	742	1134	959
100	515	790	546	1098	1159	790	1228	1098
90	581	888	613	1235	1308	888	1379	1235
80	675	1190	705	1367	1518	1190	1587	1367
70	792	1571	820	1548	1781	1571	1846	1548
60	924	1958	959	1917	2079	1958	2158	1917
50	1061	2312	1098	2254	2387	2312	2471	2254
40	1193	2610	1247	2536	2685	2610	2807	2536
30	1298	2840	1382	2753	2921	2840	3109	2753
21.6	1353	2981	1470	2885	3044	2981	3307	2885
17.1	1392	3038	1554	2939	3131	3038	3497	2939
10	1416	3105	1584	3001	3185	3105	3564	3001
2.2	1418	3157	1587	3050	3190	3157	3571	3050
0	1418	3169	1587	3061	3191	3169	3571	3061
-2.05	1418	3175	1587	3067	3191	3175	3571	3067

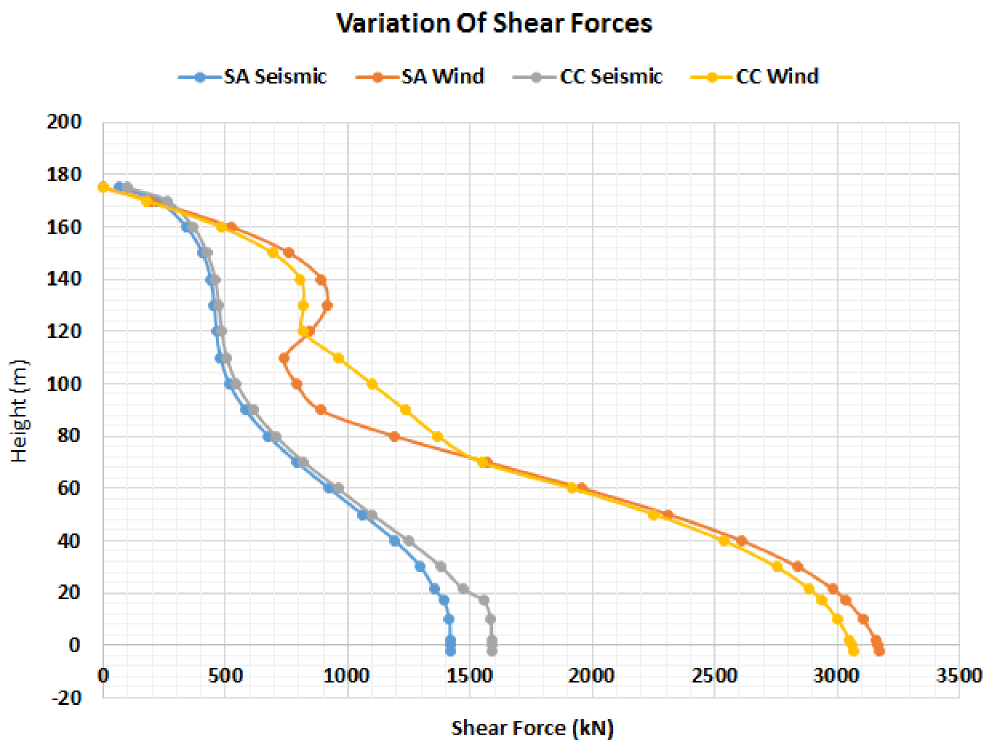

Figure 6.6: 44 - III - Variation Of Shear Forces

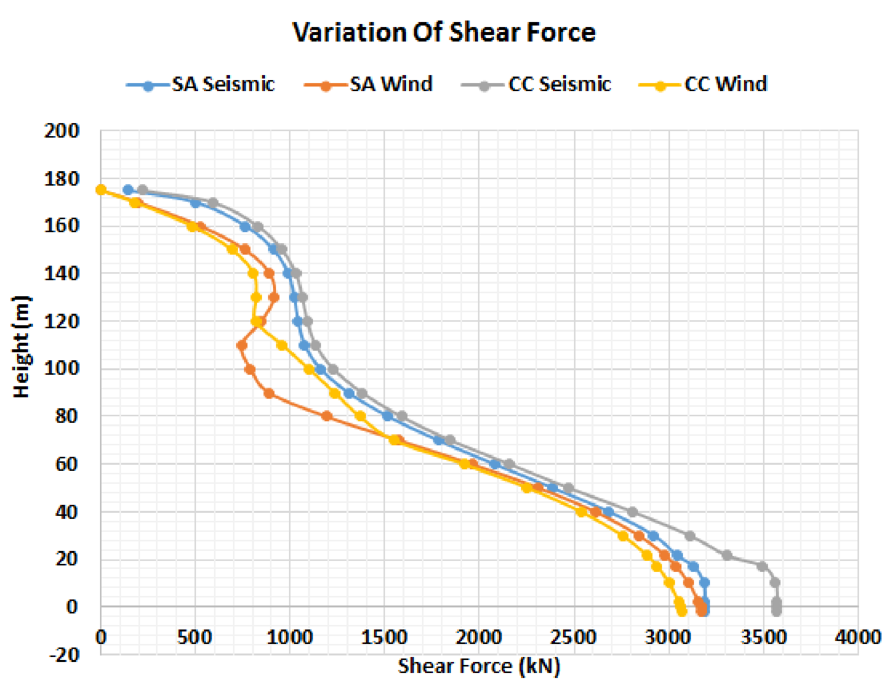

Figure 6.7: 44 - V - Variation Of Shear Forces

Table 6.4: Combination (B) - Variation Of Bending Moments

GOVERNING BENDING MOMENTS								
CITY	BHARUCH (ZONE : III & BASIC WIND SPEED : 44 m/s)				KOHIMA (ZONE : V & BASIC WIND SPEED : 44 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	0	0	0	0	0	0	0	0
170	324	493	486	679	730	493	1094	679
160	2556	4168	3105	4674	5750	4168	6986	4674
150	5887	10684	6694	11270	13245	10684	15061	11270
140	9709	19032	10637	19492	21845	19032	23932	19492
130	13652	28106	14599	28296	30717	28106	32848	28296
120	17439	36801	18373	36614	39238	36801	41339	36614
110	20890	44176	21800	43560	47003	44176	49050	43560
100	23927	49629	24822	48571	53835	49629	55849	48571
90	26583	53103	27432	54317	59812	53103	61720	54317
80	29046	55340	29881	67515	65354	55340	67232	67515
70	31663	58969	32508	82027	71240	58969	73141	82027
60	34914	70320	35776	97804	78555	70320	80494	97804
50	39331	82547	40201	114797	88494	82547	90451	114797
40	45338	95608	46262	132944	102011	95608	104090	132944
30	53128	113514	54192	152163	119538	113514	121930	152163
21.6	61008	134831	62342	169067	137267	134831	140269	169067
17.1	65671	147095	67250	178384	147759	147095	151311	178384
10	73567	167344	75749	193411	165526	167344	170434	193411
2.2	82823	190531	85859	210308	186350	190531	193180	210308
0	85512	197213	88816	215143	192401	197213	199834	215143
-2.05	88044	203483	91605	219670	198098	203483	206110	219670

