STUDY ON CHARACTERIZATION OF WIND AND ITS EFFECTS ON STRUCTURES

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Study on Characterization of Wind and its Effects on Structures

Major Project

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CIVIL ENGINEERING

(Computer Aided Structural Analysis And Design)

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Ruchita R. Jamdar

Certificate

This is to certify that the Major Project Report entitled **"Study on Characterization of Wind and its Effects on Structures"** submitted by **Ms. Ruchita R. Jamdar (Roll No: 12MCLC10)** towards the partial fulfillment of the requirements for degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis And Design) of Nirma University is the record of work carried out by her under our supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Due to the complexity of wind, all the major codes and standards of various countries have considered it as Equivalent Static Wind Load (ESWL). For tall and slender structures the dynamic method i.e. Gust Factor Method, originally proposed by Davenport(1967) for the estimation of wind load on structure, is based on the Displacement based Gust Loading Factor (DGLF). Zhou and Kareem (2003) have highlighted that the Moment based Gust Loading Factor (MGLF) offers a more realistic way of distribution of the ESWL along the height of the building compared DGLF.

The present study focuses on understanding the wind characterization methodology of DGLF and MGLF in detail. It also aims towards comparing DGLF based existing Indian code IS:875 (Part-III)-1987, the method proposed in IS 875 Draft code by Bhandari et. al. (2002) and the MGLF procedure proposed by Zhou and Kareem(2003). A 30 storey, wind governed, Reinforced Concrete (R.C.) symmetric building is considered. Response quantities like Lateral Wind Force, Base Shear, Overturning Moment, Displacement and Storey Drift are calculated and compared using the above mentioned three approaches. Also a parametric study has been conducted by varying height of the building considering 40,50 and 60 storeys to compare DGLF and MGLF method and the same quantities have been compared with the addition of comparison of column reinforcement.The MGLF method gives maximum values of lateral forces as compared to other two methods. As a result it is observed that application of MGLF increases the column reinforcement on an average by 30% for all the three buildings.

Further, the application of the MGLF method is extended to a problem of a steel chimney and the results are compared with the existing design code IS 6533(Part 2)-1989. In case of chimney too, the implementation of MGLF yields higher results of lateral forces and results in higher thickness of the stack plates which results in increase in steel quantity.

Acknowledgement

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Abbreviations, Notations and Nomenclature

β .... Mode shape coefficient

λ .... Mass reduction factor

V_z .... Design wind speed in m/s at height z;

V_b .... Basic wind speed in meter per second.

k_1 .... Risk coefficient factor

k_2 Terrain, height and structure size factor given in Table 2 of IS: 875 (Part 3)-1987;

k_3 .... Topography factor given in Section 5.3.3 of IS: 875 (Part 3)-1987;

p_z .... Design wind pressure in N/m2 at height z;

F .... Force acting in a direction parallel to the direction of the wind;

C_f .... Force coefficient for the building or structure

A_e .... Effective frontal area of the building or structure; and

p_d .... Design wind pressure.

C_y .... Lateral correlation constant

C_z .... Longitudinal correlation constant

b = Breadth of the structure normal to the wind stream;

h= Height of the structure;

V_h .... V_z = Hourly mean wind speed at height z;

f_o .... Fundamental natural frequency of the structure; and

L_h .... Measure of turbulence length scale

k_1 ...... Probability factor given in Table 1 of IS: 875 (Part 3): Proposed Draft and Commentary;

k_2 .... Terrain roughness and height factor given in Table 2 of IS: 875 (Part 3): Proposed Draft and Commentary;

k_3 .. Topography factor given in Section 5.3.3.1 of IS: 875 (Part 3): Proposed Draft and Commentary;

k_4 ..... Importance factor cyclonic region given in Section 5.3.4 of IS : 875 (Part 3): Proposed Draft and Commentary;

p_z .... Wind pressure at height z in N/m^2;

V_z .... Design wind speed in m/s at height z;

p_d .... Design wind pressure in N/m^2 at height z;

K_d .. Wind directionality factor given in Section 5.4.1 of IS: 875 (Part 3): Proposed Draft and Commentary;

K_a . Area averaging factor given in Table 4 of IS: 875 (Part 3): Proposed Draft and Commentary;

K_c .. Combination factor given in Table 19 of IS: 875 (Part 3): Proposed Draft and Commentary;

F_z Along wind equivalent static load on the structure at any height z corresponding to strip area A_e;

A_e .... Effective frontal area.

TC .... Terrain Category

DGLF .... Displacement based Gust Loading Factor

MGLF .... Moment based Gust Loading Factor

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Chapter 1

Introduction

1.1 Background

Wind is air in motion. Any structure acts like an obstruction to the flow and deflects or stops the wind, converting the winds kinetic energy into potential energy of pressure, thus creating wind loads.

The effect of wind loads on structure depends on the interaction of various natural as well as building variables. Together these variables create differences in the pressure termed as pressure fluctuations whose effect is to push or pull the building's exposed surfaces.

As many uncertainties are involved, the maximum wind loads acting upon the structure during its service period may vary widely from its assumed design. Also, while designing for wind, the structure cannot be considered independent of its surroundings. The influence of nearby buildings and topography on the dynamic response of the building can be considerable. These effects are termed as interference effects.

These fluctuating pressures can result in fatigue damage to structures, and in dynamic excitation, if the structure happens to be dynamically wind sensitive.

These pressures are also not uniformly distributed over the surface of the structure, but vary with position.

While designing for wind, the main response quantities are displacement and acceleration. The sway at the top of a tall building caused by wind is of great concern to those occupying its top floors. The limits are specified in different codes and standards as limiting acceleration.

1.2 Need of the Study

Till date, the most reliable estimate of wind loading is only obtained by a thorough wind tunnel testing of the scaled model of structure which is time consuming as well as expensive.

Hence, it is necessary to study and evaluate the accuracy and reliability of the analytical approach given in standard codes.

1.3 Objectives of Study

The objectives of the present study are:

i To understand the characterization of wind.

ii To study the wind load in detail and its effect on structures.

iii Codal comparison for calculation of wind load using gust factor approach for buildings.

iv Application of MGLF procedure to calculation of wind load for buildings and steel chimney.

v To carry out analysis and design of building using professional software ETABS.

vi To carry out analysis of steel chimney using software SAP 2000.

1.4 Scope of Work

The scope of the present study consists of the following:

i Characterization of Wind Load.

ii Comparison of IS 875(III)-1987[5] and the IS 875(III) Proposed Draft Code[10] and Australian Code AS/NZS1170.2: 2002 Structural Design Actions-Part 2: Wind Actions.[6]

iii Understanding the gust factor approach in detail given in IS 875(III)-1987 and IS875 (III) Draft Code.

iv Calculation of wind effect on a tall building using static and dynamic methods given in IS 875(III)-1987[5] and the Proposed Draft Code[10].

v Use of professional software ETABS for analysis and design of tall building.

vi Comparison of Moment based gust loading factor(MGLF) and Displacement based gust loading factor(DGLF) by comparing IS 875(III)-1987 Dynamic Method and MGLF procedure suggested by Zhou and Kareem[8].

vii To carry out parametric study by varying height of tall building to compare DGLF and MGLF.

viii To apply MGLF to a problem of Steel Chimney.

ix Use of SAP 2000 for purpose of analysis of steel chimney.

1.5 Organization of Report

The contents of major project are divided in to various chapters as follows: **Chapter1** covers the introduction to the topic and the overall background of the report in the form of need of study, objective of study and scope of work.

The literature review is presented in **Chapter 2**. It provides an overview of the referred research papers available in journals and reference books and they are categorized as per their content.

The behaviour of the wind and its characterization is discussed in **Chapter 3**. It includes the basic information from research papers and books related to how wind is described and characterised. A brief comparison of clauses of IS 875(III)-1987 and IS 875 (III) Draft Code along with the description of static and dynamic method presented in both the codes and the important clauses and the formulae are presented. It also covers details regarding the gust loading factor approach and the suggested modification to the traditional gust loading factor given in codes by a new model proposed by Kareem and Zhou.[8].

The **Chapter 4** PART I: A 30 storey sea facing RC symmetric building is considered. The building sea face is assumed to be in Terrain Category (TC) 1 and the other 3 faces are considered to be in TC 4. The wind forces on this building are evaluated by three methods:(i) IS 875(III)-1987 Static Method ; (ii) IS 875(III)-1987 Dynamic Method and (iii) IS 875(III) Draft Code. The Lateral forces and Storey Shear Distribution are compared.PART II: The same 30 storey building is solved by MGLF procedure and is compared with the existing DGLF procedure and quantities like lateral forces, displacement, base shear, overturning moment, storey drift are determined and compared.PART III: Parametric study has been carried out to compare MGLF and DGLF by varying height of the building i.e. considering 40,50 and 60 storey buildings. The same response quantities are evaluated and compared. Also comparison of reinforcement for columns has been done.

Chapter 5 contains the example of application of MGLF to steel chimney. The comparison is carried out between IS 6533(Part 2)-1989 and the MGLF method and the analysis and design of chimney has been carried out.

Chapter 6 contains the summary and the future scope.

Chapter 2

Literature Review

2.1 General

Various reference books and research papers have been referred to understand basic behaviour, modelling and derivation of wind loads and dynamic analysis of structure in response to wind excitation.

An extensive review of the literature relevant to development of wind spectrum i.e. its characterization, derivation of gust loading factors for evaluating the dynamic response of wind to structures and comparison of major international codes were referred and their brief description is presented in this chapter.

2.2 Literature Review

Various books and research papers have been studied and a brief review of the same is discussed.

2.2.1 Characterization of wind:

Davenport's [2] paper discusses three key spatial functions which control the magnitude of responses: the influence lines, the mode shapes and pressure distributions.

The paper describes how the different time dependent loadings - the mean, the background and resonant responses - are related to the spatial functions.

Giovanni Solari [21] presented the equivalent wind spectrum technique which is a mathematical model according to which wind is schematized as a stochastic stationary Gaussian process made up of a mean-speed profile on which an equivalent turbulent fluctuation, perfectly coherent in space, is superimposed.

This paper presents the basic assumptions and the theoretical steps leading to the characterization of the equivalent velocity fluctuation through a power spectrum assigned in closed form. The method proposed herein allows one to estimate the dynamic along-wind response of structures, both in frequency and in time domain, with a high level of precision and simplicity; furthermore it makes it possible to treat wind effects, as well as those of earthquakes, through the well-known response spectrum technique.

Agarwal et. al. presented a comparitive study of different wind characteristics related to calculation of dynamic wind load for various terrain categories with experimental results verified with available literature. The different codes studied are Japanese, Australia/New-Zealand, American, British/European, Canadian, Hong-Kong, Chinese and Indian [existing (1987) as well as proposed (2011)]. It describes the definitions and explainations of various wind characteristics like mean wind velocity, turbulent intensity profiles, integral length scale of turbulence and power spectral density.Also the differences in various codes' standards for the above parameters have been discussed with reasons.

For the purpose of understanding of characterization of wind and basic description of wind the following two books were referred namely **Simiu and Scanlan**[11] & **Dyrbye and Hansen.**[12].

2.2.2 Gust Loading Factor

Kareem and Zhou[1] presented a detailed study and derivation of the traditional and the moment based gust factor approach. It describes how the traditional gust loading factor adopted in almost all codes and standards is displacement based and they have also highlighted some of the short comings of this displacement based gust loading factor(DGLF). To overcome this shortcoming, a more realistic and consistent procedure in the form of an alternate model is presented, in which, the gust loading factor is based on the base bending moment rather than displacement.Hence it is known as Moment Based Gust Loading Factor (MGLF). Further in the paper, this approach is also extended to 3D gust loading factor. Hence, not limiting it to just along wind response but extending to across wind responses also. It is formulated in a format that is similar to code procedure and familiar to most design engineers.

Zhou et. al.[8] presented gust loading factors for design application. Numerical examples are presented to demonstrate the efficacy of the proposed procedure in light of the traditional approach. The traditional DGLF method usually does not differentiate the cases that have non-linear mode shapes or non-uniform mass, or both, from the case that has a linear mode shape and uniform mass. Solving a hypothetical tall building as an example, it is shown that the equivalent static wind(ESWL) load derived from the traditional DGLF method may deviate from the actual value, and consequently may lead to unfavourable estimates of some wind induced load effects. The proposed method i.e. the MGLF method uses the existing information, which permits a smooth transition from the DGLF to the MGLF formulationa convincing feature for possible adaptation by codes and standards.

2.2.3 Code Comparison

Zhou et. al[3] presented the comparative study of all the major international codes namely ASCE 7-98 (United States), AS1170.2-89 (Australia), NBC-1995 (Canada), RLB-AIJ-1993 (Japan), and Eurocode-1993 (Europe) using a detailed example, to obtain along wind load effects on tall buildings. The comparisons consider the definition of wind characteristics, mean wind loads, gust loading factors based on displacement, moment and wind velocity. It is noted that the variation in the predicted wind loads and their effects arises primarily from the variations in the definition of wind field characteristics in the respective codes and standards. Such variations lead to variation in results of different parameters.

P. Harikrishna et.al. [4] have presented the design of dynamically sensitive steel lattice towers against wind loads using a gust response factor (GRF) approach using IS, BS and AS codes. A full-scale field experiment on a 52 m tall steel lattice tower has been carried out to measure wind characteristics and structural response. The GRF for base bending moment and top deflection have been evaluated using the measured structural response and are compared with those obtained from the IS, AS and BS codes using the measured wind velocities and the terrain roughness lengths.

Halder and Dutta [20] have given comparisons of the wind forces obtained by Indian Standard and that by American Standard are presented for some representative cases to show the relative level of protection attributed by Indian wind codes. The study also includes an exhaustive comparison of the wind forces obtained by Force coefficient based static analysis and Gust factor based dynamic analysis interpreting where which method should be used for better protection. The large number of case studies are presented in the paper in the form of the various curves.

2.2.4 Steel Chimney

Raghupathi M. [24] comprises basic theory related to the chimney, includes different chimney parameters like dimensions, allowable stresses, loading,allowances, load cases etc. from the different IS codes for the analysis and design. For present study this is book is the main literature from which the problem statement of the steel chimney is taken.

Chhaya Z. [26] has developed an interactive software for the complete analysis, design and drafting of the self supported mild steel. he has also presented a comparison of methods of modelling a chimney in software wherein he has concluded that for stick model of chimney the dynamic parameters like time period and mode shapes are in close agreement with the code of practice for chineys i.e. IS 6533 (Part-2)-1989.

2.3 Summary

Some of the key people in the wind engineering are A. G. Davenport, Ahsaan Kareem, T. Stathopoulous, G. Solari and Yin Zhou. Their work can be considered as the most fundamental in the field of wind engineering and some of their key publications have been mentioned. In most of the codes and standards the dynamic method of analysis i.e. the gust factor method is based on the work by Davenport(1967). But still there is a great deal of scatter present in the estimated wind load even for the same problem. Hence there is great deal of scope of work required to be done for comparison of these codes and to understand them in detail.

There are various other methods also presented in literature which give different methods of evaluating the equivalent static wind load(ESWL) for different structures. The moment based gust laoding factor is one of those methods. It is proposed that it presents a more realistic way of calculating the ESWL for a given structure.

Chapter 3

Characterization of Wind Load

3.1 General

All buildings sway during windstorms, but the motion in earlier tall buildings with heavy full-height partitions was imperceptible and certainly not a cause for concern. But structural innovations and lightweight construction technology have reduced the stiffness, mass, and damping characteristics of modern buildings.

In buildings experiencing wind motion problems, objects may vibrate, doors and chandeliers may swing, pictures may lean, and books may fall off shelves. If the building has a twisting action, its occupants may get an illusory sense that the world outside is moving, creating symptoms of vertigo and disorientation. In more violent storms, windows may break, creating safety problems for pedestrians below. Sometimes, strange and frightening noises are heard by the occupants as the wind shakes elevators, strains floors and walls, and whistles around the sides, whistles around any leakages in window panes or openings in buildings at higher altitudes.

Thus in order to control wind it is first essential to understand it completely and to be able to formulate it in the best possible manner.

3.2 Behaviour of Wind

Wind is composed of a crowd of eddies of varying sizes and rotational features carried along in a general stream of air which is moving relative to the earths surface mainly due to temperature and pressure differentials present in the atmosphere.

These eddies give wind its gusty or turbulent nature. The gustiness of wind is observed to be more where the terrain is more rough. At greater heights and planar surfaces, wind is much more smoother and free flowing.

Consider Figure 3.1, which shows the measured wind speed at three elevations on a mast during an 8-minute time interval.

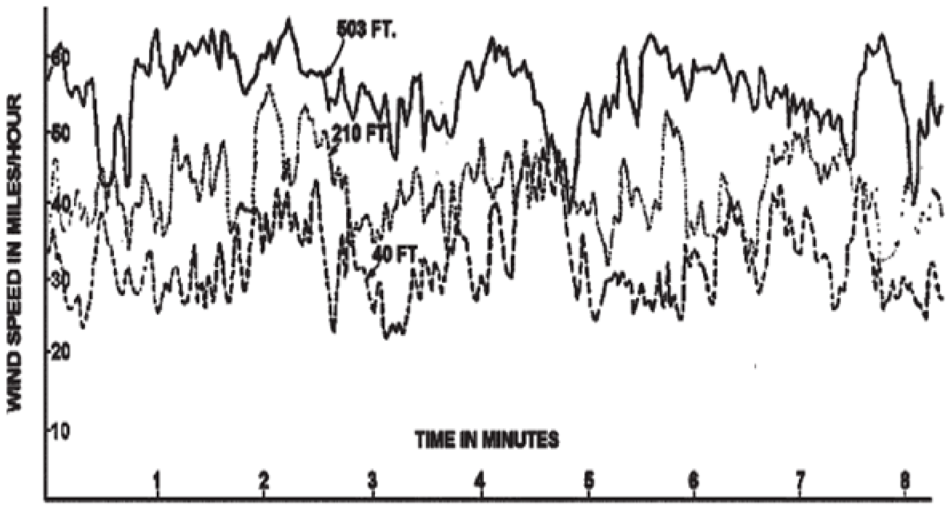


Figure 3.1: Wind speeds at three heights on a 500-ft mast (Davenport 1966, 1967)

The following quick observations can be made from the plot:

a. The wind speed can be described as a mean value upon which random fluctuations or "gusts" are superimposed(as shown in Figure 3.2).

b. The mean wind speed increases with height above the ground.

c. There is no obvious correlation between the fluctuations at the different heights.

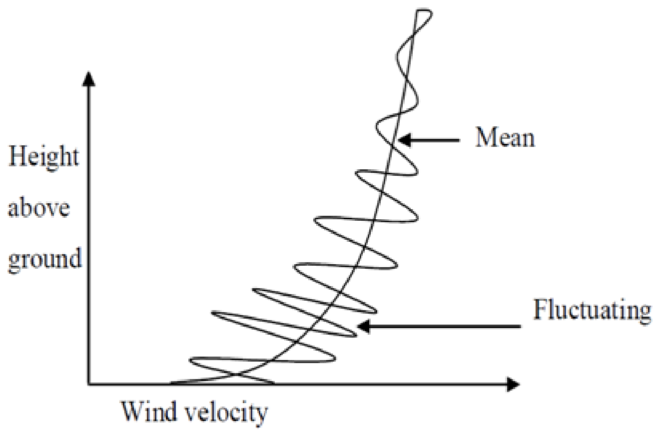


Figure 3.2: Variation of wind velocity with height.

d. The average wind speed tends to increase with height, while the gustiness tends to decrease with height.

e. The fluctuations are also random in time i.e. the waveforms do not repeat.

f. The wind speed at any time can be described statistically but not predicted exactly.

Therefore, in the most elementary description of wind, the wind velocity vector at a point may be regarded as the sum of mean wind vector (static component) and a dynamic, or turbulence component.

$$V\ (z,t) = V\ (z) + v(z,t)$$

In the later discussions, the static or mean component is addressed as background component and the fluctuating component is addressed as resonant component.

3.3 Characterization of Wind Loading

The characterization of the wind loading on structures is essential for the assessment of the performance of the structure under wind loading.

The nature of wind is stochastic and therefore the Power Spectral Density(PSD) is a convenient way to characterize the dynamic wind loads. The Power spectral density reflects the contribution to turbulence energy at each frequency.