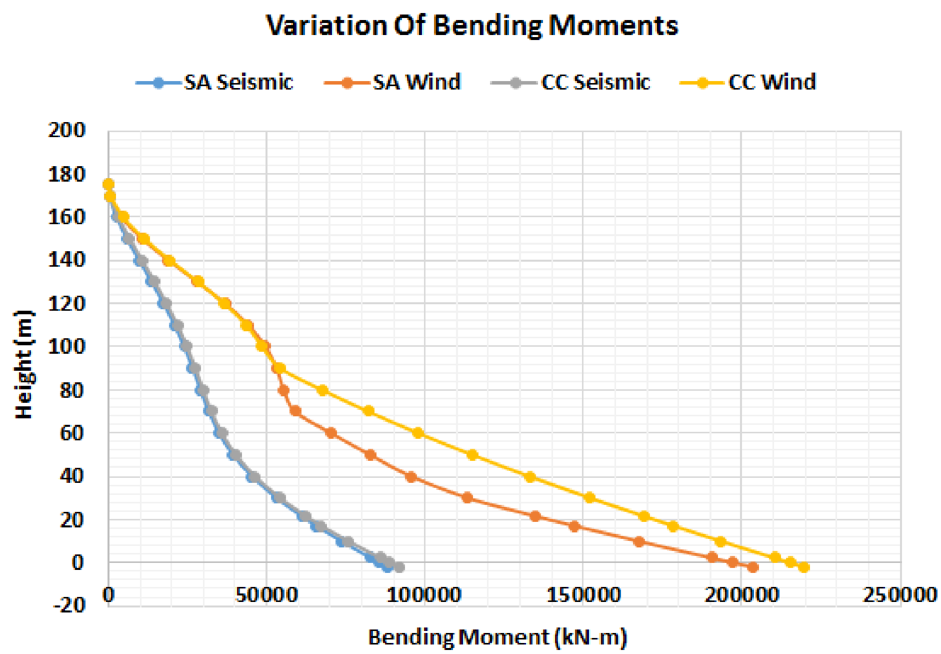

Figure 6.8: 44 - III - Variation Of Bending Moments

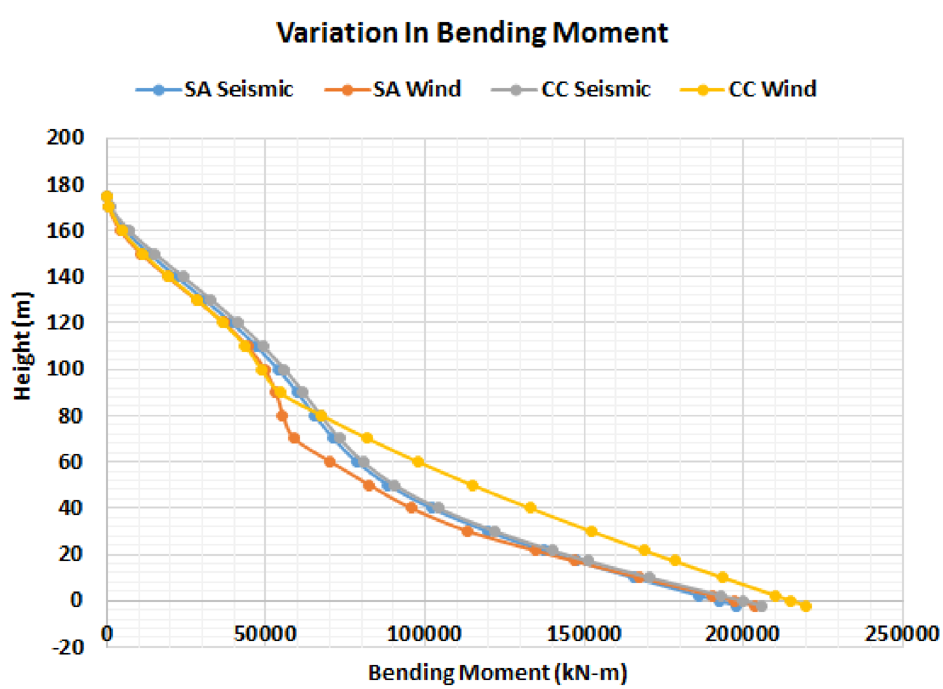

Figure 6.9: 44 - V - Variation Of Bending Moments

6.3.3 Combination (C)

Combination (C) houses the comparison of variation in shear force and bending moment values in case of a 175 m tall RCC chimney located in Agra and Imphal, Manipur having a similar basic wind speed of 47 m/s and seismic zones of III and V respectively. Table 6.5 houses the details of variation in shear forces due to varying parameters and on the same line Table 6.6 houses the variation in bending moments.

Table 6.5: Combination (C) - Variation Of Shear Forces

GOVERNING SHEAR FORCES								
CITY	AGRA (ZONE : III & BASIC WIND SPEED : 47 m/s)				IMPHAL (ZONE : V & BASIC WIND SPEED : 47 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	65	0	97	0	146	0	219	0
170	223	195	262	179	503	195	590	179
160	340	525	368	482	765	525	828	482
150	406	762	425	694	912	762	956	694
140	440	892	458	806	990	892	1030	806
130	454	915	473	819	1021	915	1063	819
120	463	847	484	947	1041	847	1090	947
110	479	799	504	1112	1077	799	1134	1112
100	515	915	546	1273	1159	915	1228	1273
90	581	1029	613	1430	1308	1029	1379	1430
80	675	1190	705	1583	1518	1190	1587	1583
70	792	1571	820	1731	1781	1571	1846	1731
60	924	1958	959	1917	2079	1958	2158	1917
50	1061	2312	1098	2254	2387	2312	2471	2254
40	1193	2610	1247	2536	2685	2610	2807	2536
30	1298	2840	1382	2753	2921	2840	3109	2753
21.6	1353	2981	1470	2885	3044	2981	3307	2885
17.1	1392	3038	1554	2939	3131	3038	3497	2939
10	1416	3105	1584	3001	3185	3105	3564	3001
2.2	1418	3157	1587	3050	3190	3157	3571	3050
0	1418	3169	1587	3061	3191	3169	3571	3061
-2.05	1418	3175	1587	3067	3191	3175	3571	3067

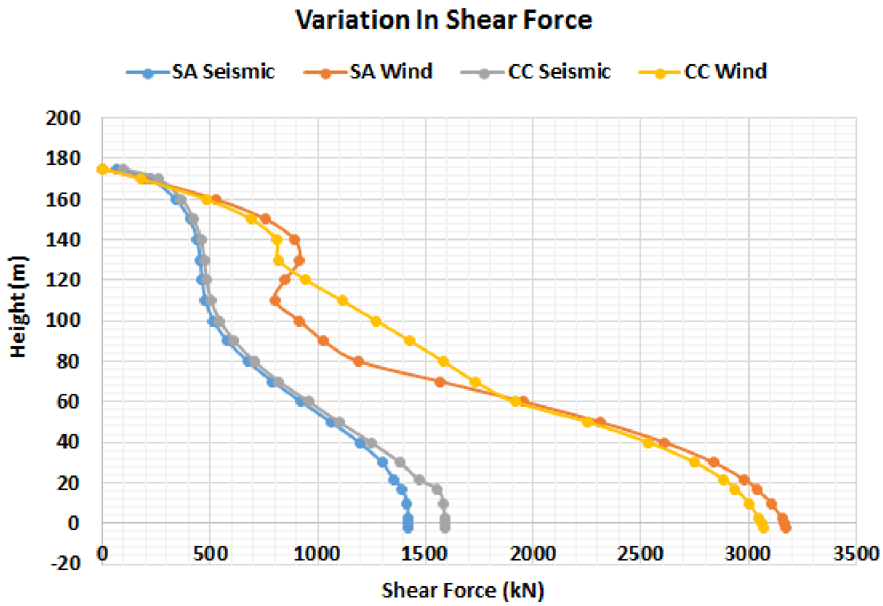

Figure 6.10: 47 - III - Variation Of Shear Forces

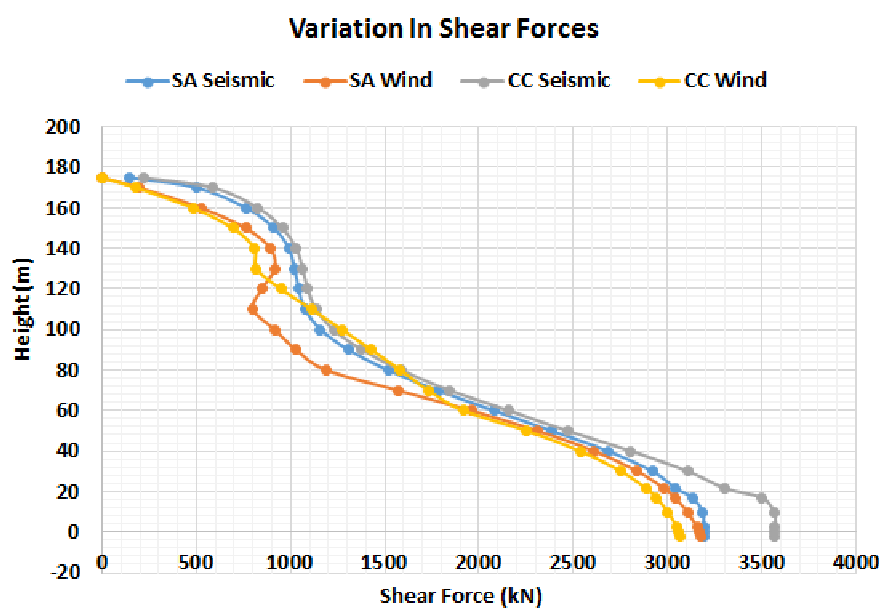

Figure 6.11: 47 - V - Variation Of Shear Forces

Table 6.6: Combination (C) - Variation Of Bending Moments

GOVERNING BENDING MOMENTS								
CITY	AGRA (ZONE : III & BASIC WIND SPEED : 47 m/s)				IMPHAL (ZONE : V & BASIC WIND SPEED : 47 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	0	0	0	0	0	0	0	0
170	324	493	486	679	730	493	1094	679
160	2556	4168	3105	4674	5750	4168	6986	4674
150	5887	10684	6694	11270	13245	10684	15061	11270
140	9709	19032	10637	19492	21845	19032	23932	19492
130	13652	28106	14599	28296	30717	28106	32848	28296
120	17439	36801	18373	36614	39238	36801	41339	36614
110	20890	44176	21800	43560	47003	44176	49050	43560
100	23927	49629	24822	49278	53835	49629	55849	49278
90	26583	53103	27432	62996	59812	53103	61720	62996
80	29046	56254	29881	78280	65354	56254	67232	78280
70	31663	68335	32508	95078	71240	68335	73141	95078
60	34914	81467	35776	113332	78555	81467	80494	113332
50	39331	95607	40201	132985	88494	95607	90451	132985
40	45338	110704	46262	153966	102011	110704	104090	153966
30	53128	126689	54192	176177	119538	126689	121930	176177
21.6	61008	140744	62342	195705	137267	140744	140269	195705
17.1	65671	148489	67250	206466	147759	148489	151311	206466
10	73567	167344	75749	223818	165526	167344	170434	223818
2.2	82823	190531	85859	243327	186350	190531	193180	243327
0	85512	197213	88816	248908	192401	197213	199834	248908
-2.05	88044	203483	91605	254134	198098	203483	206110	254134