For design purpose, there are four possible approaches to determine the power spectral density of wind:

a. **Utilization of established wind Power Spectral Density shapes proposed in Literature.(Method applied in standard codes).**

   Based on site observations and detailed investigation of wind time histories, the von Karman spectrum has been found to adequately represent the wind energy content in the frequency domain.

   The von Karman spectrum characterizes the energy content of wind in the frequency domain using three parameters:

   (1) The mean wind velocity $\bar{U}$.

   (2) The integral scale of turbulence, which gives information on the average size of the turbulent eddies in the stream and is obtained from the autocorrelation function of the turbulent velocity.

   $$R = \frac{\int_0^{To}(u(t)u(t+\tau)dt\tau}{\int_0^{To} u^2(t)dt} \tag{3.1}$$

   (3) The turbulence intensity, which is defined as the ratio of the standard deviation of the wind speed divided by the mean speed indicates the turbulence level.

   $$I = \frac{\sigma u}{U} \tag{3.2}$$

   Turbulence is generated by the friction on the ground and drag on surface obstacles, and is influenced by the terrain roughness just as is the mean wind speed profile.

After setting all these parameters, the **von Karman spectrum** takes the form of following expression of power spectral density of fluctuating wind velocity,

$$S_u(f) = I(\bar{U})^2 \frac{4L}{\bar{U}} [\frac{1}{1 + 70.78(\frac{fL}{\bar{U}})^{2^{\frac{5}{6}}}}] \quad (3.3)$$

where; $\bar{U}$ is the mean speed, L is the integral scale of turbulence, I is the turbulence intensity and f is the frequency. This spectral density is modified by a multiplication factor known as aerodynamic admittance function, which takes into account the interaction between structure and the wind flow. The **aerodynamic admittance function** χ**(f)** relates Su(f) to the power spectral density of fluctuating wind flow Sp(f).

$$\text{Sp(f)}=\chi\text{(f) Su(f)}$$

Thus, to conclude, this approach requires guessing a number of flow characteristics and flow related structural parameters upon which the resulting wind power spectral density depends. But this process of presumption is delicate and sensitive and mainly based on experienced judgement or detailed study of various flow situations.

Also the naive use of the aerodynamic admittance function, which greatly lowers the wind energy content at high frequencies for large structures, may lead to erroneous results.

Moreover these results loose validity if the interaction between wind and structure happens in a region of flow re-circulation or at high turbulence intensity or the structure is too large or tall.

b. **Use of Wind Tunnel Tests**

A wind tunnel test is arguably the most valuable and nearly accurate method of determining the power spectral density of wind flow. But the main difficulty of this approach is that it requires available facilities, hardware models and the scaled replica of the exact site condition. Also matching the turbulence intensity and the integral turbulence scale is difficult. In addition to that matching the Reynold's number sometimes limits the scale of model to be tested. Nevertheless, it still is an important tool to obtain the exact pressure distributions on the surface of the structure.

c. **Computational Fluid Dynamics(CFD)**

CFD also provides a method to study fluid flow. It requires use of very powerful computing facilities hence its use was limited to simple geometries and less turbulent flows in the past. But now with the advent of powerful computational tools, most of the computer programs solve the complete Navier-Stokes equations CFD has become an effective mean to characterize both steady and transient flow parameters. It gives the possibility to calculate accurate and unconditionally stable velocity and pressure time histories in highly complicated geometries and high Reynolds numbers. Wind pressure on surfaces, global reactions, flow speed can be calculated in a number of points of interest which act exactly like instrumented points in a wind tunnel model.

d. **Full scale measurements**

This is of course the best way to characterize the wind flow loading on a structure. It may be possible for small structures. It may also represent a viable method if a structure comparable to the one being designed exists. The main difficulty is to extend the results to the actual case, for instance because of different input wind PSD due to differences in the topography of the site or of terrain roughness.

3.4 Components of Wind

In general, wind against a bluff body gets diverted in three mutually perpendicular directions, giving rise to forces and moments about the three directions.

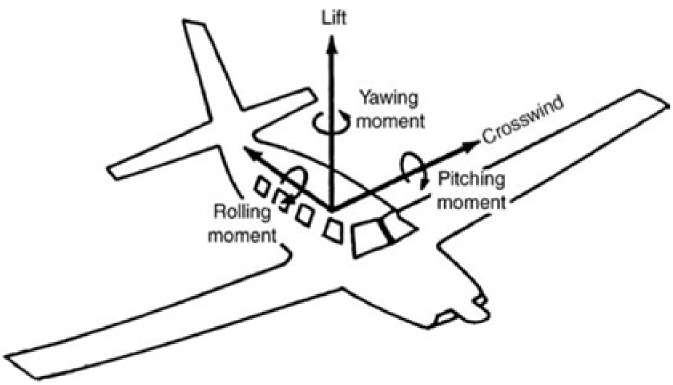


Figure 3.3: Six Components of Wind

Although all six components, as shown in Figure 3.3 , are significant in aeronautical engineering, in civil and structural work, the force and moment corresponding to the vertical axis (lift and yawing moment) are of little significance. Therefore, aside from the uplift forces on large roof areas and lift forces for decks of long span bridges, the flow of wind is simplified and considered two-dimensional.

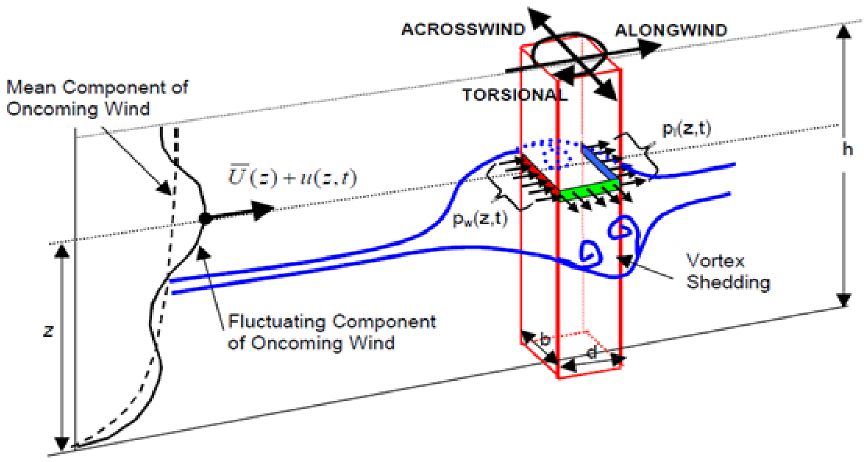


Figure 3.4: Description of oncoming wind field and resulting wind-induced effects on structure.

Not only is the wind approaching a building a complex phenomenon, but the flow pattern generated around a building is equally complicated by the distortion of the mean flow forming boundary layer, flow separation, the formation of vortices, and development of the wake. Under the collective influence of these fluctuating forces, a building tends to vibrate in rectilinear and torsional modes, as shown in Figure 3.4 above.

The three dimensional simultaneous loading due to wind on the structure results in three structural response components:

a. **Along-wind Component -** Primarily results from pressure fluctuations in the approach flow and results from drag forces, leading to a swaying of the structure in the direction of the wind.

b. **Across-wind Component -** It causes swaying motion perpendicular to the direction of the wind and are introduced by side-face pressure fluctuations primarily induced by the fluctuations in the separated shear layers, vortex shedding and wake flow fields.

c. **Torsional Component -** It results from the imbalances in the instantaneous pressure distribution on the building surfaces.

The amplitude of such oscillations is dependent on the nature of the aerodynamic forces and the dynamic characteristics of the building.

Also these wind load effects are further amplified on asymmetric buildings as a consequence of inertial coupling, uneven stiffness's...etc in the building structural system.

3.5 Codal Comparison

IS 875(III)-1987[5] is the present code for calculation of wind loads on structures. Apart from the present code a **draft code** [10] has also been proposed recently which suggests a different method for calculation of dynamic response of building. The dynamic response of a low-rise building is likely insignificant, assuming it has been adequately designed for both strength and stiffness limit states. (As per all design codes including IS 875(Part III)-1987).

However, it is also important to quantify and justify the case where dynamic response may be neglected.

Present code IS 875(III)-1987 specifies two methods for evaluating the wind equivalent wind forces:

a. **Static Method**

b. **Dynamic Method (Gust Factor Approach)**

The buildings fundamental natural frequency of vibration, f_o is the most widely accepted property of a structure used to determine whether dynamic response will be significant under wind loading.

"Any buildings or structure with a height to minimum lateral dimension ratio of more than about 5.0 and/or whose natural frequency in the first mode is less than 1.0 Hz shall be examined for the dynamic effects of wind. i.e. it is to be solved by gust factor method."

However, due to the simplicity of the procedure, the design engineers are more comfortable in the static procedure for analyzing the typical low, medium and high rise buildings which are widely constructed.

3.6 Static Method(Force Coefficient Method)

In case of static method the equivalent wind load is calculated in the form of pressure varying with height of the structure. It only takes into account the mean component of wind velocity by neglecting the fluctuating component.

3.7 Dynamic Method(Gust Loading Factor Approach)

3.7.1 Displacement Based Gust Loading Factor(DGLF):

The gust loading factor (GLF) approach is for evaluating the along wind loads due to the buffeting action of wind. The traditional gust loading factor expressed in codes was originally formulated by A. G. Davenport in 1967.

$$X_{max} = X_{mean} + X_{fluctuating}$$

The **Gust response factor** is defined as

$$G(z) = 1 + \frac{Xmax(z)}{Xmean(z)} \tag{3.4}$$

According to GLF method, the equivalent static wind load(ESWL) is equal to the mean wind force multiplied by the GLF.

$$P(z) = G.\bar{P}(z) \tag{3.5}$$

This gust factor is known as Displacement Based Gust Loading Factor(DGLF).

As per Kareem and Zhou [1] it ensures accurate estimation of displacement response, it falls short in providing a reliable estimate of the other responses like bending moment and shear forces. In this scheme, the equivalent-static wind loading used for design is equal to the mean wind force multiplied by the GLF. The GLF accounts for the dynamics of wind fluctuations and any load amplification introduced by the building dynamics.

Despite its simplicity and many advantages, it is noted that the current GLF-based formulation has the following shortcomings:

a. Relatively stiffer structures may also be affected by the potential inaccuracy in the distribution of the background loading component.

b. Although the gust factor was originally defined for any load effect, it is actually based on the displacement response, i.e., the gust factor is essentially the ratio between the extreme and the mean displacement response.

c. The DGLF is used indiscriminately for any response component in practice, which may yield inaccurate estimates. Because only the fluctuating and mean displacement responses in the first mode are included in the derivation, the gust factor is constant for a given structure.

   When a constant gust factor, i.e., independent of height is used for estimating the extreme equivalent wind loading, its distribution is the same as that of the mean wind loading. This contradicts the common understanding of the equivalent wind loads on tall, long and flexible structures. For this type of structures, the resonant response is the dominant one. Therefore, the distribution of the equivalent wind loads should depend on the structural mass distribution and mode shape.

   Zhou et al. have noted that the GLF method provides an accurate assessment of the structural displacement, but results in less accurate estimation of other response quantities, such as, the base shear force.

d. The GLF method is not valid if either the mean wind force or the mean response is zero. For example in case of suspension bridges and tall chimneys.

3.7.2 Moment Based Gust Loading Factor(MGLF):

To overcome the shortcomings in the DGLF, a new concept is introduced by Kareem et.al.[1] for determining design loads on tall structures. Here the expected extreme base moment is computed by multiplying the mean base bending moment by the new GLF. The base moment is then distributed to each floor in terms of the floor load just like the earthquake base shear is distributed. The new GLF is derived such that the existing background information from the codes may directly be applied.

The procedure to be followed for application of MGLF is given by Zhou and Kareem [1] in the form of steps which are mentioned below. The same steps are followed in the further work.
The steps as mentioned by Kareem and Zhou [8] are as follows:
Step 1: Compute the mean wind force at each floor.

$$\bar{P}_i = \left(\frac{1}{2}\rho\bar{U}_H^2\frac{Z_i}{H}^{2\alpha}\right)C_D(W\Delta H_i) \tag{3.6}$$

Step 2: Compute the mean BBM

$$\bar{M} = \sum_{i=1}^{N}\bar{P}_i Z_i \tag{3.7}$$

where N is the number of floors of the structure. Step 3: Following the guideline of any current code or standard, obtain B; S and E and compute the DGLF using a linear mode shape

$$G_{MB} = G_{YB} = 2g_v I_H\sqrt{B} \tag{3.8}$$

$$G_{MR} = G_{YR} = 2g_R I_H\sqrt{\frac{SE}{\zeta}} \tag{3.9}$$

$$G_M = 1 + \sqrt{G_{MB}^2 + G_{MR}^2} \tag{3.10}$$

Step 4: Compute the resonant extreme BBM component.

$$M_R = G_{MR}\bar{M} \tag{3.11}$$

Step 5: Compute the extreme ESWL at each floor. The resonant component can be obtained by distributing the BBM to each floor as a fraction of the extreme BBM according to

$$P_{Ri} = \frac{m_i\phi_i}{\sqrt{m_i\phi_i Z_i}}M_R \tag{3.12}$$

where ϕi = ϕi(z).

$$P_{Bi} = G_{MB}\bar{P} \tag{3.13}$$

Step 6: Estimate the extreme responses of interest through a simple static analysis. For example, the extreme displacement response can be computed simply by

$$Y_i = G_M\bar{Y}_i \tag{3.14}$$

and the acceleration at each floor level is given by

$$a_i = G_{MR}\bar{Y}_i(2\pi f_1)^2 \tag{3.15}$$

For other response components involving both the resonant and background contributions, e.g., the base shear and other internal forces, the resultant value can be obtained using an SRSS combination rule.

$$r = \bar{r} + \sqrt{(r_B)^2 + (r_R)^2} \tag{3.16}$$

where r; r_B and r_R are the mean, background and resonant response components obtained from the static structural analysis by employing the above ESWL components separately. The resultant wind-induced response can then be combined with the response under the action of other loads.

3.8 Codal Provisions

3.8.1 Provisions of IS 875(III)-1987

Wind load can be calculated by:

a. Force Coefficient Method.

b. Gust Factor Method.

a. **Force Coefficient Method:** Three main equations are used to calculate the wind loading as per Force Coefficient Method:

$$V_z = V_b k_1 k_2 k_3 \tag{3.17}$$

$$pz = 0.6Vz^2 \tag{3.18}$$

$$F = C_f A_e p_d. \tag{3.19}$$

where;

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

V_b = basic wind speed in meter per second, which is based on the peak gust velocity averaged over a short time interval of about 3 seconds and corresponding to mean heights of about 10m above ground level in an open terrain;

k_1 = risk coefficient factor and it is dependent on the design life of the structure and the basic wind velocity. The values are given in Table 1 of IS: 875 (Part 3)-1987.

k_2=terrain, height and structure size factor given in Table 2 of IS: 875 (Part 3)-1987;

k_3=topography factor given in Section 5.3.3 of IS: 875 (Part 3)-1987;

p_z =design wind pressure in N/m^2 at height z;

F= force acting in a direction parallel to the direction of the wind;

C_f = force coefficient for the building or structure and depends on the shape of the structures and shall be interpreted from Figure 4 of IS: 875 (Part 3)-1987;

A_e = effective frontal area of the building or structure; and

$p_d = p_z$ = design wind pressure.

b. **Gust factor Method:** The Gust factor method must be considered for the flexible buildings. Here the hourly mean wind speed at any height at a particular location is calculated the same manner as for static method except that the k_2 factor here has to be read from a separate table containing a relatively lower value.

The along wind load on a strip area (A_e) at any height (z) is given by

$$F_z = C_f A_e p_z G \tag{3.20}$$

where;

G = gust factor = (peak load/ mean load), and is given by

$$G = 1 + g_f r \sqrt{B(1+\phi)^2 + \frac{SE}{\beta}} \tag{3.21}$$

where;

g_f= peak factor defined as the ratio of the expected peak value to the root mean value of fluctuating load;

r = roughness factor which is dependent on the size of the structure in relation to the ground roughness.

The value of g_fr is given in Figure 8 of IS: 875 (Part 3)-1987 as a function of height for different terrain category;

B = back ground factor indicating a measure of slowly varying component of fluctuating wind load and is obtained from Figure 9 of IS: 875 (Part 3)-1987;

SE/ β = measure of the resonant component of the fluctuating wind load;

S = size reduction factor and is obtained from Figure 10 of IS:875 (Part 3)-1987;

E = measure of available energy in the wind stream at the natural frequency of the structure and is given in Figure11 of IS: 875 (Part 3)-1987;

β= damping coefficient as a fraction of critical damping of the structure and the value is given on the Table 34 of IS: 875 (Part 3)-1987;

ϕ= g_fr $\sqrt{B}/4$ and is to be accounted only for building less than 75m high in terrain category 4 and for building less than 25m high in terrain category 3, and is to be taken zero for all other cases.

For interpreting the B, S and E from the plots presented in Figures 9-11 of IS: 875 (Part 3)-1987 [7] the following parameters are required

$$\lambda = \frac{C_y b}{C_z h} \tag{3.22}$$

$$F_o = \frac{C_z f_o h}{V_h} \tag{3.23}$$

where;

C_y = lateral correlation constant which may be taken as 10 in the absence of more precise load data;

C_z = longitudinal correlation constant which may be taken as 12 in the absence of more precise load data;

b = breadth of the structure normal to the wind stream;

h= height of the structure;

V_h =V_z = hourly mean wind speed at height z;

f_o = fundamental natural frequency of the structure; and

L_h = a measure of turbulence length scale and the value can be obtained from plot presented in Figure 8 of IS: 875 (Part 3)-1987.

The procedure prescribed in the dynamic analysis of Indian code is based on the values obtained from various figures. Hence, error may creep in the values read from such graphs, especially in reading from the log-log plots.

3.8.2 Provisions of IS 875(III) Draft Code

This draft code also suggests two methods for finding out wind loads considering the building as a whole, likewise the previous version on the basis of same philosophy.

According to Force coefficient method the design wind loads are calculated by using the following equations:

$$V_z = V_b k_1 k_2 k_3 k_4 \tag{3.24}$$

$$pz = 0.6V_z^2 \tag{3.25}$$

$$p_d = K_d K_a K_c p_z \tag{3.26}$$

$$F_z = C_f A_e p_d \tag{3.27}$$

where; V_z = design wind speed at any height z in m/s;
k_1= probability factor given in Table 1 of IS: 875 (Part 3): Proposed Draft and Commentary;
k_2 = terrain roughness and height factor given in Table 2 of IS: 875 (Part 3): Proposed Draft and Commentary;
k_3 = topography factor given in Section 5.3.3.1 of IS: 875 (Part 3): Proposed Draft and Commentary;
k_4 = importance factor cyclonic region given in Section 5.3.4 of IS : 875 (Part 3): Proposed Draft and Commentary;
p_z = wind pressure at height z in N/m^2;
V_z = design wind speed in m/s at height z;
p_d = design wind pressure in n/m2 at height z;
K_d = wind directionality factor given in Section 5.4.1 of IS: 875 (Part 3): Proposed Draft and Commentary;
K_a = area averaging factor given in Table 4 of IS: 875 (Part 3): Proposed Draft and Commentary;
K_c = combination factor given in Table 19 of IS: 875 (Part 3): Proposed Draft and Commentary;
F_z = along wind equivalent static load on the structure at any height z corresponding to strip area A_e;
C_f = the force coefficient for the building given in Figure 6 of IS : 875 (Part 3):

Proposed Draft and Commentary;

A_e = effective frontal area.

According Dynamic response factor method the following equations are used:

$$F_z = C_f A_e p_z C_{dyn} \tag{3.28}$$

where; C_{dyn} = dynamic response factor (total load / mean load) and is given as follows:

$$C_{dyn} = \frac{1 + 2I_h\sqrt{[g_v^2 B_s + \frac{H_s g_r^2 SE}{\beta}]}}{(1 + 2g_v I_h)} \tag{3.29}$$

where;

I_h = turbulence intensity, obtained from Table 31 of IS: 875 (Part 3): Proposed Draft and Commentary;

g_v = peak factor for the up wind velocity fluctuations, which shall be taken as 3.5;

B_s = back ground factor, which is a measure of the slowly varying background component of the fluctuating response, caused by the low frequency wind speed variations, given as follows.

$$B_s = \frac{1}{\left[1 + \frac{\sqrt{36(h-s)^2 + 64b_{sh}^2}}{2I_h}\right]} \tag{3.30}$$

h = average roof height of structure above the ground;

s = level at which action effects are calculated; and

H_s = height factor for resonant response, which is expressed as follows:

$$H_s = 1 + (\frac{s}{h})^2 \tag{3.31}$$

where;

$$g_r = \sqrt{2log_e(3600 f_o)} \tag{3.32}$$

and S = size reduction factor given by the expression presented below.

$$S = \frac{1}{\left[1 + \frac{4 f_o h (1+g_v I_h)}{V_h}\right]\left[1 + \frac{4 f_o b_{oh} (1+g_v I_h)}{V_h}\right]} \tag{3.33}$$

and E = ($\pi/4$) times the spectrum of turbulence in the approaching wind stream.

$$E = \frac{\pi N}{(1 + 70.8 N^2)^{\frac{5}{6}}} \tag{3.34}$$

Further,

β= ratio of structural damping to critical damping of a structure and is given in Table 32 of IS: 875 (Part 3): Proposed Draft and Commentary;

b_{sh} = average breadth of the structure between height s and h;

L_h = measure of the integral turbulence length scale at height h, and can be expressed as

$$L_h = 100(\frac{h}{10})^{0.25} \tag{3.35}$$

f_o = first mode natural frequency of vibration of a structure in the along wind direction in Hertz;

b_{oh} = average breadth of the structure between height 0 and h; and

N = reduced frequency, and is given by

$$N = \frac{f_o L_h [1 + (g_v I_h)]}{V_h} \tag{3.36}$$

where;

V_h = design wind speed at height h.

Table 3.1: Comparison of IS 875(III)-1987 AND IS875(III) Draft Code:

Sr. No.	IS 875(III)-1987	IS 875(III) Draft Code
1	Code defines the basic wind speed as the peak gust wind speed averaged over a period of 1 hour for gust factor approach.	Code defines the basic wind speed as the peak gust wind speed averaged over a period of 3 seconds for gust factor approach.
2	Effect of cyclonic winds not considered.	k_4 factor introduced as importance factor for cyclonic regions to increase the estimated wind pressure.
3	The k_2 factors mentioned in gust factor method were not pertaining to Indian weather conditions but adopted from other standard codes.	Well defined $k_2$factors relevant to Indian conditions have been given.
4	Basic wind speed $V_z = k_1\ k_2\ k_3$	Basic wind speed $V_z = k_1\ k_2\ k_3\ k_4$
5	No effect considered of directionality of wind.	Wind Directionality Factor introduced as 'K_d' to recognize the fact that:(1) Reduced probability of maximum winds coming from any given direction.(2) Reduced probability of the maximum pressure coefficient occurring for any given wind direction.
6	No effect of tributary area considered.	Area Averaging factor K_a introduced to consider that incoming wind becomes increasingly un-correlated as the area considered increases.
7	No modification suggested to the basic wind speed in case of cyclonic regions .	The influence of wind speed off the coast up to a distance of about 200 kilometres may be taken as 1.15 times the value on the nearest coast in the absence of any definite wind data.
8	No such combination factor considered.	Combination Factor K_c considered as a reduction factor on the computed responses of the frame is thus being permitted. The factor varies between 0.8 and 1.0.
9	The design pressure is pz = pd = 0.6 Vz^2.	The design wind pressure pd can be obtained as, pd = $K_a K_c K_d\ p_z$
10	The parameters B, S, E required in gust factor method have been expressed in the form of graphs which makes it difficult to read and may also lead to errors.	The graphs have been replaced by equations to calculate these factors which makes it more accurate and easy to calculate.
11	The Background factor B is constant throughout its height. But the value decreases with increase in the height of the frame.	The Background factor B_s varying with height for a given frame. The background factor increases with increase in height of the frame.

12	The Size reduction factor (S) depends on the reduced frequency (f_o) for a given lambda value for a given building. The reduced frequency decreases with the increase in the height of the building and as a result the size reduction factor increases with the height of building.	As per the proposed draft the size reduction factor (S) depends on the first mode natural frequency of vibration of a structure (f_o) and design wind speed at any height (V_h). It increases with the height of building and decreases with increase in breadth of the structure.
13	The mean energy spectrum gives the energy content with respect to the fundamental frequency.	The draft code has adopted an empirical formula based on von Karman spectral density for calculating the energy factor. This factor depends on the reduced frequency.
14	There is no Height factor in the present code.	The draft code has considered the effect of height on the resonant response by introducing a height factor (H_s).
15	Dynamic analysis does not include the across wind motion.	Equations to calculate the across wind forces are included for specific aspect ratio of buildings.

3.9 Comparison with Australian Code AS/NZS1170.2: 2002

Apart from comparison of IS 875(III) Draft Code and the present IS 875(III)-1987 the comparison is also made between Australian Code AS/NZS1170.2: 2002 Structural Design Actions-Part 2: Wind Actions.

It is apparent that there is a great deal of similarity in the IS 875(III) Proposed Draft Code and the Australian Standard with the following minor differences.

a. For the wind directionality factor K_d, AS Code gives varying values for different situations based on a more detailed study of wind directionality. whereas in IS Draft Code flat values have been mentioned depending on shape and type of building.

b. The design wind speed V_h at any height h calculated in the Dynamic response factor method is also calculated considering the direction of wind whereas in case of IS Draft Code the value of V_z is directly taken at the maximum height of building.

c. The equation of C_{dyn} factor mentioned in the AS Code is valid only for frequency range of 0.2 < f < 1Hz. Although the equation is exactly similar in IS Draft Code no such mention of the frequency range is there.

3.10 Summary

The proposed draft code of IS 875(III)-1987 has many similarities with the Australian code AS/NZS1170.2: 2002 Structural Design Actions-Part 2: Wind Actions. The draft code has modified the procedure for calculating wind forces in a more user friendly manner as the charts and tables are omitted and equations have been given and hence, it gives a more appropriate method of calculating wind forces for a building as compared to the present code. As per literature, the moment based gust loading factor is a more appropriate and accurate method of determining the dynamic response of structure to wind.

Chapter 4

Estimation of Wind Load

There are various methods for estimation of the ESWL on buildings. As the methodology for obtaining these wind loads changes the value of wind forces as well as the distribution of these wind forces change along the height of the building. These changes mainly occur due to differences in the characterization of wind and the structural characteristics of the building. Hence it is essential to study and compare the methods of estimating wind loads so that more realistic and accurate results may be obtained.

4.1 Methodology

The following methodology is adopted in order to study and compare the methods of evaluating wind forces. The ESWL for tall buildings is calculated by different methods and is compared. The study is carried out in three parts which are mentioned below.

PART I: A 30 storey sea facing RC symmetric building is considered. The building sea face is assumed to be in Terrain Category (TC) 1 and the other 3 faces are considered to be in TC 4. The wind forces on this building are evaluated by three methods:(i) IS 875(III)-1987 Static Method ; (ii) IS 875(III)-1987 Dynamic Method and (iii) IS 875(III) Draft Code. The Lateral forces and Storey Shear Distribution are compared.

PART II: The same 30 storey building is solved by MGLF procedure and is compared with the existing DGLF procedure and quantities like lateral forces, displacement, base shear, overturning moment, storey drift are determined and compared.

PART III: Parametric study has been carried out to compare MGLF and DGLF by varying height of the building i.e. considering 40,50 and 60 storey buildings. The same response quantities are evaluated and compared. Also comparison of reinforcement for columns has been done.

4.2 Building Data

A thirty storey RC building with following details is considered for the computation of wind force using three different approaches.

Location and Geometry:

Location of building: Mumbai

Plan dimensions of building: 24 x 24 m

Wind Zone: III

Basic Wind Speed: 44m/s

Average storey height: 3m

Frame spacing in X-Direction:8m

frame spacing in Y-Direction:8m

Number of storeys:30

Aspect ratio: 3.75:1:1

Positioning of building:

One face of the building is facing the sea and hence assumed to be in Category 1 while all the other faces are assumed to be in Category 4.

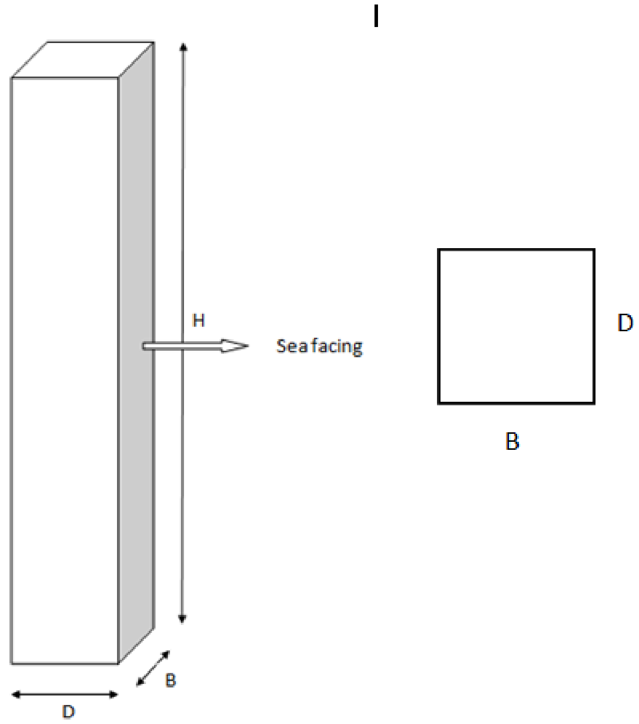


Figure 4.1: Building Elevation and Plan

Note:

a. The building plan is taken as a square plan so as to keep minimum influence of the building parameters on the calculation of wind load. The stiffness, exposed area, mass distribution, geometry...etc are all hence constant for the problem.

b. In order to calculate the k_2 factor given in codes in the form of a table, plots have been ploted as mentioned in Appendix A. Thereafter using curve fitting technique, the best fit curve equation is used to calculate the factor in Excel.

c. Same has been applied to the Turbulence intensity mentioned in the draft code.

The building is modelled in ETABS 9.7.4 and the calculated forces from different methods are entered as user defined wind load.

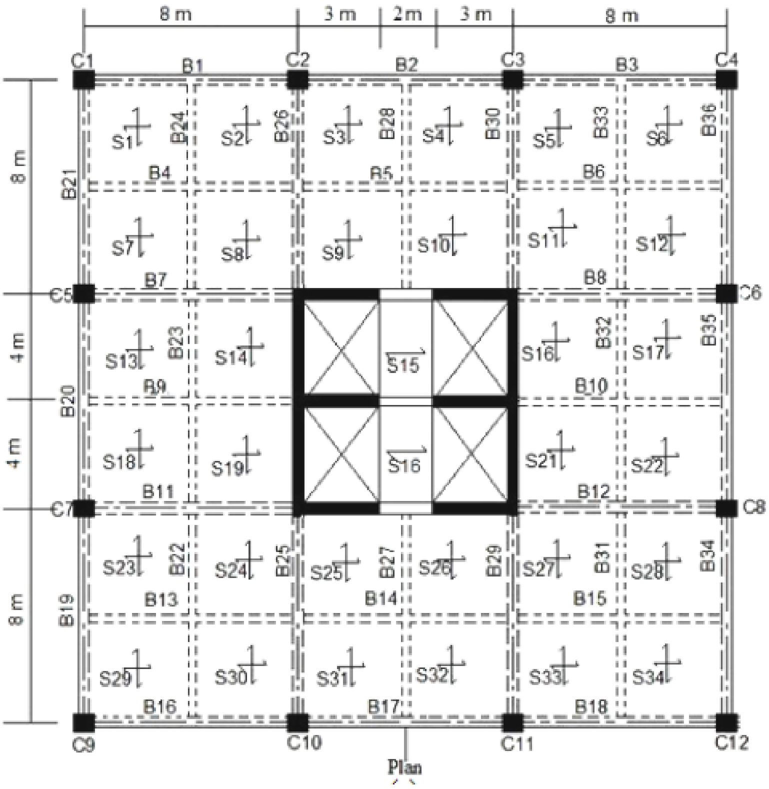


Figure 4.2: Detail of floor level plan.[Courtesy: Patel Jigneshkumar C., Study Of Outrigger Structural System For High Rise Building , M.tech Thesis.]

Building Parameters:

Size of beam: 300 x 600 mm

Size of columns: 750 x 750 mm

Slab Thickness: 125mm

Thickness of Shear Wall: 300mm

Number of storeys:30

Typical Storey height:3m

Material Characteristics:

Characteristic Strength of concrete, fck = 30MPa

Characteristic strength of reinforcing steel, fy = 415MPa

Density of Concrete = 25kN/m^3

Loads:

Floor Finish: 1kN/m^2

Live Load: 3kN/m^2

The above building is considered as a hypothetical problem for comparison of wind forces for the comparison in Part I and Part II of the study which are:

a. PART I: Comparison of IS:875 (Part-III) - 1987 and the Proposed Draft Code.

b. PART II: Comparison Displacement Based Gust Factor(DGLF) and Moment Based Gust Loading Factor(MGLF).

4.3 PART I: Comparison of IS:875 (Part-III) - 1987 and the Proposed Draft Code

The wind forces on the above 30 storey building are calculated as per:

a. **Present Code (IS 875(III)-1987)**

   (1) Static Method.

   (2) Gust factor Method.

b. **IS 875(III) Proposed Draft Code**

   (1) Dynamic Response Factor Method.

The calculation of forces by these methods is done by preparing excel sheets which can be referred from the Appendix A. The results are expressed in the from of tables and plots.

The purpose of this study is to mainly highlight the basic differences in the characterization of wind in all the three methods.Hence, the comparison is done between lateral(wind) forces, gust factors and base shear value. The earthquake load for the building is calculated as per IS 1893:2002 (Part 1).

4.3.1 Results

After calculation of all the forces the following results have been obtained.

Considering Lateral Forces

The following plots in Figure4.3 and Figure4.4 show the distribution of lateral forces obtained due to wind by all the three methods.

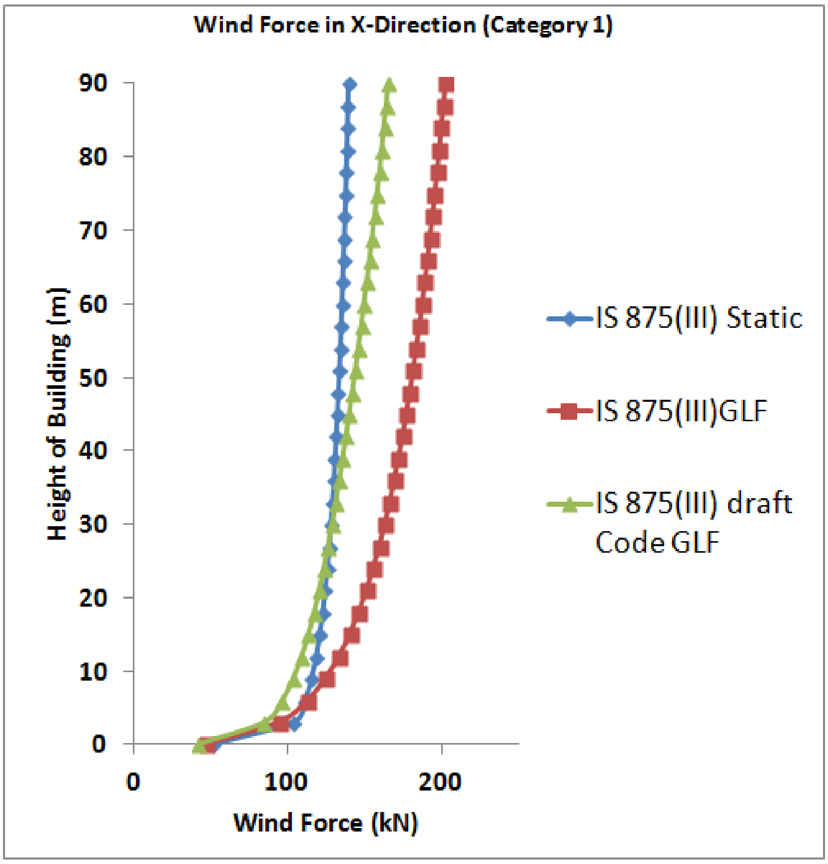


Figure 4.3: Variation of Wind Force along Height of Building in X-Direction.

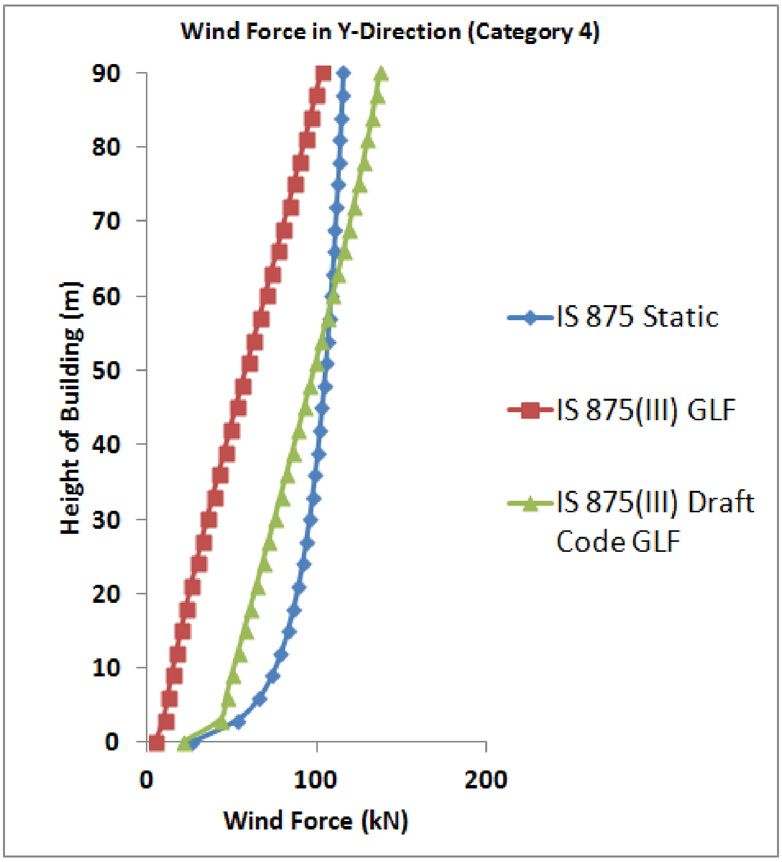


Figure 4.4: Variation of Wind Force along Height of Building in Y-Direction.

The following observations can be made from the above two plots:

a. The static method of IS 875(III)-1987 gives higher value of wind loads in the lower region of the building as it does not account for the effect of turbulence intensity on the pressure.

b. In the dynamic method, the turbulence intensity function takes care of the turbulence generated by friction on the ground and drag on surface obstacles. hence the value of forces is lower in the lower height region.

c. The wind force in TC 1 is observed to be highly overestimated in case of gust loading factor method whereas the same in TC 4 is highly underestimated compared to draft code results.

Considering Base Shear

The total base shear in both the direction in case of earthquake loading obtained from ETABS 9.7.4 is 2009.83kN. (See Table 2.1).

Table 4.1: Comparison od Earthquake and Wind Base Shear

Parameter	Earthquake	IS 875(III) Static	IS 875(III) GLF	IS 875(III) Draft Code
Base Shear in X-Direction(kN)	2009.83	3945.92	5151.40	4160.11
Base Shear in Y-Direction(kN)	2009.83	2994.00	1646.83	2801.03

The following figures, Figure4.5 and Figure4.6 show the comparison of base shear in the form of column chart.

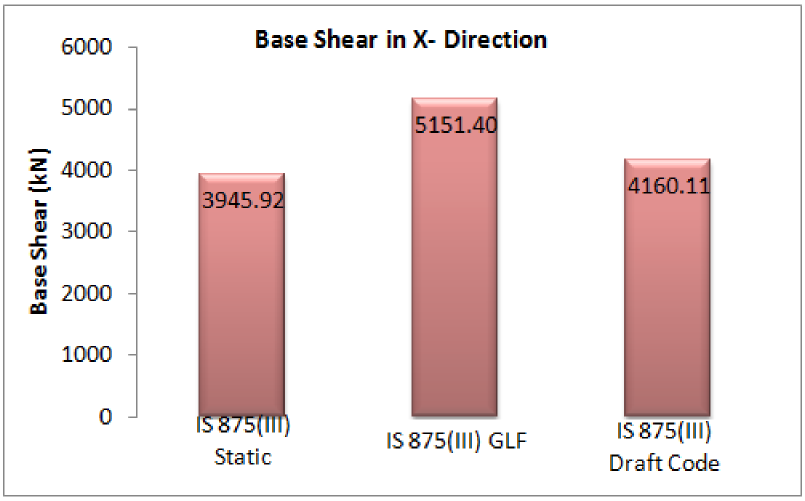


Figure 4.5: Comparison of Base Shear in X-Direction.