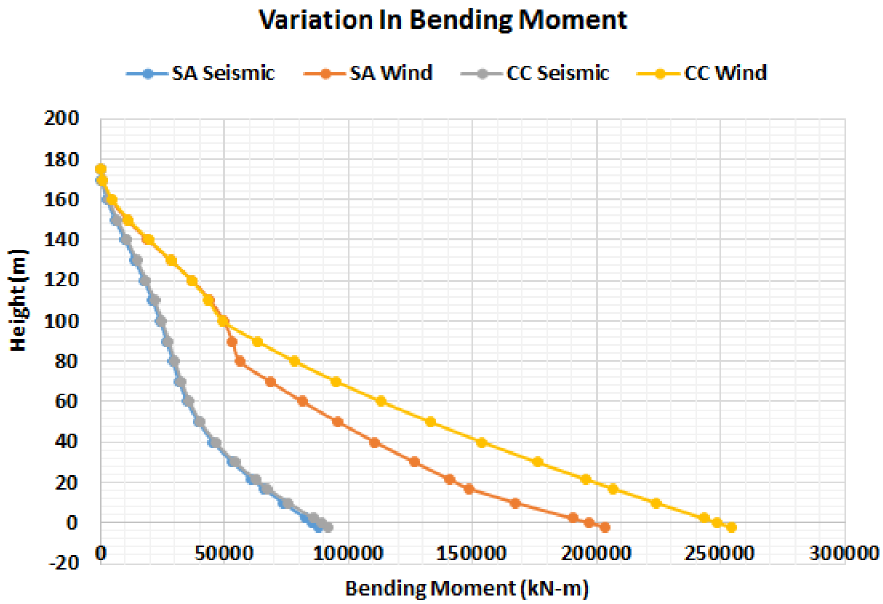

Figure 6.12: 47 - III - Variation Of Bending Moments

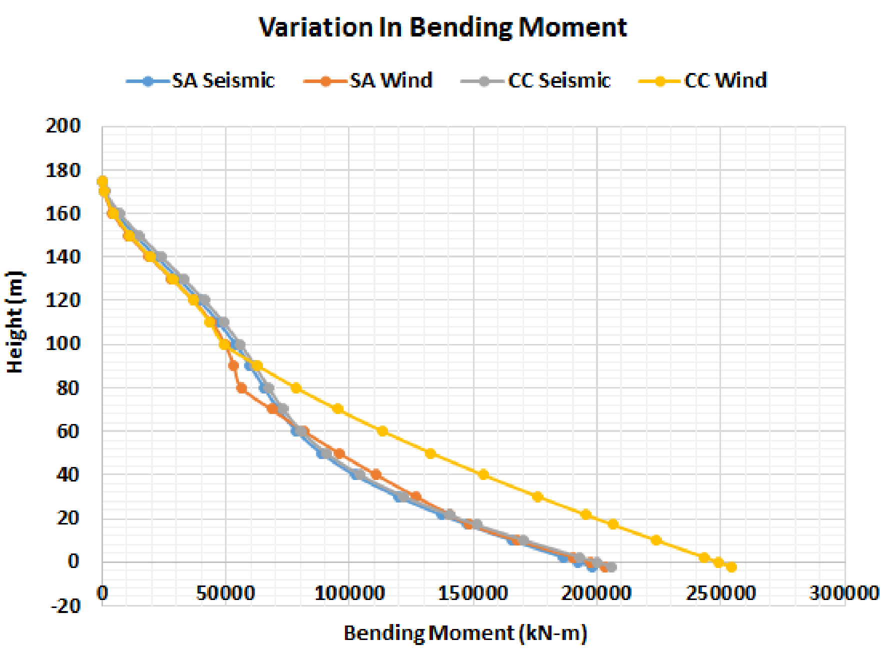

Figure 6.13: 47 - V - Variation Of Bending Moments

6.3.4 Combination (D)

Combination (D) houses the comparison of variation in shear force and bending moment values in case of a 175 m tall RCC chimney located in Bhubhaneshwar and Bhuj having a similar basic wind speed of 50 m/s and seismic zones of III and V respectively. Table 6.7 houses the details of variation in shear forces due to varying parameters and on the same line Table 6.8 houses the variation in bending moments.

Table 6.7: Combination (D) - Variation Of Shear Forces

GOVERNING SHEAR FORCES								
CITY	BHUBHANESHWAR (ZONE : III & BASIC WIND SPEED : 50 m/s)				BHUJ (ZONE : V & BASIC WIND SPEED : 50 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	65	0	97	0	146	0	219	0
170	223	195	262	179	503	195	590	179
160	340	525	368	482	765	525	828	482
150	406	762	425	694	912	762	956	694
140	440	892	458	806	990	892	1030	806
130	454	915	473	898	1021	915	1063	898
120	463	847	484	1090	1041	847	1090	1090
110	479	919	504	1278	1077	919	1134	1278
100	515	1052	546	1462	1159	1052	1228	1462
90	581	1181	613	1643	1308	1181	1379	1643
80	675	1307	705	1817	1518	1307	1587	1817
70	792	1571	820	1986	1781	1571	1846	1986
60	924	1958	959	2150	2079	1958	2158	2150
50	1061	2312	1098	2307	2387	2312	2471	2307
40	1193	2610	1247	2536	2685	2610	2807	2536
30	1298	2840	1382	2753	2921	2840	3109	2753
21.6	1353	2981	1470	2885	3044	2981	3307	2885
17.1	1392	3038	1554	2939	3131	3038	3497	2939
10	1416	3105	1584	3001	3185	3105	3564	3001
2.2	1418	3157	1587	3050	3190	3157	3571	3050
0	1418	3169	1587	3061	3191	3169	3571	3061
-2.05	1418	3175	1587	3067	3191	3175	3571	3067