From the results of base shear, considering Figures 4.5 and 4.6, it can be seen clearly that wind is the governing load in this case:

a. Except for the case of IS 875(III)-1987 GLF Method wherein the wind base shear in Y direction is less than the earthquake base shear in that direction.For

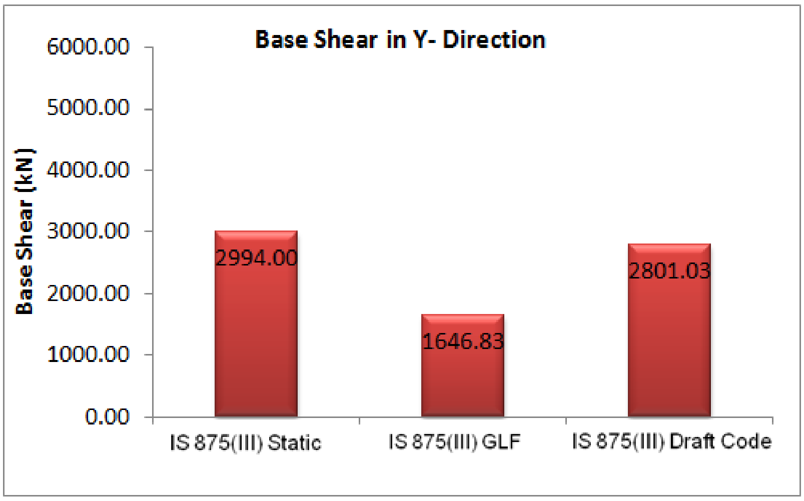


Figure 4.6: Comparison of Base Shear in Y-Direction.

calculation purpose this is neglected and the building is considered to be Wind Sensitive and wind load is the governing load.

b. The Base Shear obtained from the static method in the case is nearly equal to that obtained through the draft code method, but the distribution of the shear along the storey is different.

c. The Static method gives higher value of storey shear in lower storeys and lesser value of storey shear in higher storeys. As a result the estimation of the storey drift would be affected and the value of drift obtained in case of static method would be less than the actual.

Considering Gust factors:

As per IS 875(III)-1987, the gust loading factor is a constant value for a given building in one direction i.e. it is not a function of height of the building.

The gust factors obtained for the building are:

G, X-Direction = 1.7822 ....Category 1

G, Y-Direction = 2.7603 ....Category 2

While in case of draft code, the gust factors,known as Dynamic response Factors in the code, are varying with the height of the building. The figure Figure4.7 shows the variation of Cdyn along height of building in both the directions.

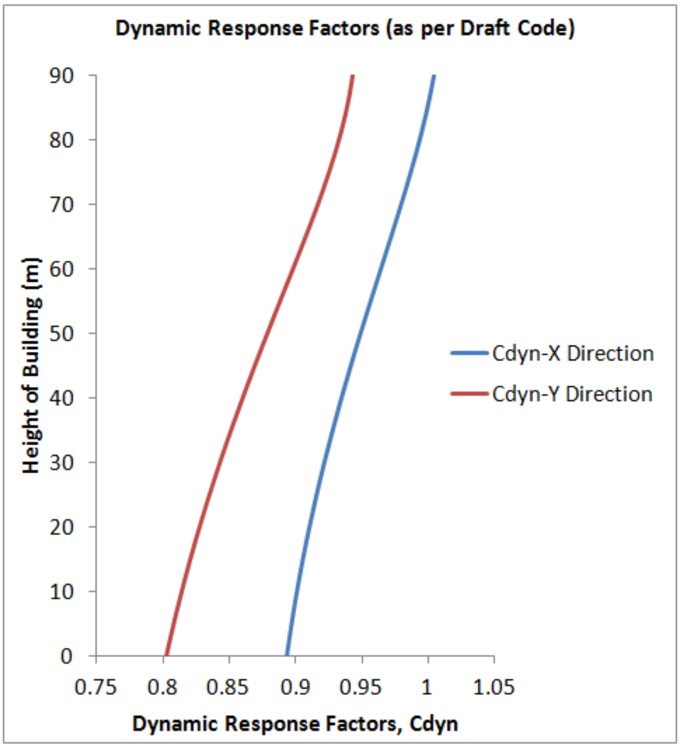


Figure 4.7: Variation of Dynamic Response factor along Height in X and Y Direction.

It can be seen from the plot and the values that,

a. The gust loading factor is a constant value in case of the dynamic method given in IS 875(III)-1987 whereas the dynamic response factor in draft code is derived as varying with height.

b. The background factor B is constant as per recent code and does not take into account the effect of height.

c. The gust loading factor increases with higher terrain roughness which is obvious as the amount of turbulence in the air would be more if there are more obstacles.

4.3.2 Summary and Discussion:

From the plots the following deductions can be made:

a. As the height of the building increases, the dynamic response becomes more predominant and hence the static method cannot be relied upon.

b. The Base Shear obtained from the static method in the case is nearly equal to that obtained through the draft code method, but the distribution of the shear along the storey is different.

c. The variation of force in case of static method and dynamic method of present code is dependent on the wind velocity profile only as a result the variation is parabolic.

d. The k_2 factor presented in the present IS code is not pertaining to Indian conditions whereas the k_2 factor given in the IS 875(III) draft Code have been revised to suite Indian conditions.As a result of this, the calculated forces in TC 1 and TC 4 as per both codes have been found to vary, mainly in TC 4.

4.4 PART II: Comparison of Displacement Based Gust Factor(DGLF) and Moment Based Gust Loading Factor(MGLF)

In this section, comparison is carried out between Displacement Based Gust Loading factor and Moment Based Gust loading factor procedure suggested by Kareem[8]. In case of DGLF the Dynamic Response Factor method given in the draft code is considered while for MGLF the steps followed (as per Kareem[8] are mentioned below.

4.4.1 Steps for Application of MGLF:

The steps as mentioned by Kareem and Zhou [3] are as follows:

Step 1: Calculate the mean wind force at each floor using,

$$\dot{P} = C_d p_z A_e \tag{4.1}$$

Step 2: Calculate the mean Base Bending Moment (BBM) using

$$\dot{M} = \sum_{i=1}^{N} \dot{P}_i Z_i \tag{4.2}$$

where N is the number of floors of the structure.

Step 3: Obtain B, S and E through equations of IS:875(Part-III) Draft Code and plots of IS:875(Part-III)-1987.

Step 4: Calculate Gust Factor by splitting Cdyn equation (code specific) into Background (G_{MB}) and Resonant (G_{MR}) component. These components, as per IS:875(Part-III) draft code, is as follows.

$$G_{MB} = \frac{2g_v I_h \sqrt{B}}{1 + 2g_v I_h} \tag{4.3}$$

$$G_{MR} = \frac{2g_R I_h \sqrt{\frac{SEH_s}{\zeta}}}{1 + 2g_v I_h} \tag{4.4}$$

Combined equation for Gust factor can be given by,

$$G_M = \frac{1}{1 + 2g_v I_h} + \sqrt{G_{MB}^2 + G_{MR}^2} \tag{4.5}$$

which if simplified would return the same gust factor equation as given in draft code.

Step 5: Compute the resonant extreme BBM component.

$$\bar{M}_R = G_{MR}\dot{M} \tag{4.6}$$

Step 6: Compute the extreme ESWL at each floor. The resonant component can be obtained by distributing the BBM to each floor as a fraction of the extreme BBM according to,

$$P_{Ri} = \frac{m_i\phi_i}{\sqrt{m_i\phi_i Z_i}}\bar{M}_R \tag{4.7}$$

where,first mode shape function ϕ is given by,

$$\phi_i = \phi_i(z) = \left(\frac{z}{H}\right)^{\beta} \tag{4.8}$$

and mass at each storey expressed as,

$$m = m_o\left[1 - \lambda\left(\frac{z}{H}\right)\right] \tag{4.9}$$

where, λ = mass reduction parameter; β = mode shape coefficient; H = height of building.

Step 7: Compute the background component of extreme ESWL at each floor by

$$P_{Bi} = G_{MB}\dot{P} \tag{4.10}$$

Step 8: Compute response quantities like Base Shear and Overturning Moment obtained by Square Root Sum Square (SRSS) combination rule as follows.

$$r = \bar{r} + \sqrt{(r_B)^2 + (r_R)^2} \tag{4.11}$$

where $\bar{r}$; r_B and r_R are the mean, background and resonant response components obtained from the static structural analysis by by using individual components of ESWL. The resultant wind-induced response can then be combined with the response under the action of other loads.

Step 9: To calculate resultant lateral force, obtain storey shear along the height of building by combining the mean, background and resonant components as per Step 8 and convert the final storey shear into lateral forces. This value of lateral forces is considered to be applied at the centre of mass of the building at each storey.

4.4.2 Cases considered for comparison

The same 30 storey RC building is considered. The wind forces are calculated as per IS 875(III)-1987, IS 875(III)-draft code and the MGLF procedure. Both, the present code, IS 875(III)-1987 and the draft code present the gust factor which is displacement based. The lateral forces comparison is done between DGLF and MGLF where the DGLF forces are as per IS 875(III)-1987 Gust Factor method.

As discussed earlier, the DGLF method used in IS 875(III)-1987 and draft code does not differentiate the cases that have nonlinear mode shapes or non-uniform mass, or both, from the case that has a linear mode shape and uniform mass.But the MGLF procedure is capable of considering non uniform mass distribution and non linear mode shapes.

In order to study the effect of mass non uniform mass and non linear mode shape four different cases are considered for the study, wherein;

Case 1:$\beta = 1.0$ and $\lambda = 0.0$;

Case 2:$\beta = 1.6$ and $\lambda = 0.0$;

Case 3:$\beta = 1.0$ and $\lambda = 0.2$;

Case 1:$\beta = 1.6$ and $\lambda = 0.2$;

where, β = mode shape coefficient and λ = mass reduction factor.

The calculation of wind forces by MGLF method is done in Excel and the sheets of calculation are given in the Appendix A. The above mentioned steps for MGLF have been followed in the calculation done in Excel sheets.

In case of MGLF, the mean, background and resonant components of force are calculated individually and then the response quantities are obtained by SRSS method. In the present study, in order to input the lateral forces only once in ETABS, the storey shear distribution is obtained by combining all the three components, as per MGLF procedure, ant the lateral forces are obtained from this final storey shear distribution. Thus, the lateral forces are obtained. The calculation for the same has been given in Appendix A.

4.4.3 Results

Comparison is carried out in the form of plots, between lateral forces, storey shear, overturning moment, displacement and storey drift by both the methods i.e. DGLF and MGLF. Considering all the parameters one by one.

Lateral Forces

In case of DGLF, the gust factor used is a combined factor for resonant and the background component of the forces. Whereas, in case of MGLF the gust factor is obtained separately for resonant and background components of lateral forces. Hence, in case of MGLF, it is possible to obtain the resonant and the background component of the lateral force.
In the present study, all the three components of the lateral force i.e. mean, background and resonant are calculated and plotted against height of building.

The effect of non linear mass distribution and non linear mode shape is studied on the components of lateral forces for all the four cases considered, in the form of Figures 4.8 and 4.9.

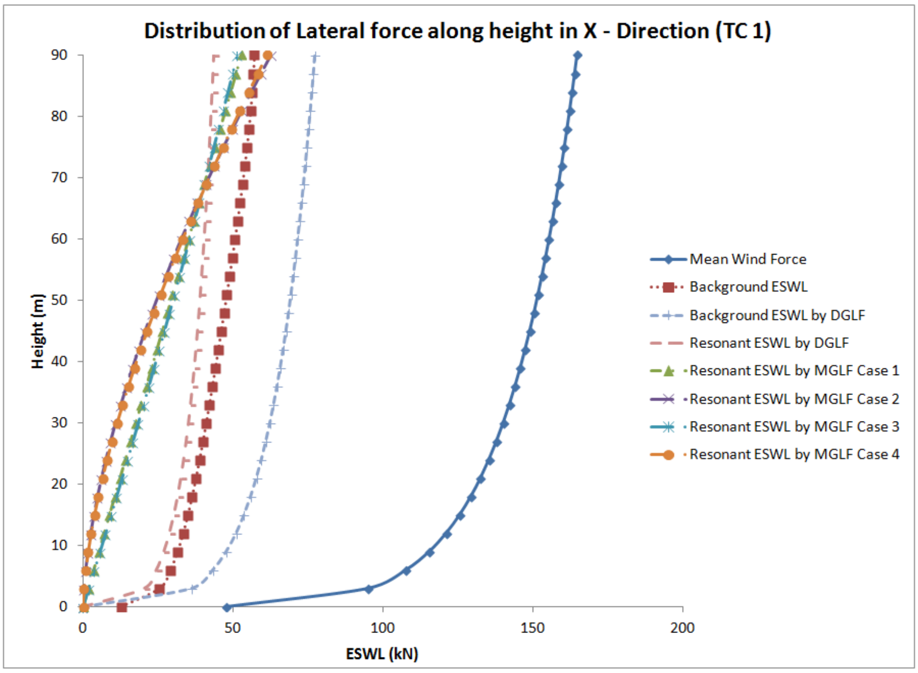


Figure 4.8: Distribution of Lateral Force along height in X-Direction.

The following deductions can be made from the Figures 4.8 and 4.9:

a. The mean and background components are independent of the effect of mode shape and mass variation.

b. The distribution of the resonant components varies with the mode shape and the mass ariation of the building, but the forces are more or less overlapping each other.

c. In TC 1, the value of forces are higher as compared to TC 4.

d. The resonant component of the force is quite underestimated in TC 4 in case of DGLF method as compared to MGLF. This was observed in the first part of this study too.

e. In case of TC 1, near the top of the building the resonant force in case 4 is more than the background force which suggests that as the height of the

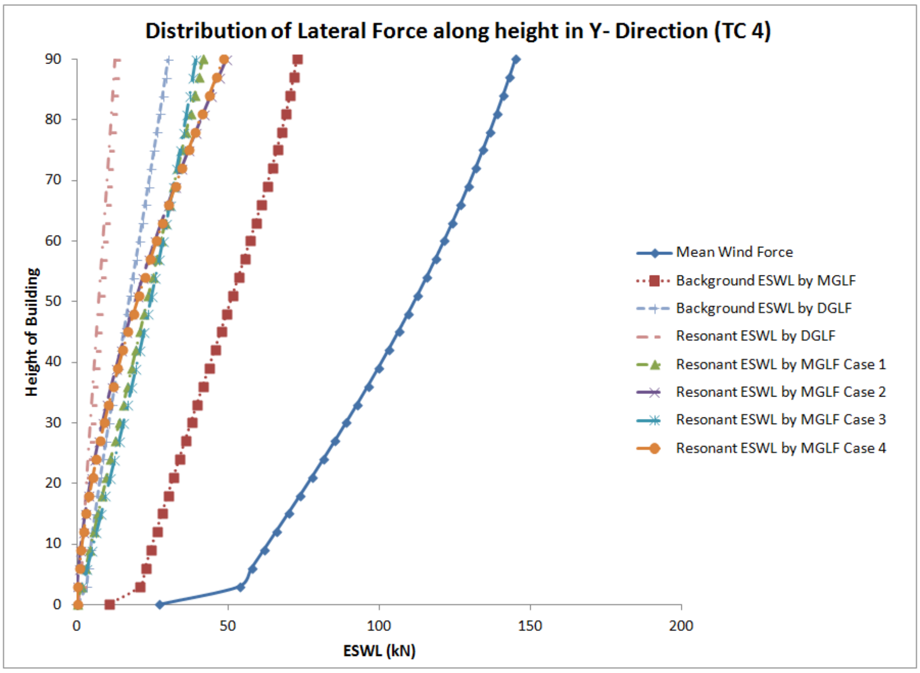


Figure 4.9: Distribution of Lateral Force along height in Y-Direction.

building increases the effect on the resonant component is more. This effect is not captured in the DGLF approach which can be seen from the Figure 4.8 and 4.9.

Storey Shear and Overturning Moment

The following plots show the storey shear and overturning moment profile for the building obtained by MGLF method. The mean background and the resonant components are plotted against height of building. It can be seen that the resonant components are overlapping eachother. Hence, it can be concluded that the effect of mass variation and non linear mode shape does not much effect regular proportionate buildings.The storey shear distribution can be seen from the Figures 4.10 and 4.11. The final storey shear dstribution can be seen from Figure 4.12. And the overturning moment profile in both the directions i.e. X - and Y- can be seen fron the Figures 4.13 and 4.14.

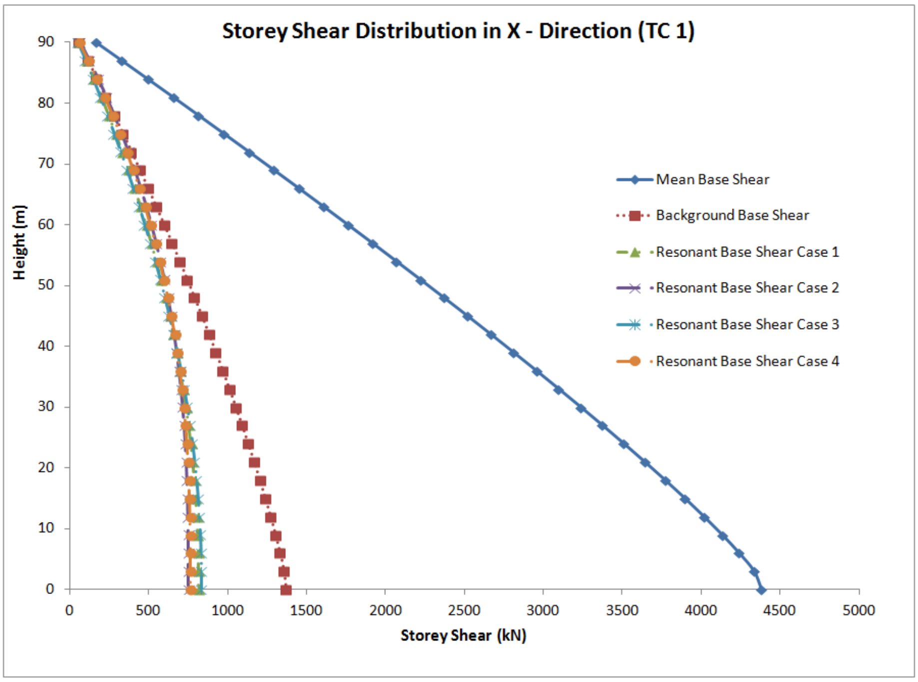


Figure 4.10: Storey Shear Distribution in X-Direction.

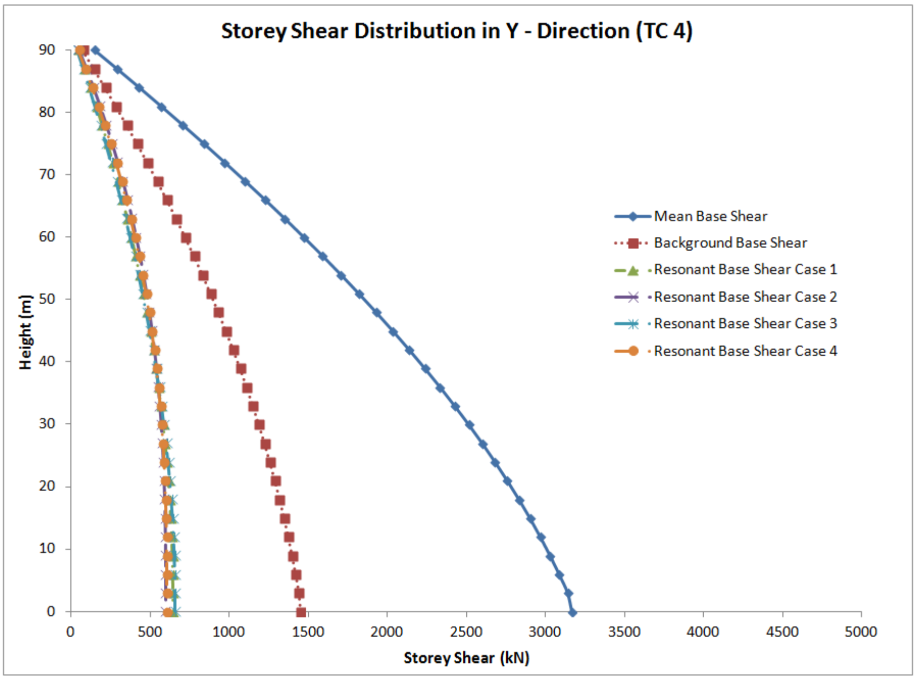


Figure 4.11: Storey Shear Distribution in Y-Direction.

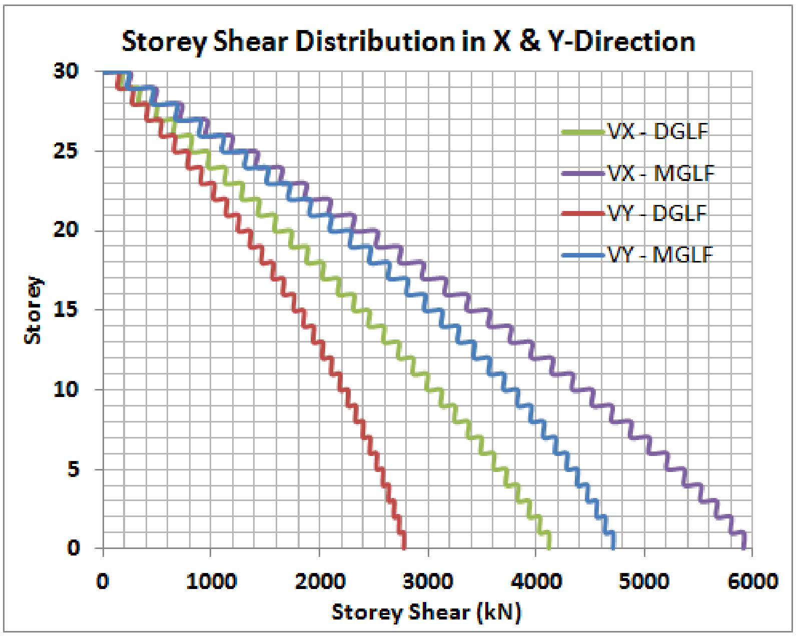


Figure 4.12: Storey Shear Distribution in X- and Y- Direction.

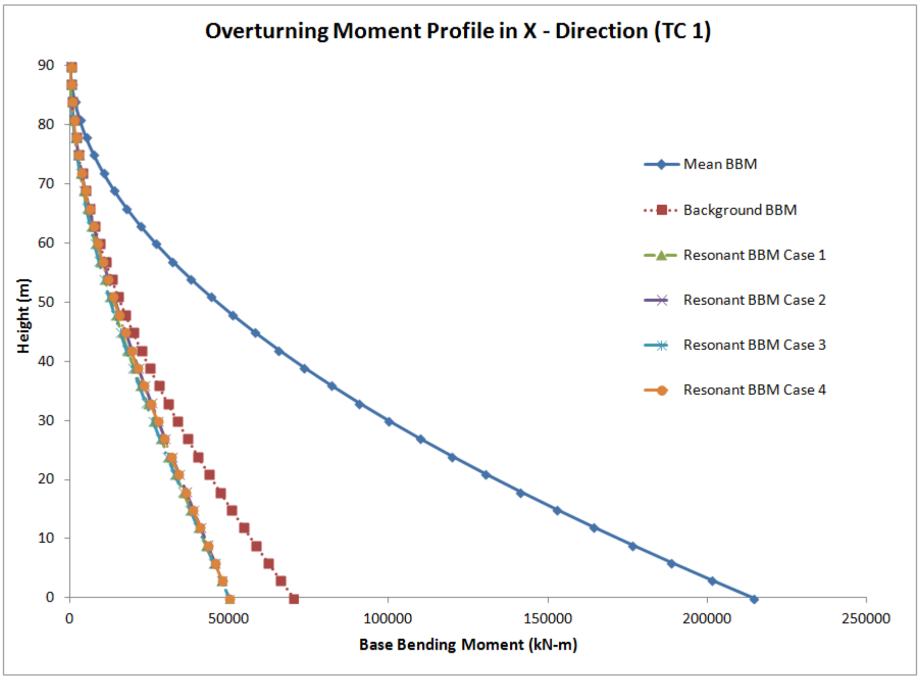


Figure 4.13: Overturning Moment Profile in X-Direction.

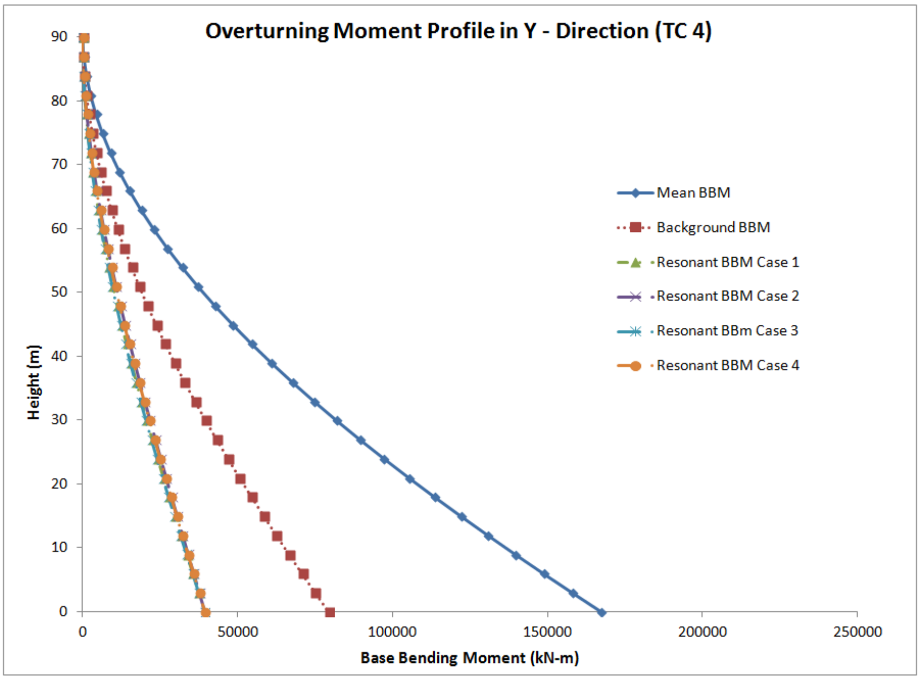


Figure 4.14: Overturning Moment Profile in Y-Direction.

The following deductions can be made from the plots of storey shear and the overturning moment:

a. The effect of the non-uniform mass is insignificant and the effect of a nonlinear mode shape is very less on the resonant forces as the plots are nearly overlapping each other. Hence, the approach given in codes to consider uniform mass variation and linear mode shape is justified.

b. However, this is justified only for regular buildings having constant mass distribution and constant stiffness throughout the building.

Displacement and Storey Drift

As the value of forces increases with the application of MGLF, there is effect in the displacement and the storey drift of the building too. The following plots show the effect on displacement and storey drift of the building:

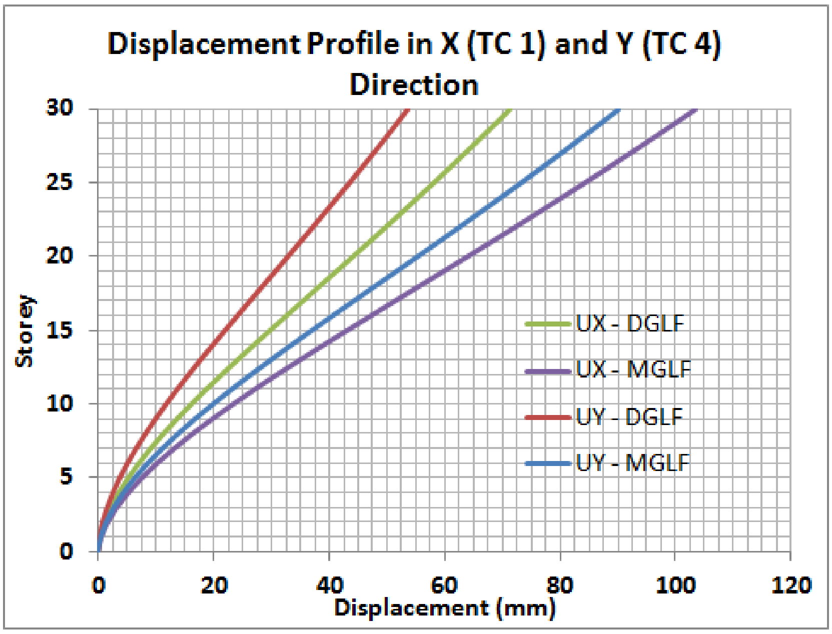


Figure 4.15: Displacement Profile in X- and Y- Direction

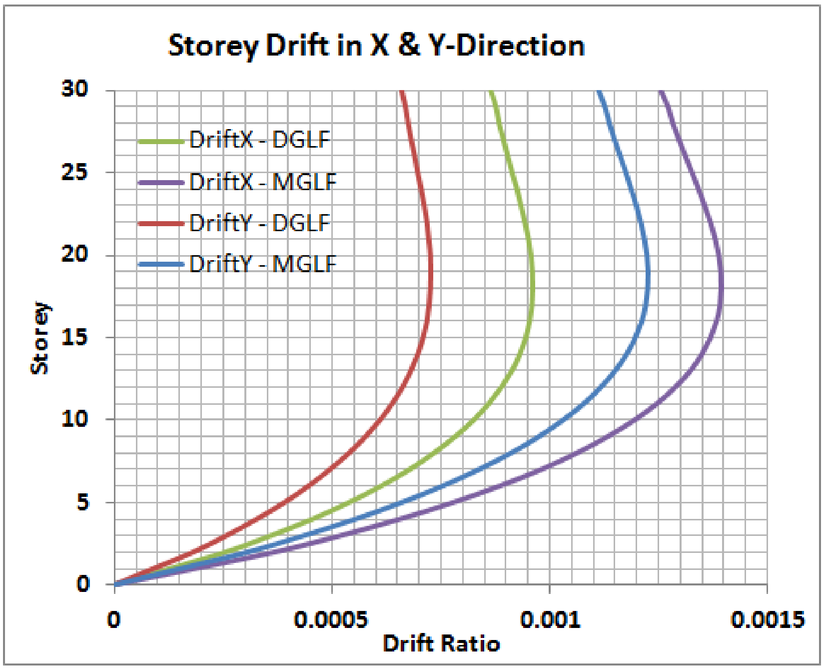


Figure 4.16: Storey Drift in X- and Y- Direction.

From the above two plots it can be seen that the displacement and storey drift values increase with the application of MGLF as compared to DGLF.

4.4.4 Summary and Discussion

In this section the comparison of DGLF and MGLF method has been carried out considering a 30 storey tall building as an example. The quantities that have been compared are lateral forces, storey shear, overturning moment, displacement and storey drift. The following conclusions have been derived on the basis of the results:

a. In case of DGLF, the lateral forces are highly underestimated in the TC 4. In case of MGLF, due to proper consideration of the resonant component of wind force, a more realistic and reliable distribution of ESWL in Y- direction i.e. in TC 4 is obtained.

b. As the height of the building increaases the resonant component starts governing more than the background component.

c. The effect of non uniform mass distribution and non linear mode shape is insignificant on the building. Hence, the assumption made in the codes to assume unifom mass and linear mode shape for the building can be justified.

d. From the plots it can be seen that the values of storey shear, displacement and storey drift are more in case of MGLF than DGLF.

4.5 PART III: Parametric study has been carried out to compare MGLF and DGLF

4.5.1 General

From the study in Part II, it has been observed that the resonant component of wind force starts governing as the height of the building increases. In the present code and draft code i.e. the DGLF method the resonant component is not obtained separately and accounted for. Hence, there is substantial difference in the forces calculated by both the methods.

A parametric study has been carried out by considering **three tall buildings of different heights.** Comparison is carried out between DGLF method and the MGLF method and various parameters like lateral forces, storey shear, overturning moments, displacements, and storey drifts have been evaluated and compared. Also, in order to study the effect of MGLF on design of building, a comparison of reinforccement has been carried out for selected column of the buildings.

4.5.2 Parameters considered

Three reinforced concrete tall buildings of heights 40, 50 and 60 storey have been considered for the comparison of DGLF and MFLF.

Location and Geometry:

Location of building: Mumbai

Plan dimensions of building: 24 x 24 m

Wind Zone: III

Basic Wind Speed: 44m/s

Average storey height: 3m

The structural parameters of the buildings are tabulated as follows:

Table 4.2: Structural parameters of Buildings

Description	I	II	III
No. Of storeys	40	50	60
Size of Beam(mm)	300 x 650	350 x 750	350 x 800
Size of Column(mm)	800 x 800	1100 x 1100	1500 x 1500
Thickness of Shear Wall(mm)	400	450	550
fck(Mpa)	40	40	60

Loads:

Floor Finish: 1kN/m^2

Live Load: 3kN/m^2

Building Plan

The structural system for the buildings considered can be seen from the following plans:

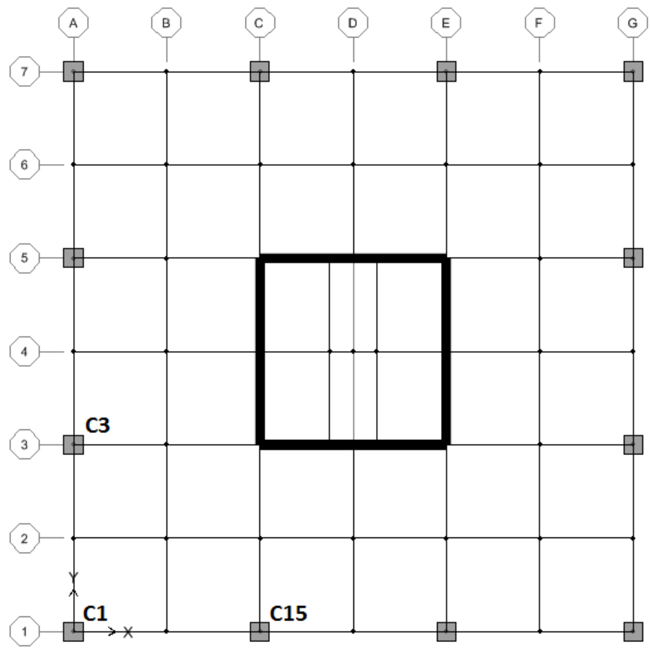


Figure 4.17: Plan of 40 and 50 storey Building

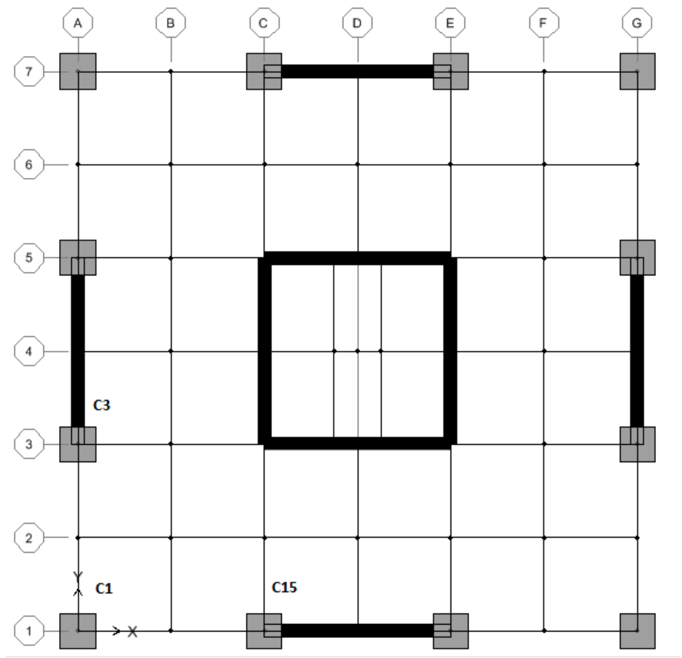


Figure 4.18: Plan of 60 storey building

For MGLF again the four cases of mass variation and non linear mode shape are considered which are: **Case 1**:$\beta = 1.0$ and $\lambda = 0.0$; **Case 2**:$\beta = 1.6$ and $\lambda = 0.0$; **Case 3**:$\beta = 1.0$ and $\lambda = 0.2$; **Case 1**:$\beta = 1.6$ and $\lambda = 0.2$; where, β = mode shape coefficient and λ = mass reduction factor.

The effect of Terrain category, non uniform mass variation and non linear mode shape is studied on the resonant components of the wind forces. The lateral forces, storey shear distribution, displacement, storey drift and reinforcement percentage are compared.

4.5.3 Results and Discussion

Comparison of Lateral Forces

Considering X- Direction i.e. TC 1, the following plots show the variation of mean, background and resonant components of the wind force for all the three buildings considered.

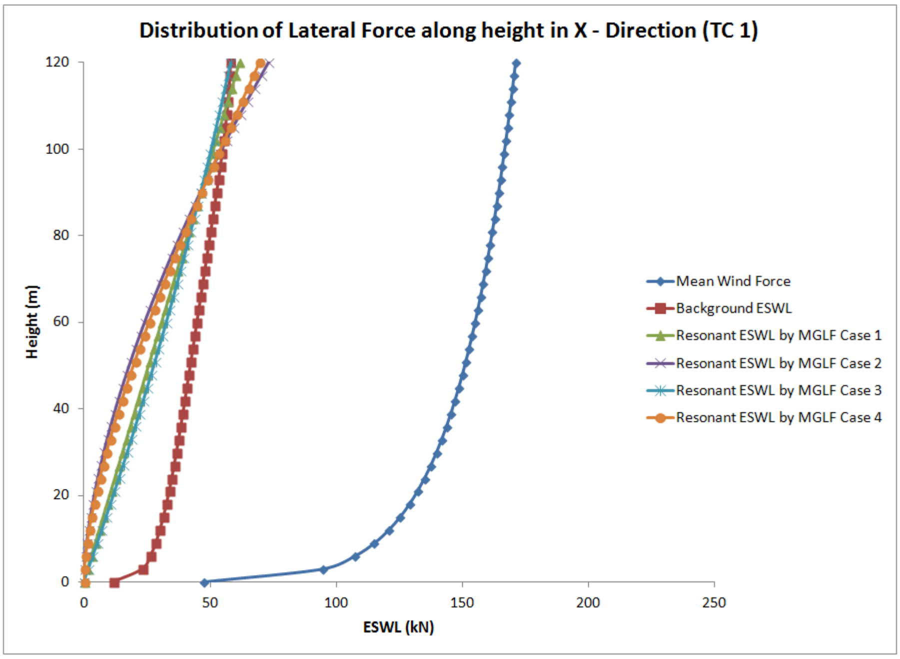


Figure 4.19: Distribution of Lateral Force along in X- Direction(TC 1) for 40 storey

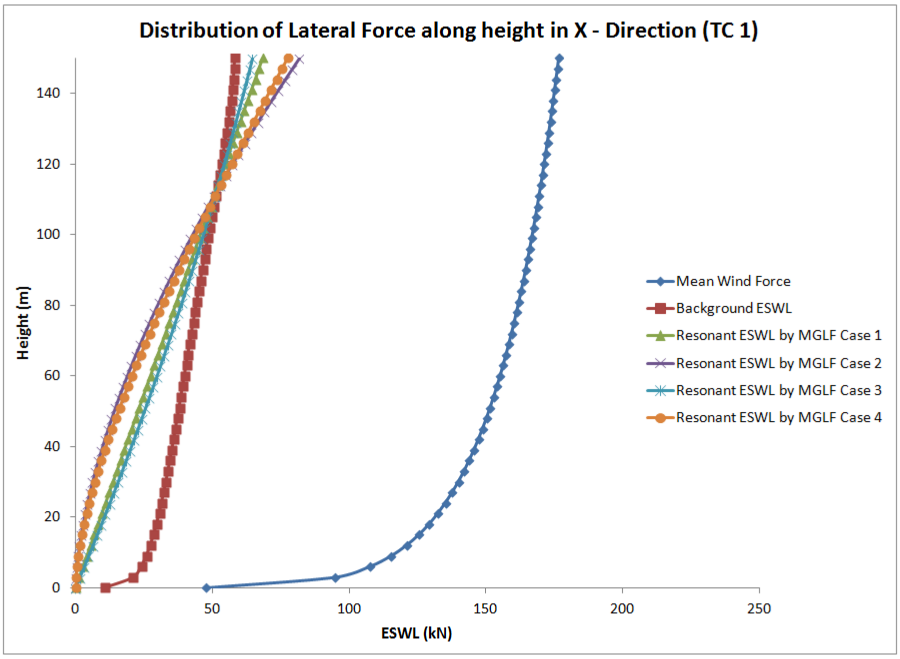


Figure 4.20: Distribution of Lateral Force along in X- Direction(TC 1) for 50 storey

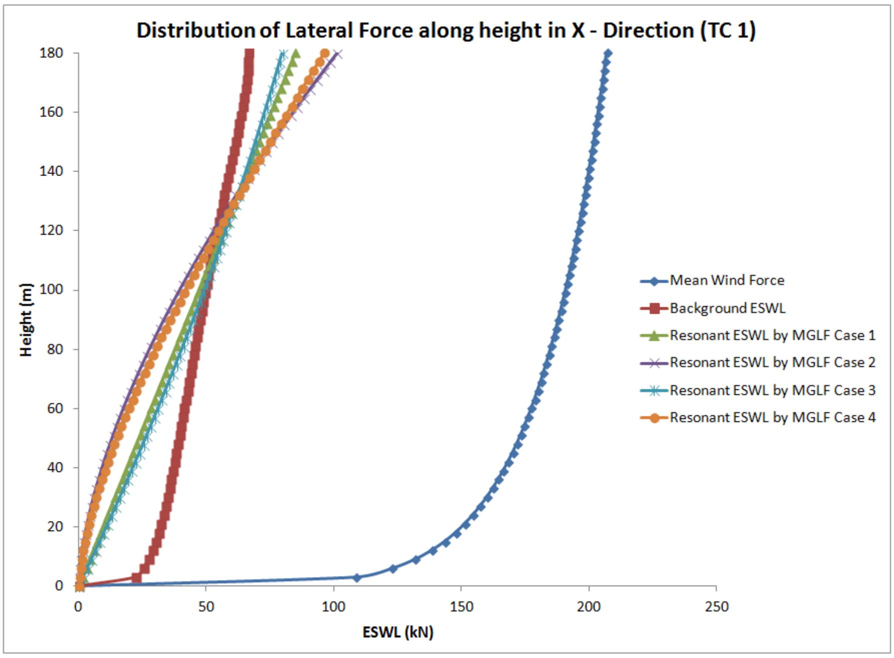


Figure 4.21: Distribution of Lateral Force along in X- Direction(TC 1) for 60 storey

From the above plots the following observations can be made:

a. From the plots 4.19, 4.20 and 4.21 it can be seen that as the height of building increases the resonant component increases in the top portion of the building beyond the background component.

b. The effect of mass variation and mode shape variation can be seen more clearly as compared to that observed for the 30 storey building.The deviation of forces from the linear mode shape case increases as the height of building increases.

c. Hence the consideration of non linear mode shape effects the calculation of wind forces more for taller buildings.