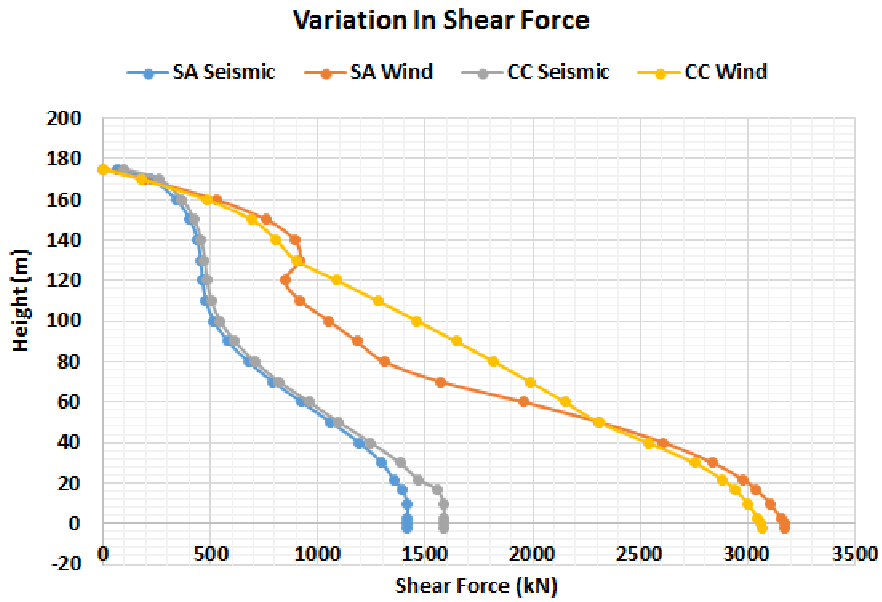

Figure 6.14: 50 - III - Variation Of Shear Forces

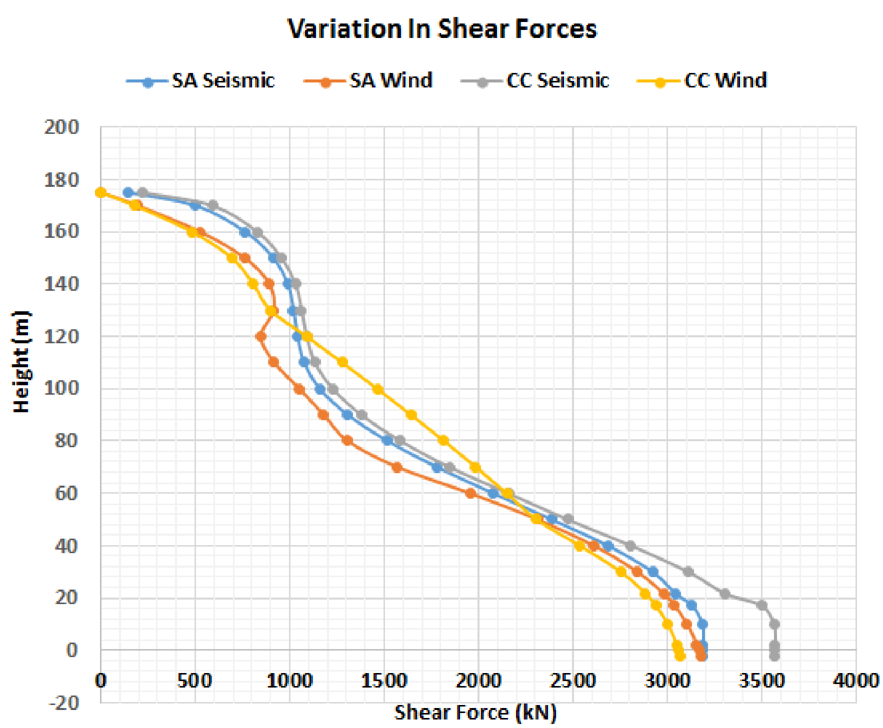

Figure 6.15: 50 - V - Variation Of Shear Forces

Table 6.8: Combination (D) - Variation Of Bending Moments

GOVERNING BENDING MOMENTS								
CITY	BHUBHANESHWAR (ZONE : III & BASIC WIND SPEED : 50 m/s)				BHUJ (ZONE : V & BASIC WIND SPEED : 50 m/s)			
Levels (m)	Shell Alone Case		Chimney Completed Case		Shell Alone Case		Chimney Completed Case	
	SA Seismic	SA Wind	CC Seismic	CC Wind	SA Seismic	SA Wind	CC Seismic	CC Wind
175	0	0	0	0	0	0	0	0
170	324	493	486	679	730	493	1094	679
160	2556	4168	3105	4674	5750	4168	6986	4674
150	5887	10684	6694	11270	13245	10684	15061	11270
140	9709	19032	10637	19492	21845	19032	23932	19492
130	13652	28106	14599	28296	30717	28106	32848	28296
120	17439	36801	18373	36614	39238	36801	41339	36614
110	20890	44176	21800	43560	47003	44176	49050	43560
100	23927	49629	24822	56685	53835	49629	55849	56685
90	26583	53103	27432	72444	59812	53103	61720	72444
80	29046	64659	29881	89996	65354	64659	67232	89996
70	31663	78524	32508	109279	71240	78524	73141	109279
60	34914	93589	35776	130225	78555	93589	80494	130225
50	39331	109804	40201	152768	88494	109804	90451	152768
40	45338	127110	46262	176823	102011	127110	104090	176823
30	53128	145427	54192	202279	119538	145427	121930	202279
21.6	61008	161527	62342	224653	137267	161527	140269	224653
17.1	65671	170397	67250	236979	147759	170397	151311	236979
10	73567	184696	75749	256850	165526	184696	170434	256850
2.2	82823	200773	85859	279186	186350	200773	193180	279186
0	85512	205373	88816	285575	192401	205373	199834	285575
-2.05	88044	209680	91605	291557	198098	209680	206110	291557