Considering Y- Direction i.e. TC 4, the following plots show the variation of mean, background and resonant components of the wind force for all the three buildings considered.

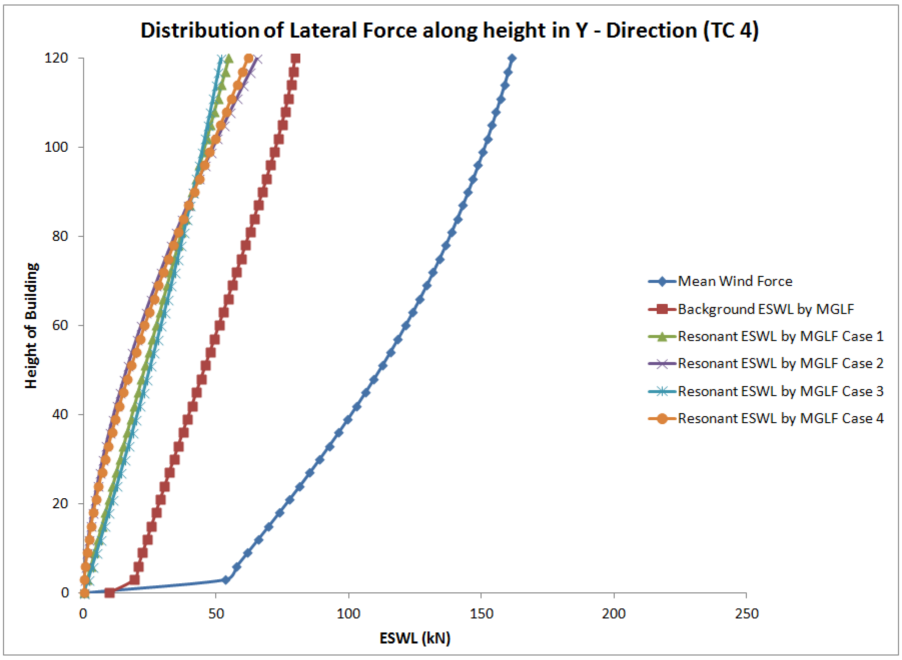


Figure 4.22: Distribution of Lateral Force along in Y- Direction(TC 4) for 40 storey

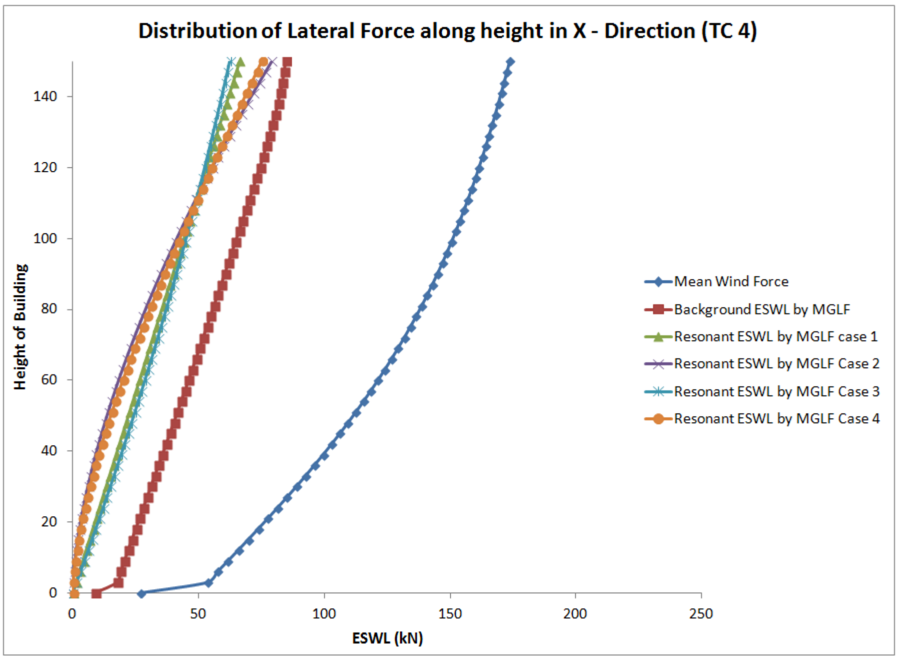


Figure 4.23: Distribution of Lateral Force along in Y- Direction(TC 4) for 50 storey

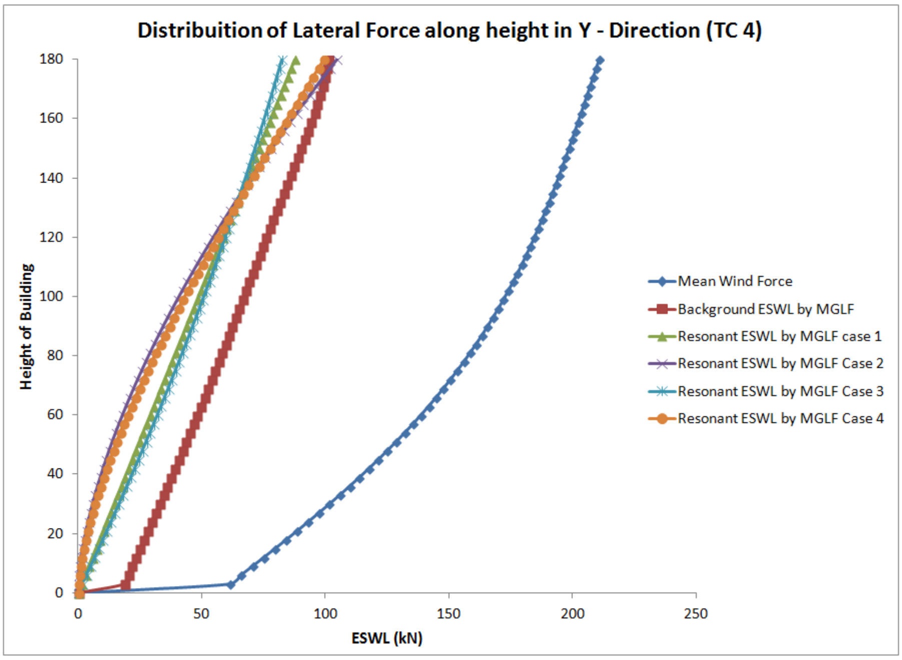


Figure 4.24: Distribution of Lateral Force along in Y- Direction(TC 4) for 60 storey

From the above plots the following observations can be made:

a. From the plots 4.22, 4.23 and 4.24, the resonant component can be seen to increase but it is not more than the background component.

b. The effect of mass variation and mode shape variation can also be seen more clearly.

Final Response Quantities

The final lateral forces obtained from the DGLF and MGLF method which have been input in ETABS are shown in the form of following plots. The calculation of the same can be seen from the Appendix. The lateral forces increase in case of MGLF method which can be seen from Figure 4.25. Also the distribution of lateral forces along the height of building can be compared for DGLF and MGLF cases.

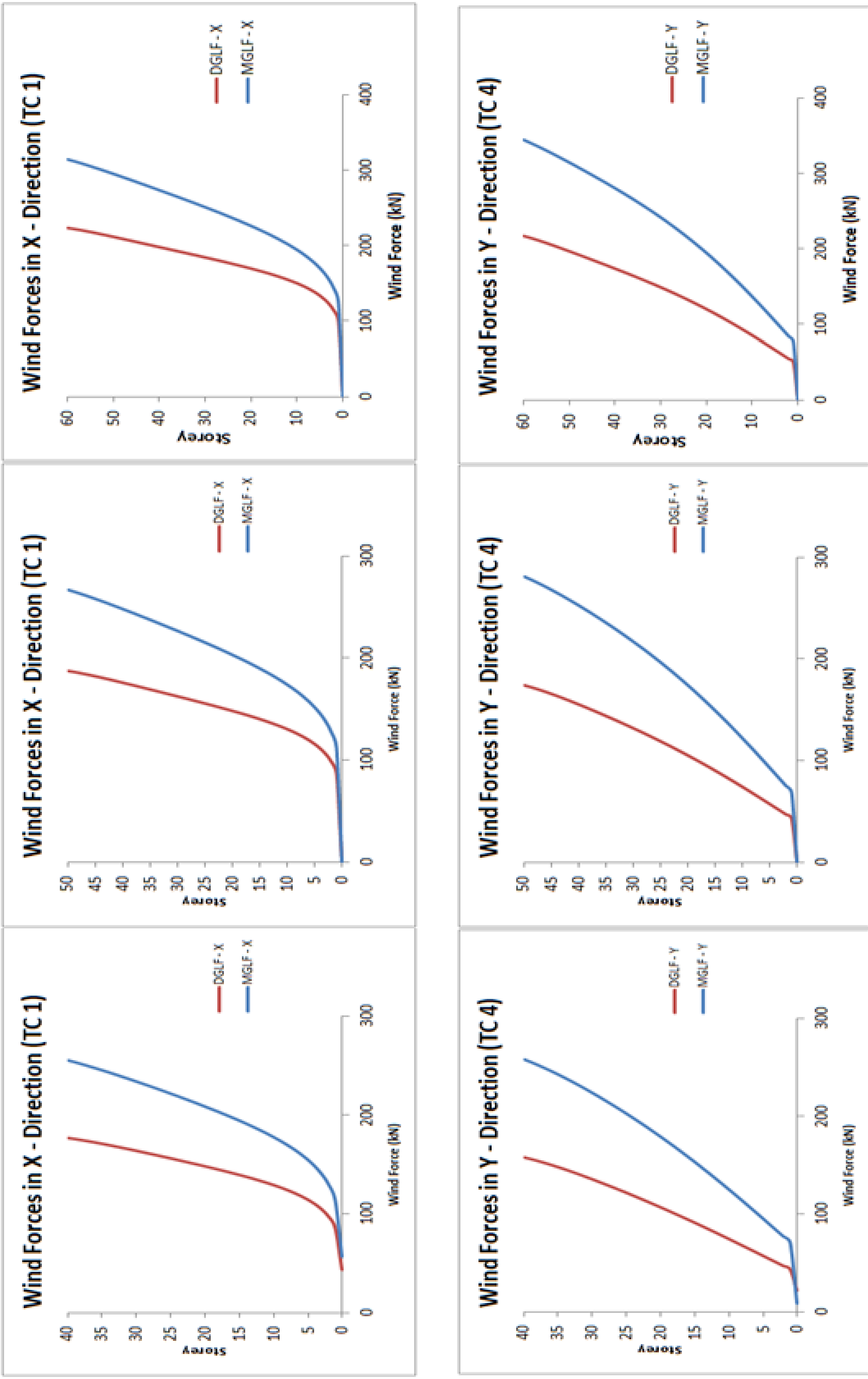


Figure 4.25: Wind Force in X and Y Direction for 40, 50 and 60 Storey

Comparison of Storey Shear Distribution

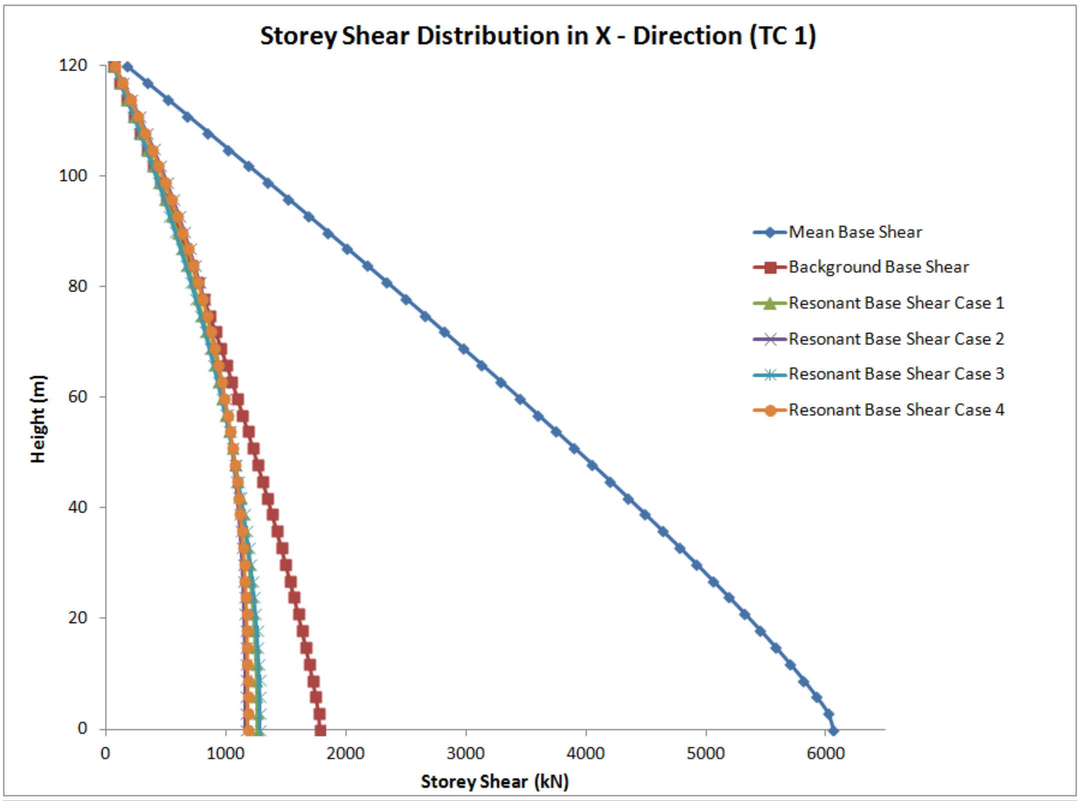
The following plots show the comparison of storey shear distribution for all the three buildings in both the X- and Y- Direction.

Figure 4.26 shows the storey shear distribution for all the three components i.e. background , resonant and mean for 40 storey building, in both the X- and the Y- direction. It can be observed that for TC 1 the resonant storey shear is equal to the background storey shear near the top storeys. Whereas, for TC 4 there is difference in the resonant and background storey shears. Thus, for TC 4 the resonant shears are less than the background shears.

Considering the four cases, the maximum variation in the resonant storey shear is observed in case 4 i.e. considering mass variation and non linear mode shape. For case 4, the it shows maximum storey shear in upper half and least shears in lower half of the building.

Figure 4.27 shows similar storey shear distribution for 50 storey building. Here again the maximum variation in the resonant storey shears can be observed in case 4. For TC 1 it can be seen from the plot that the resonant storey shear is more than the background storey shear in the top storeys. With increase in height from 40 to 50 it can be seen that the resonant component of storey shear has started governing in case of TC 4 too.

Figure 4.28 shows the storey shear distribution for 60 storey building for both the directions X and Y. Here too similar nature of plot can be observed as in case of 50 storey building.