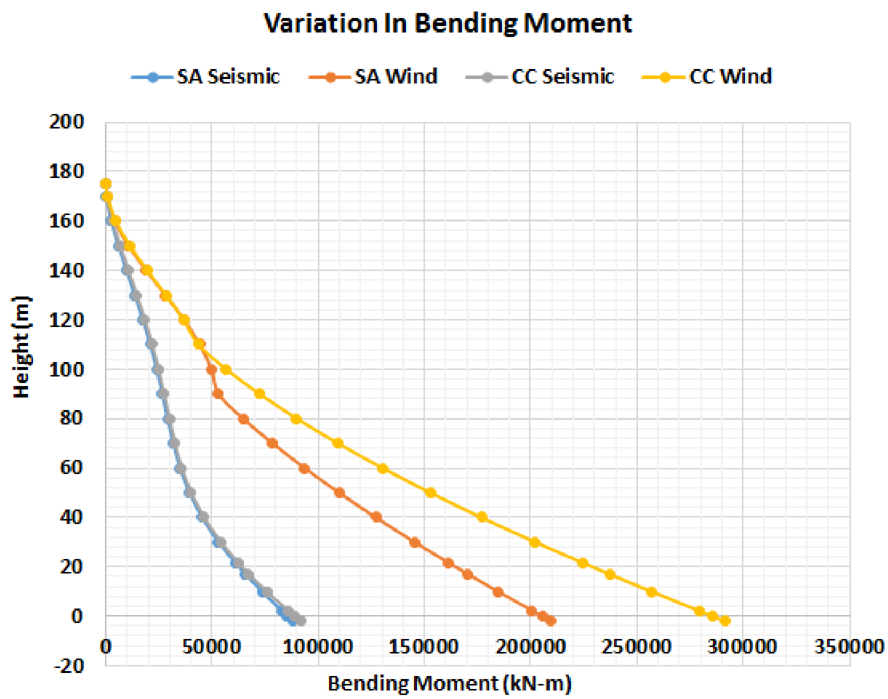

Figure 6.16: 50 - III - Variation Of Bending Moments

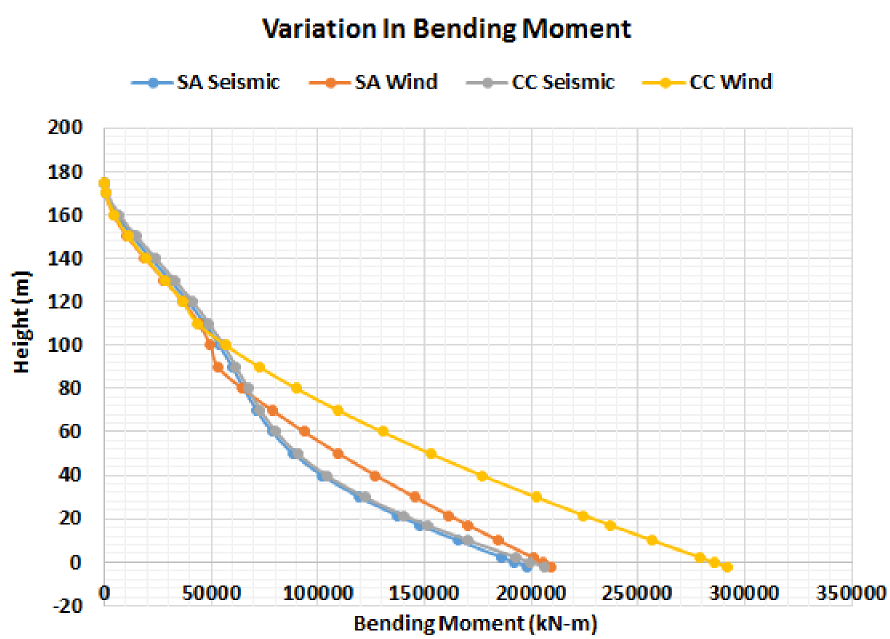

Figure 6.17: 50 - V - Variation Of Bending Moments

6.3.5 Deflection

This section of the chapter gives details of the maximum allowable tip deflection and the deflection values for the chimney under the influence of wind induced loads for different basic wind speeds. Table 6.9 houses the values of deflection of 175 m tall chimney under the influence of different magnitudes of basic wind speed.

The maximum allowable tip deflection as per IS : 4998 (Part - 1) 1975 Pg. 12 Clause 8.1

$$\left(\frac{H}{500}\right) = \left(\frac{175}{500}\right) = 0.35\ m = 350\ mm$$

Table 6.9: Deflection Values Across The Chimney Height

Deflections (mm)				
Levels (m)	Basic Wind Speed (m/s)			
	39 m/s	44 m/s	47 m/s	50 m/s
175	163	213	247	283
170	155	203	235	270
160	139	182	211	242
150	124	162	187	215
140	109	142	164	189
130	94	123	143	164
120	81	105	122	140
110	68	89	103	118
100	56	73	85	97
90	45	59	69	79
80	36	47	54	62
70	27	36	42	48
60	20	26	31	35
50	14	18	21	24
40	9	12	14	16
30	5	7	8	9
21.6	3	4	4	5
17.1	2	2	3	3
10	1	1	1	1
2.2	0	0	0	0
0	0	0	0	0
-2.05	0	0	0	0

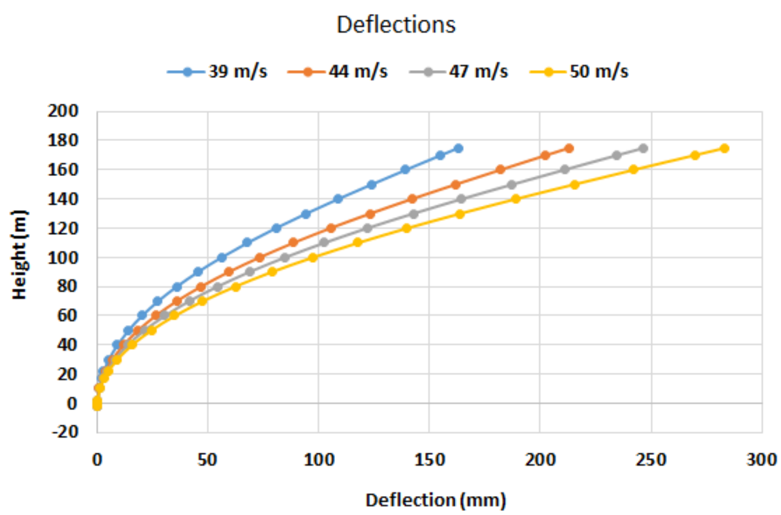

Figure 6.18: Deflection

6.4 Summary and discussion of results

- In this chapter a parametric study was undertaken for a 175 m tall RC chimney by studying the response of the chimney under the influence of four different basic wind speeds in two different seismic zones. An attempt has been made to study the dominance of the type of loading viz. wind and earthquake over the design of the chimney and to establish a zone of transition of the dominant forces. The deflection of the chimney under the influence of different wind speeds was also checked to be within permissible limits.
- From the graphs shown from Fig. 6.1 to Fig. 6.17 and the magnitudes of shear force and bending moment it is evident that in seismic zone III irrespective of the intensity of the wind speed , the magnitude of wind induced forces is higher and govern the design. In the graphs a sharp variation is seen in magnitude of forces over a dedicated zone irrespective of the seismic zone or wind speed. This because of wind speed reaching its critical value over that height range.
- From the plots it is also evident that the values of shear force and bending moment in case of chimney complete condition is more than that in case of shell alone condition irrespective of basic wind speed. Whereas if the seismic response of the chimney is

looked at then it is found to have a fairly uniform and conservative increment in the response of the structure.