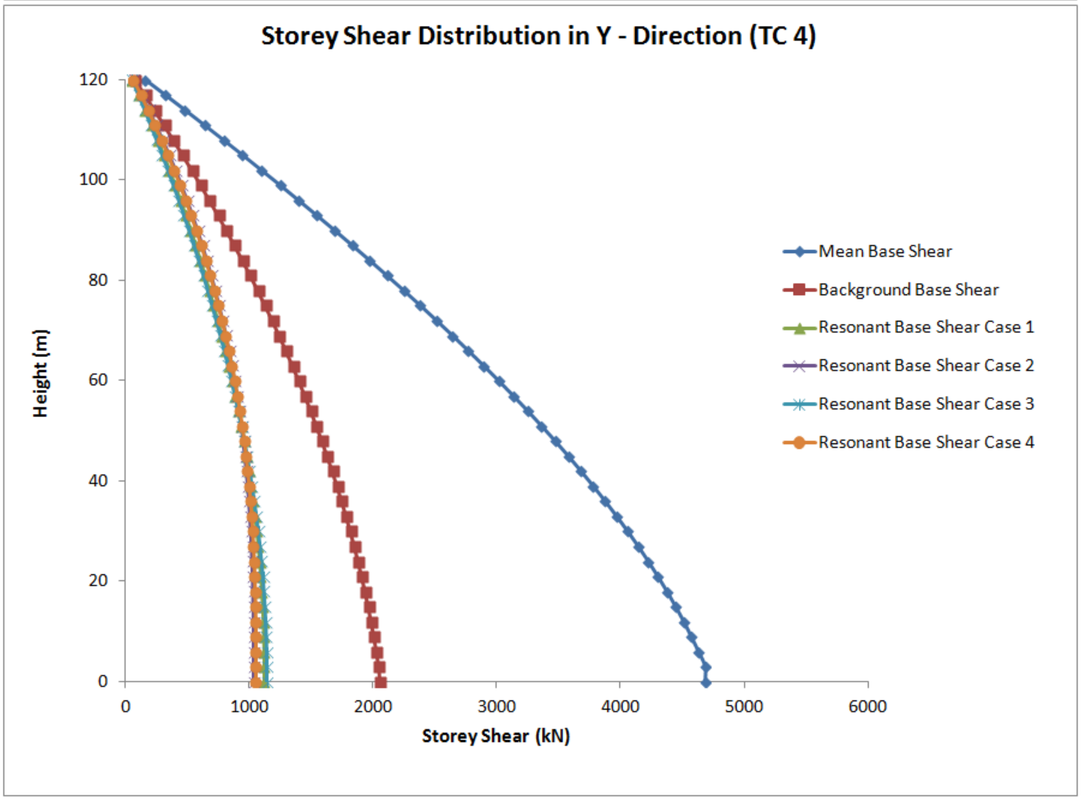


Figure 4.26: Storey Shear Distribution in X and Y- Direction for 40 storey

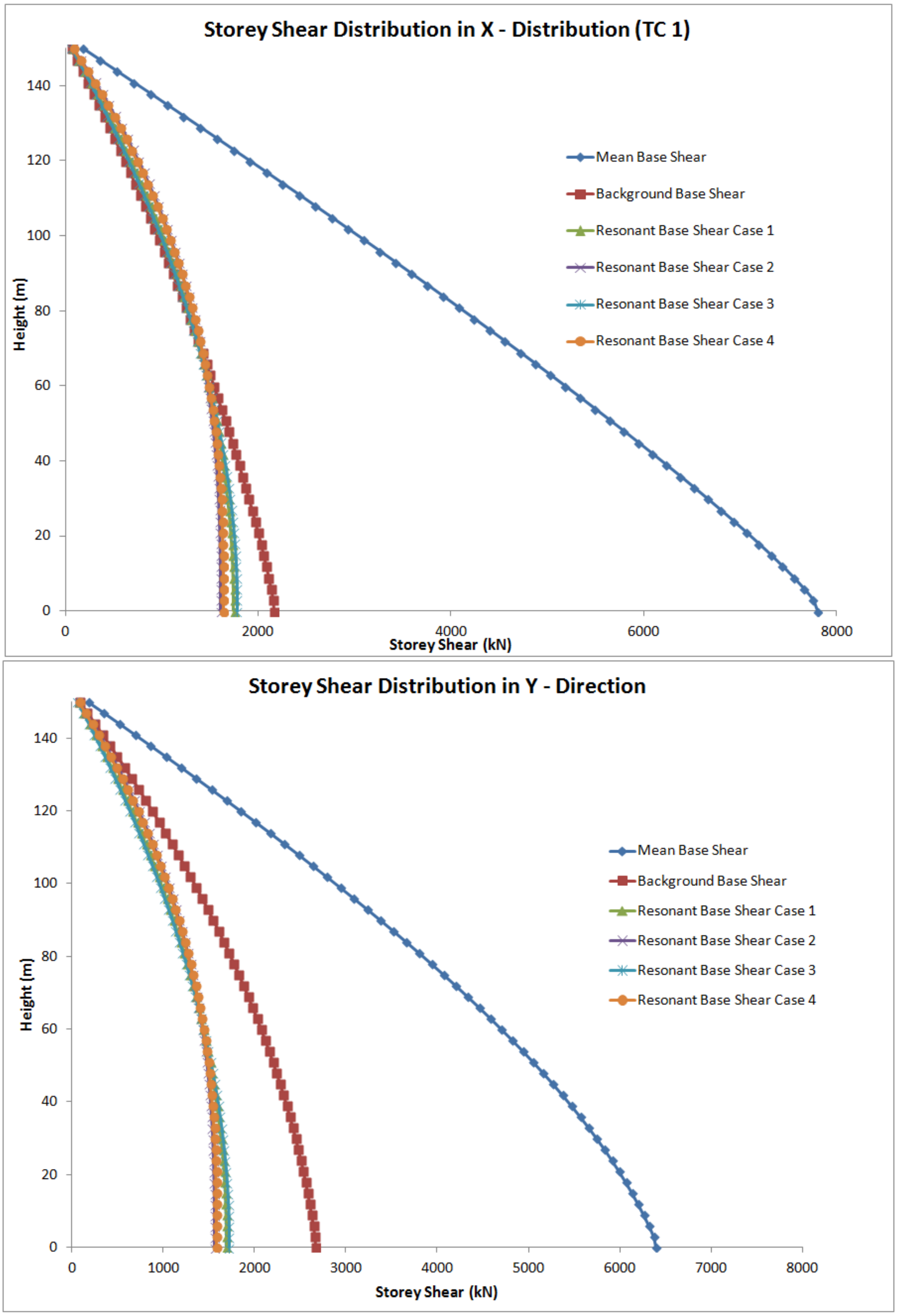


Figure 4.27: Storey Shear Distribution in X and Y- Direction for 50 storey

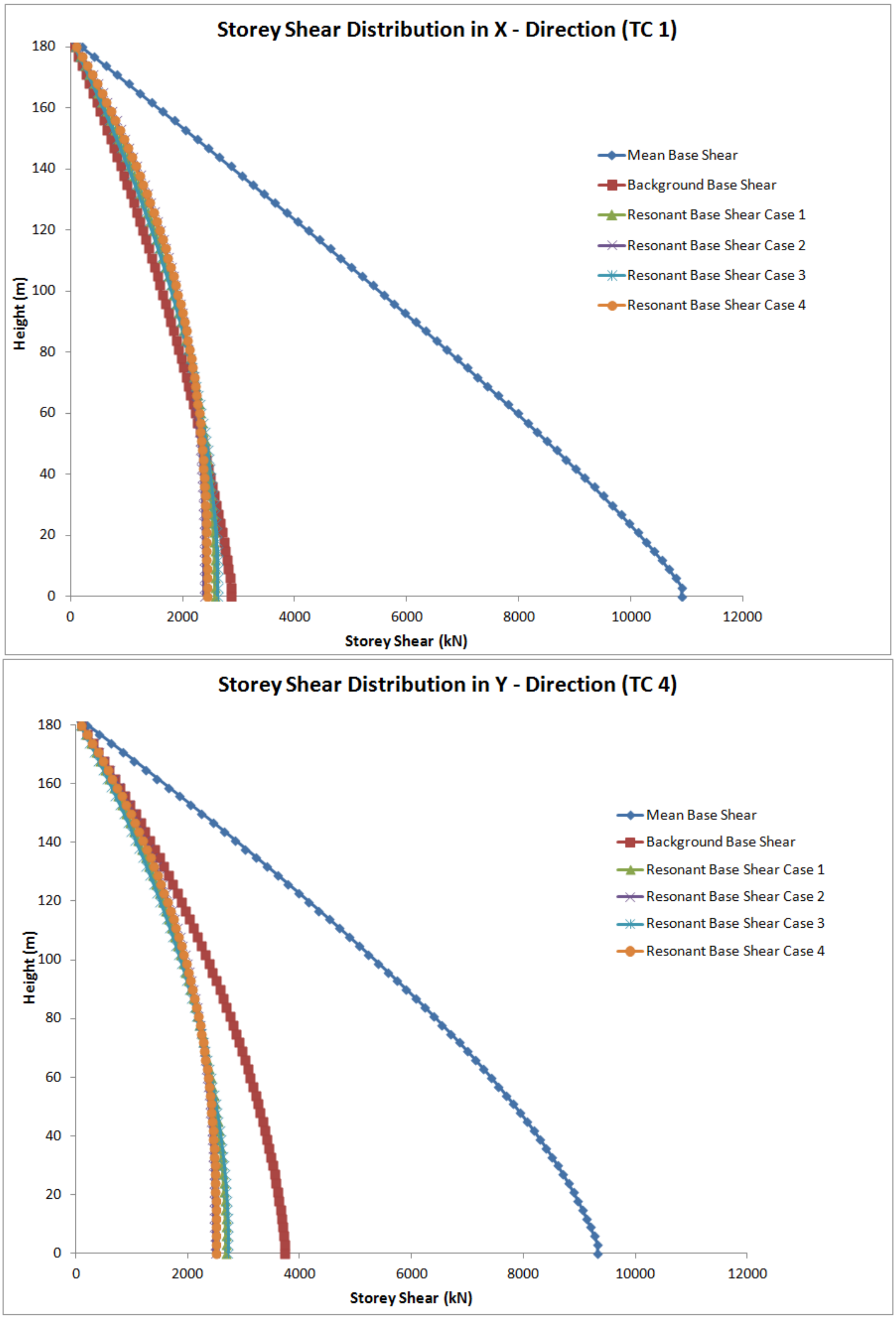


Figure 4.28: Storey Shear Distribution in X and Y- Direction for 60 storey

Comparison of Final Storey Shear

The plots show the comparison of final storey shear after the combination of all the three components. The plots are combined for X and Y direction for all the three buildings i.e. 40, 50 and 60 storey. From all the three plots it can be seen that the difference in base shear values is more for TC 4 considering both methods. The MGLF method gives higher values of storey shear as well as base shear for all the three buildings.

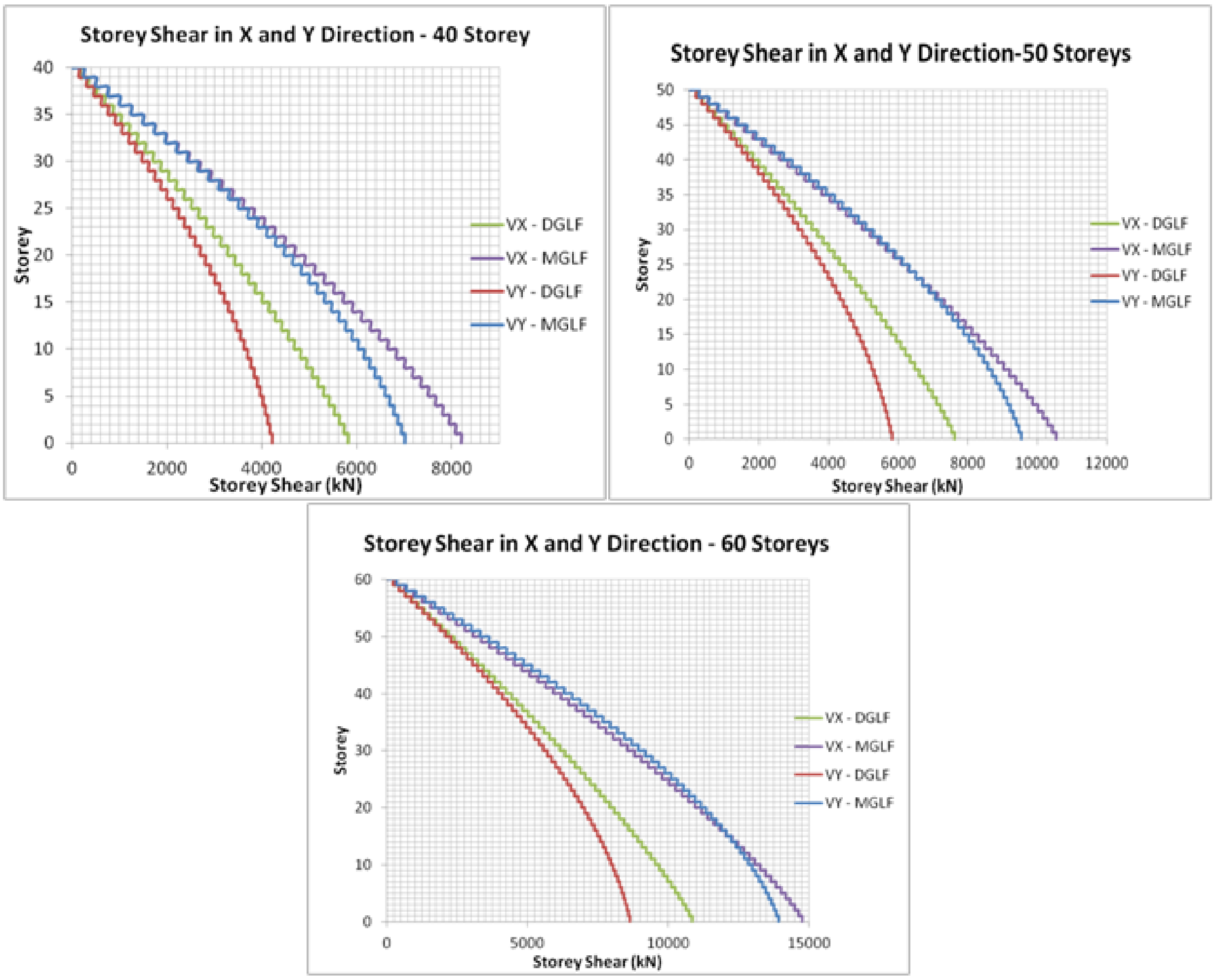


Figure 4.29: Final Storey Shear Distribution in X and Y- Direction for 40,50 and 60 storey

Comparison of Overturning Moment Distribution

The following plots show the comparison of overturning moments for all the three buildings i.e. 40, 50 and 60 storeys in X- and Y- direction i.e. TC 1 and TC 4 respectively.

From the Figure 4.30, which shows the overturning moment profile for 40 storey building in X and Y direction, it can be seen that the effect of mass variation and considereation of non linear mode shape is in significant for overturning moment, Whearas, it did significantly affect the storey shear distribuiton. All the lines for resonant moments can be seen to nearly overlap eachother. However, considering the contribution of resonant and background responses it can be seen that for TC 1 they are nearly equal and thus contribute equally to the final overturning moment.

Figure 4.31 shows the overturning moment profile for 50 storey building in both the X and Y direction. Here too the resonant response and the background response are equal to eachother along the entire height of building for TC 1. Whereas, for TC 4 in the top storeys it can be seen that they are equal but for the reat of the portion the resonant component is less than the background component. Here too the effect of mass variation and non linear mode shape is very less on the resonant component of overturning moment.

Figure 4.32 shows the overturning moment profile for 60 storey building in both the X and Y direction. Here the resonant response can be clearly seen to dominate over the background response for TC 1 and for TC 4 upto the mid height of building from the top, the resonant and background component are equal to each other. The effect of four cases of mass variation and non linear mode shape is insignificant.
Hence, it can be said that as the height of the building increases the resonant response governs. This can be observed in both the storey shear distribution as well as the overturning moment profile.

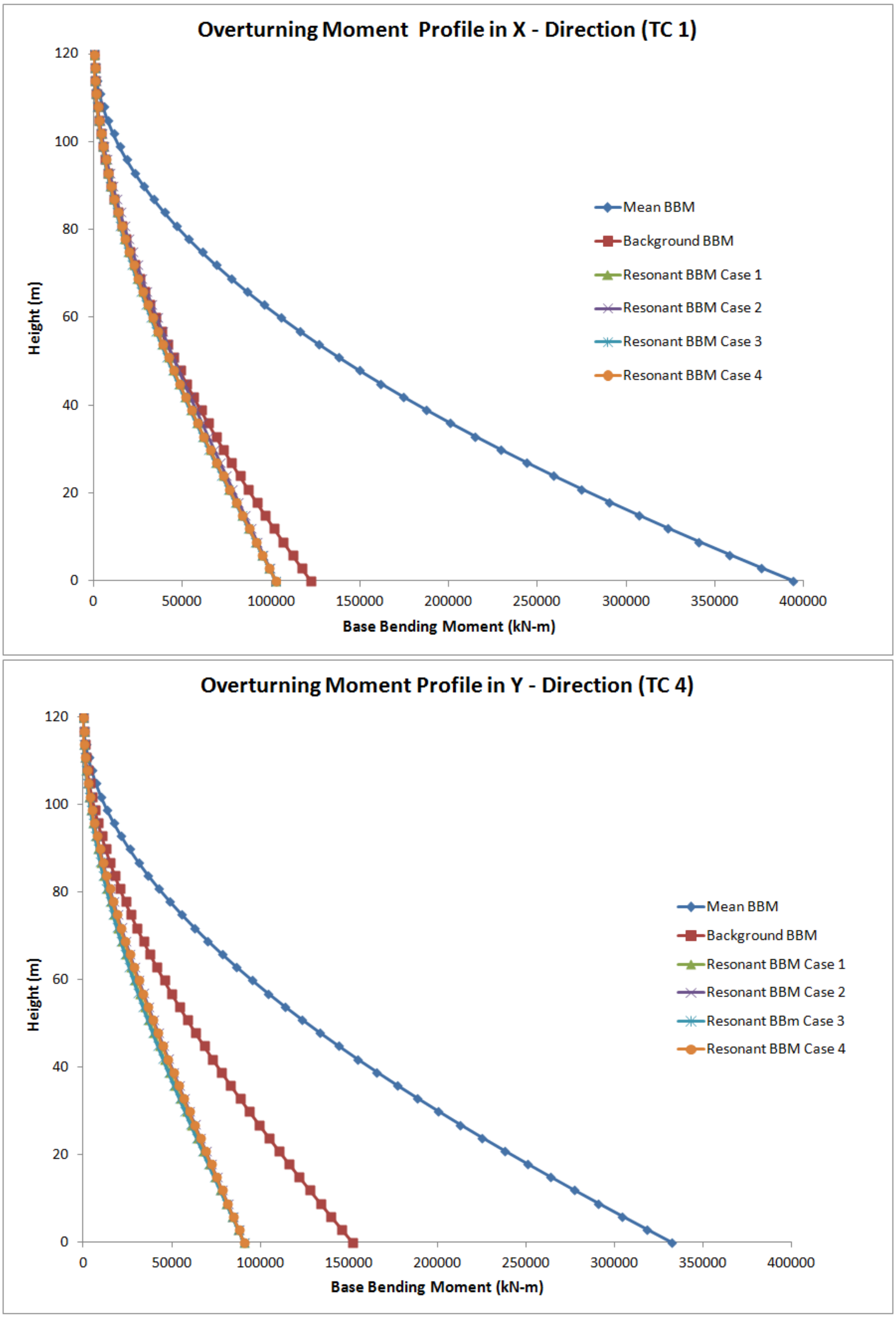
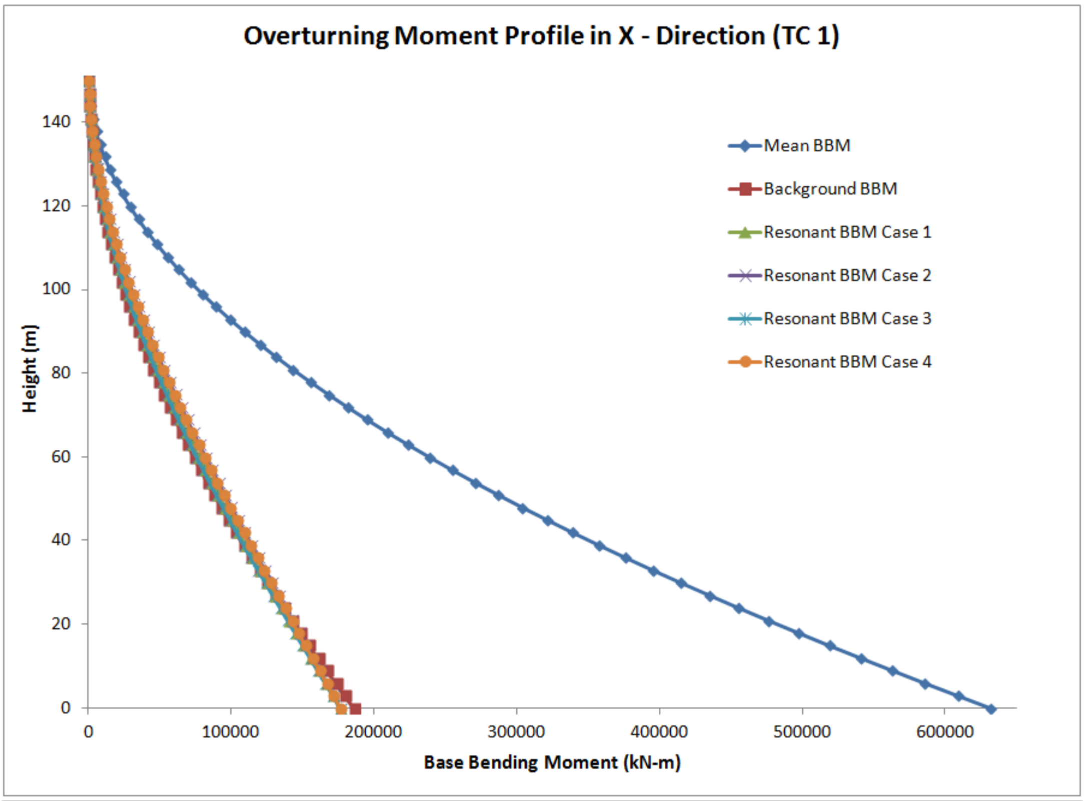