- In all the cases the bending moment is found to have a constant value almost up to half the height from the chimney top. The validation to such a nature of seismic response are the moment distribution factors given in IS : 1893 (Part - 4) 2005 Pg. 18 Table 1, which portray a similar variation. From the plots it can be seen that the values of shear force induced due to seismic forces is more for seismic zone V irrespective to wind speeds. The magnitude of earthquake induced bending moments are also considerably higher in zone V except some unduly variation observed for the values of the same in the combination of Zone V and Basic Wind Speed being 50 m/s.

- The deflection of the chimney as shown in Fig. 6.18 for all the different basic wind speed values and seismic zone combinations are very well within permissible limits. With the increase in the basic wind speed the magnitude of wind induced lateral forces and subsequently the deflections increases.

Chapter 7

Conclusions and future scope of work

7.1 Summary

Following theory summarizes in brief the entire work carried out in this major project.

- The loads governing the analysis and design of the chimney have been studied.
- The provisions of IS : 4998 (Part - 1) 1975 / 1992 and IS : 4998 (Part - 1) - April 2013 (Draft Indian Standard) for the analysis and design of reinforced concrete chimney have been studied.
- The provisions of widely used international chimney design standards ACI 307 - 08 and CICIND 2001 have been studied.
- The provisions of draft Indian standard has been compared with the existing chimney design standard as well as ACI 307 - 08 to check the efficacy and acceptability of the draft design standard as a national standard.
- Generalized excel sheets for the along wind and across wind analysis of the chimneys for both simplified method as well as random response method slated in IS : 4998 (Part - 1) 1992 have been prepared. The influence of P-δ effect on the bending moments has also been studied and subsequently calculated. The effect of co-existing along wind load has been taken care of.
- Generalized excel sheets for the calculation of stresses induced in the concrete and steel have been prepared for various load combinations in accordance with IS : 4998 (Part - 1) 1975.

- Manual calculations for foundation design have been incorporated in the report along with the reinforcement detailing sketch.

- Generalized excel sheets for the design of RCC shell (Working Stress Method) viz. vertical reinforcement, circumferential reinforcement and reinforcement around ducts/openings have been prepared.

- Software STAAD.Pro has been used for the seismic analysis to obtain natural frequencies and mode shapes of the chimney over and above the magnitudes of earthquake induced forces and bending moments.

- Parametric study has also been done for the chimney by considering two different seismic zones and four different basic wind speeds to establish an understanding regarding the governance of wind induced forces or seismic forces with varying seismic zone and wind speeds.

7.2 Conclusions

The following conclusions can be asserted from the work carried out in this major project:

- Across wind analysis by simplified method yields results which are around 30 % to 50 % higher than the results of along wind analysis using Random Response Method in both the different analysis conditions.

- The reason for the conservative results produced by this method as mentioned in the few research papers and Indian standard as well is the paucity of basic fluid-elastic interaction information, sufficiently acceptable data on atmospheric turbulence in several parts of our country and absence of any systematic full scale investigation on tall structures in our country.

- Wind induced base shear is having values considerably higher than the seismic base shear. Along wind moments computed by random response method are higher in top portion of the chimney up to a certain height.

- In a higher seismic zone the earthquake induced forces and bending moments govern the design.

- Moment and shear distribution along the height of the chimney show very minimal variation up to half the height of the chimney from the bottom irrespective of the seismic zone.

- The tip deflection values computed by simplified method give conservative results. The tip deflection values are increase with the increase in the basic wind speed values. The tip deflection values are within the permissible limit for all the basic wind speed values considered.

- The temperature gradient observed across the entire height of the chimney is fairly uniform except in the region where lining is present and a sharp decrement in the value of temperature gradient is observed. The temperature gradient in the region where lining is absent ranges from 24^0C to 27^0C and in the area where lining is present the temperature gradient is in the range of 14.23^0C to 14.77^0C, which refers to a considerably controlled value.

- The variation in the stresses due to (DL + WL) and the subsequently fluctuating position of neutral axis govern the reinforcement requirement of the chimney. The reinforcement across the height of the chimney varies from 0.45 % to 0.80 %.

- The stress calculations show that shell thickness usually provided is such that it is always adequate enough to control the stresses and the remaining part is played by the vertical steel in addressing the stresses induced in the shell. Hence minimum amount of circumferential reinforcement is usually sufficient for any chimney and so was the case in the present study.

7.3 Future Scope Of Work

- Design of chimney according to the latest revision of IS : 4998 (April 2013) – Draft Indian Standard.
- Design of chimneys considering soil structure interaction.
- Detailed study, analysis and design of Solar chimney and its foundation system.

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