Figure 4.30: Overturning Moment Profile in X and Y- Direction for 40 storey



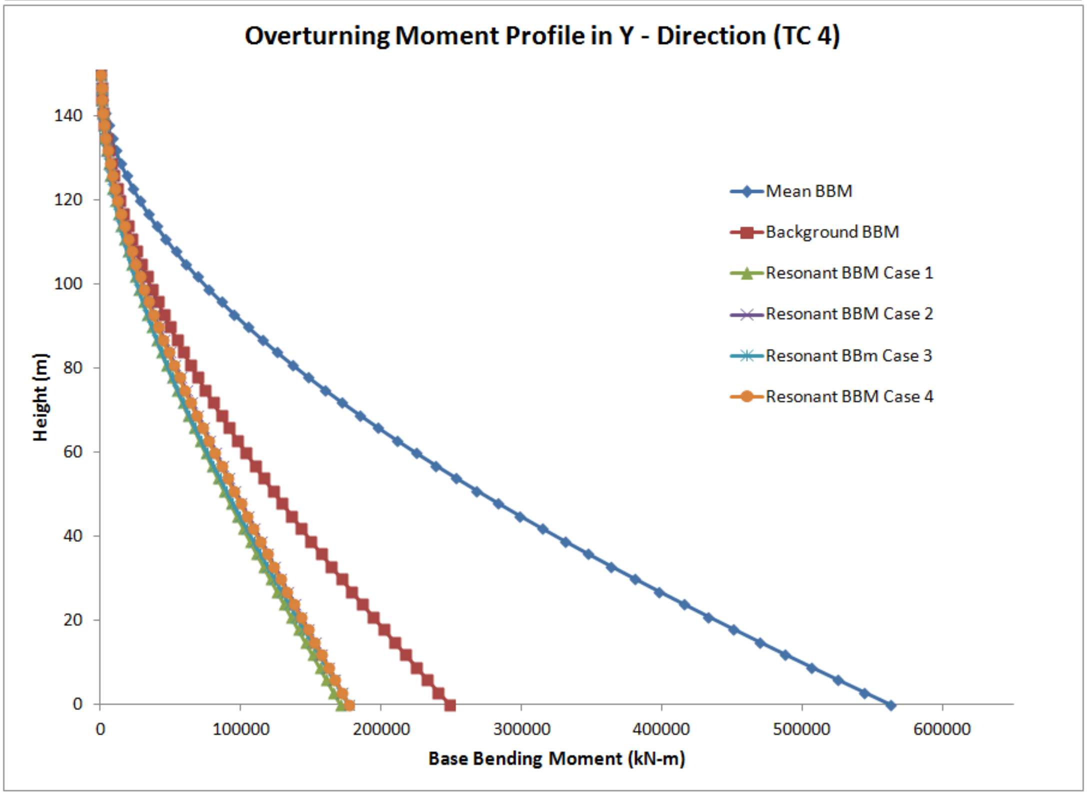
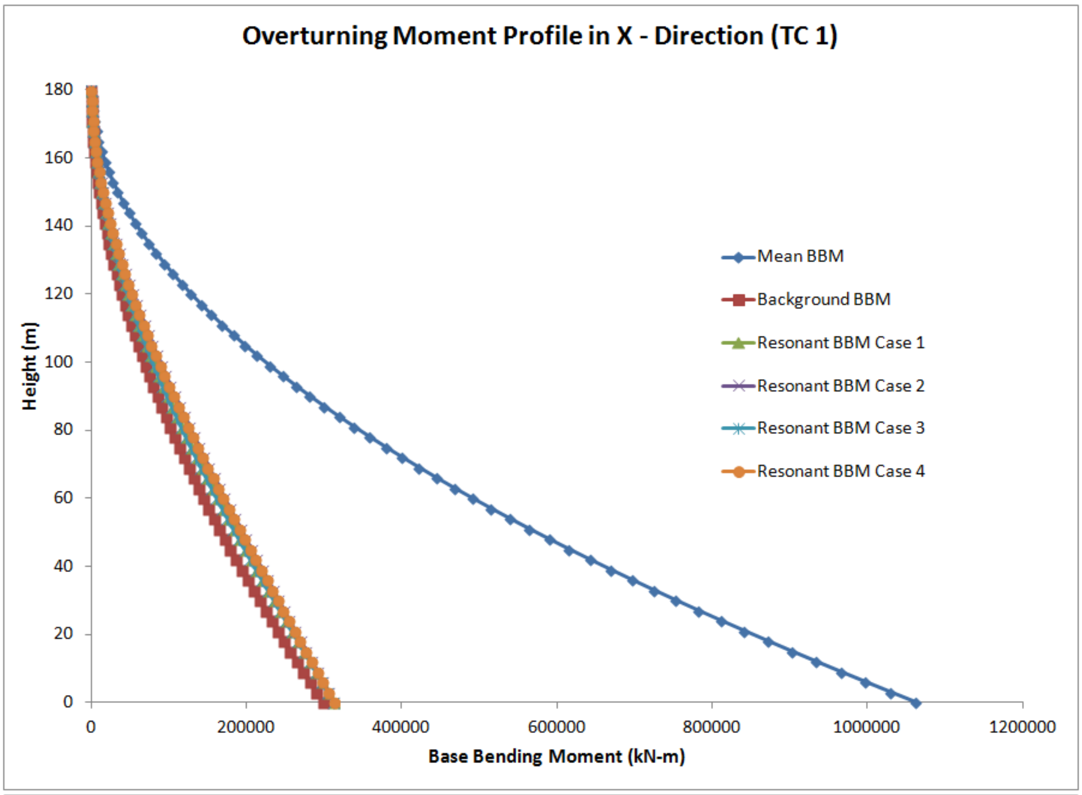


Figure 4.31: Overturning Moment Profile in X and Y- Direction for 50 storey



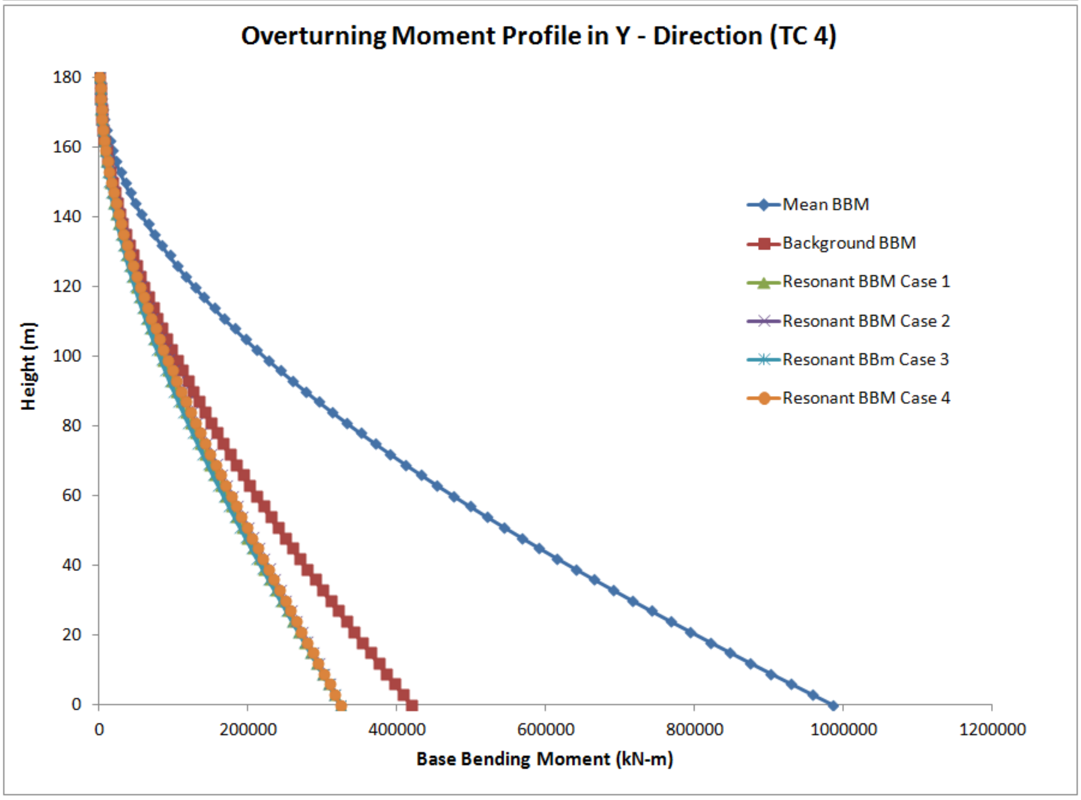


Figure 4.32: Overturning Moment Profile in X and Y- Direction for 60 storey

Comparison of Displacement

The plots in Figure 4.33 show the comparison of displacement for the buildings. The plots are combined for X and Y direction for all the three buildings i.e. 40, 50 and 60 storey. From all the three plots it can be seen that the difference in displacement values is more for TC 4 considering both methods. The MGLF method gives higher values of displacement for all the three buildings.

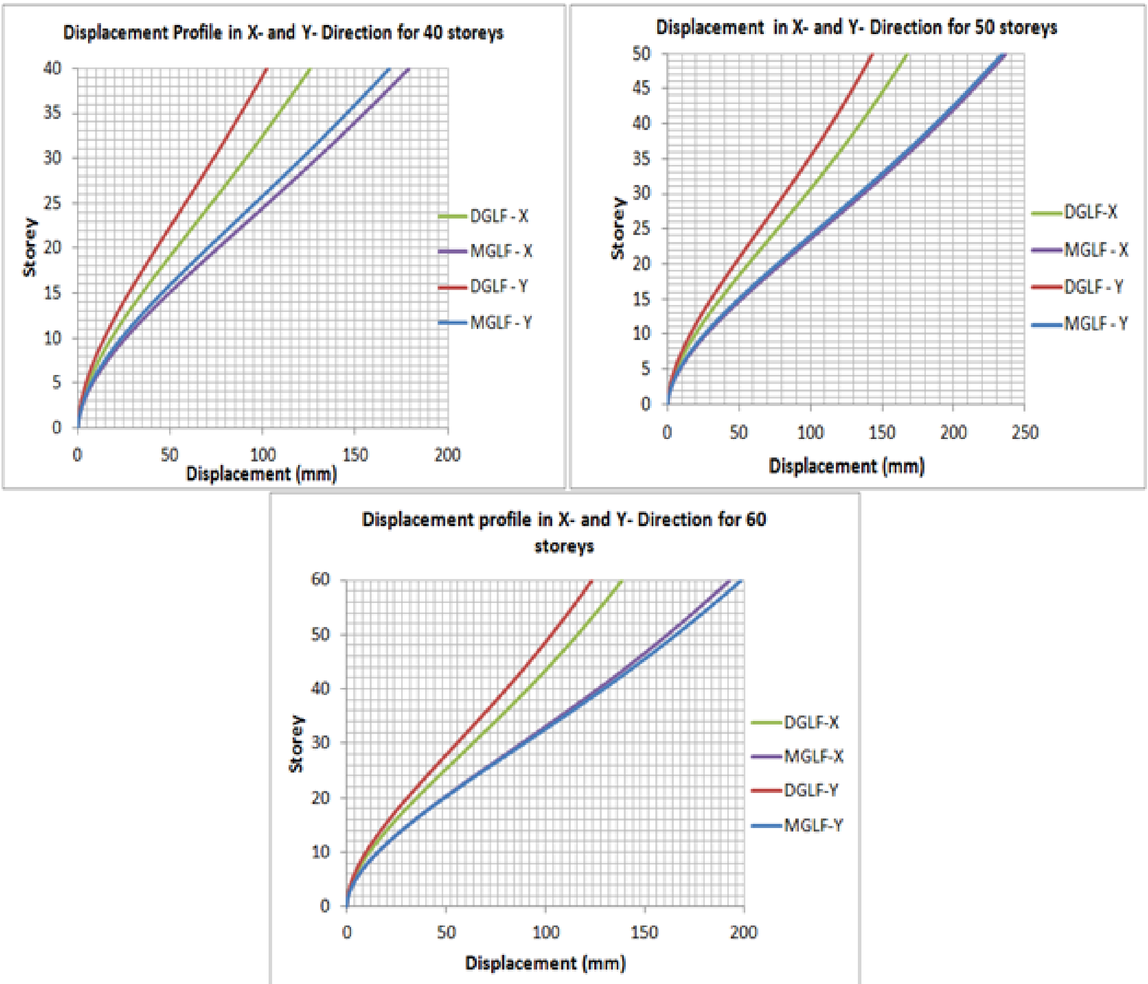


Figure 4.33: Displacement in X- and Y- Direction for 40. 50 and 60 storeys

Comparison of Storey Drift

The plots in Figure 4.34 show the comparison of storey drift for the buildings. The plots are combined for X and Y direction for all the three buildings i.e. 40, 50 and 60 storey. From all the three plots it can be seen that the difference in storey drift values is more for TC 4 considering both methods. The MGLF method gives higher values of displacement for all the three buildings. Also the drift is more in the middle portion of the building in case of MGLF method.

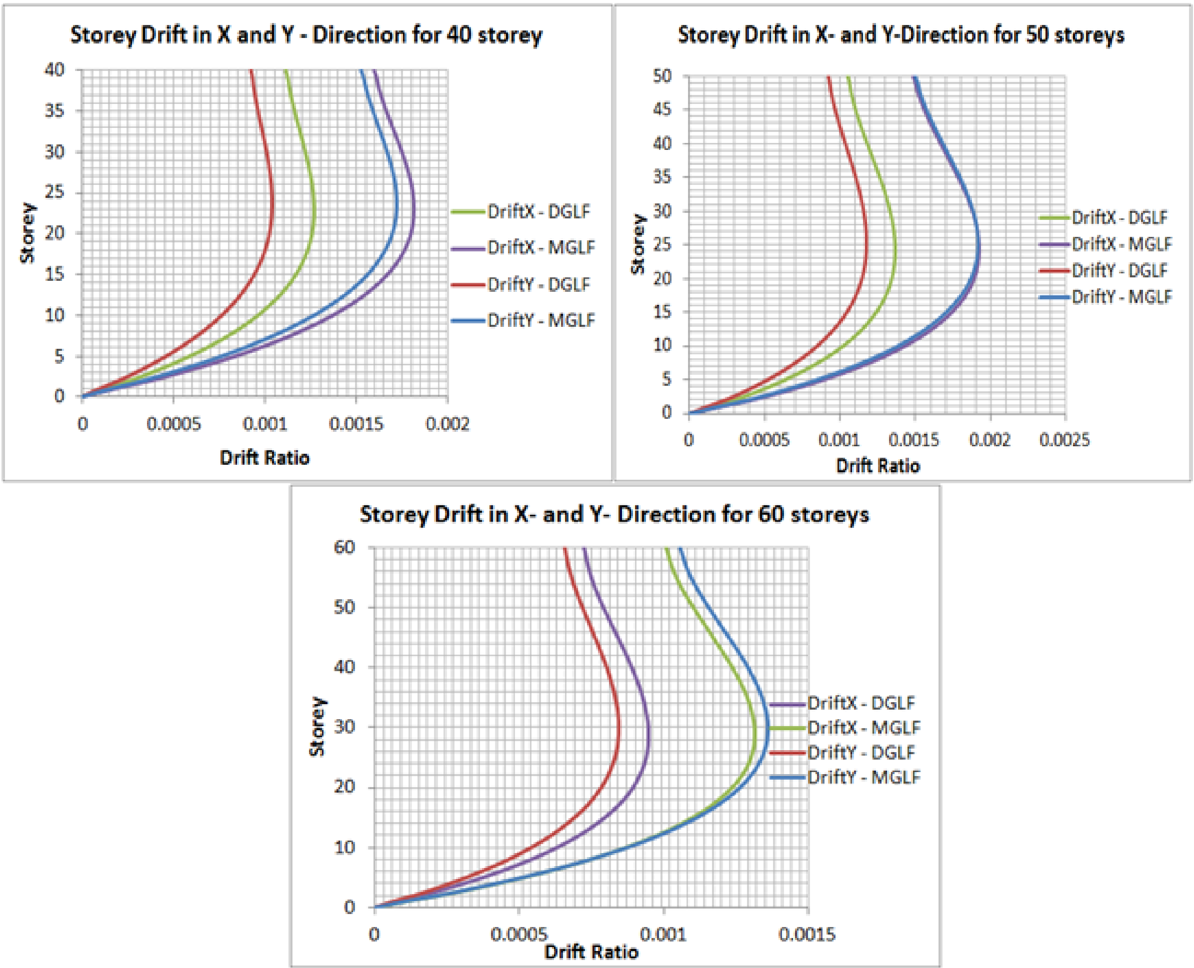


Figure 4.34: Storey Drift in X- and Y- Direction for 40. 50 and 60 storeys

From the plots of lateral forces, storey shear, overturning moment, storey drift and displacement it can be seen that the MGLF method gives higher values compared to DGLF.

Comparison of Base Shear

The following table shows the comparison of base shear value for all the three buildings. The above Table shows that the DGLF method gives a significantly lower value

Table 4.3: Comparison of Base Shear for 40,50 and 60 Storey Buildings

Base Shear (kN)	G+40		G+50		G+60	
	DGLF	MGLF	DGLF	MGLF	DGLF	MGLF
TC 1	7022	8246	9591	10582	10889	14764
TC 4	2598	7026	3838	9558	8051	13925

of Base Shear in the Terrain Category 4 compared to MGLF.Whereas, as per code the most turbulent wind would be in Terrain Category 4. The MGLF Procedure gives a more realistic value.

Comparison of Reinforcement for Columns

The columns C1, C3 and C15 as shown in the plan have been considered for the reinforcement comparison. The buildings have been modelled in ETABS and designed as per IS 456-2000. Only the wind forces have been changed and the rest of the things have been kept constant in the modelling of MGLF and DGLF building.It is observed that the reinforcement change occurs mainly in the middle portion of the building. Hence, the tabulated data contains the changes in the middle stories only. The following three Tables 4.4,4.5 and 4.6 contain the percentage increase in the reinforcement along the grouped storeys of the columns C1, C3 and C15 for all three buildings i.e. 40, 50 and 60 storey. As a common practice observed in high rise buildings, the reinforcements are grouped storeywise and the same reinforcement is provided for the clubbed stories.

Table 4.4: Comparison of Reinforcement for 40 Storey building-Summary

Comparison of Column Reinforcement for 40 storey								
Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
Storey 28 to 40	C1	C1100X1100	0.9DL-1.5EQY	5120	5120	0.9DL-1.5EQY	5120	0
Storey 24 to 27	C1	C1100X1100	1.5(DL + LL)	5120	13358	1.5(DL-WLX)	14759	10
Storey 20 to 23	C1	C1100X1100	1.5(DL + LL)	5120	17924	1.5(DL-WLX)	19166	7
Storey 16 to 19	C1	C1100X1100	1.5(DL + LL)	5120	22515	1.5(DL-WLX)	24545	9
Storey 1 to 15	C1	C1100X1100	1.5(DL + LL)	5120	25618	1.5(DL + LL)	25618	0
Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
Storey 28 to 40	C3	C1100X1100	0.9DL-1.5EQY	5120	5120	0.9DL-1.5EQY	5120	0
Storey 24 to 27	C3	C1100X1100	1.5(DL-WLX)	5120	8605	1.5(DL-WLX)	10601	23
Storey 20 to 23	C3	C1100X1100	1.5(DL-WLX)	5120	11998	1.5(DL-WLX)	15183	27
Storey 16 to 19	C3	C1100X1100	1.5(DL + LL)	5120	16919	1.5(DL-WLY)	20193	19
Storey 1 to 15	C3	C1100X1100	1.5(DL + LL)	5120	32923	1.5(DL + LL)	32923	0
Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
Storey 28 to 40	C15	C1100X1100	0.9DL-1.5EQY	5120	5120	0.9DL-1.5EQY	5120	0
Storey 24 to 27	C15	C1100X1100	1.5(DL + LL)	5120	8085	1.5(DL-WLY)	10326	28
Storey 20 to 23	C15	C1100X1100	1.5(DL + LL)	5120	14367	1.5(DL-WLY)	14708	2
Storey 16 to 19	C15	C1100X1100	1.5(DL + LL)	5120	16901	1.5(DL-WLY)	19396	15
Storey 1 to 15	C15	C1100X1100	1.5(DL + LL)	5120	32911	1.5(DL + LL)	32911	0

It can be seen that for column C1 and C15 that in case of MGLF the governing load combination has changed to DL-WLY and DL-WLX from DL+ LL. The % increase in the reinforcement can be observed in the middle stories with maximum increase in column C3.

Table 4.5: Comparison of Reinforcement for 50 Storey building-Summary

Comparison of Column Reinforcement for 50 storey								
Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
Storey 50 to 37	C1	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
Storey 31 to 36	C1	C1100X1100	1.5(DL-WLX)	9680	17438	1.5(DL-WLY)	20499	18
Storey 25 to 30	C1	C1100X1100	1.5(DL-WLX)	9680	29351	1.5(DL-WLY)	33094	13
Storey 19 to 24	C1	C1100X1100	1.5(DL-WLX)	9680	38759	1.5(DL-WLY)	44385	15
Storey 13 to 18	C1	C1100X1100	1.5(DL-WLX)	9680	47118	1.5(DL-WLY)	53130	13
Storey 1 to 12	C1	C1100X1100	1.5(DL-WLX)	9680	49679	1.5(DL-WLX)	55175	11
Storey 50 to 33	C3	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
Storey 29 to 32	C4	C1100X1101	1.5(DL-WLX)	9680	14311	1.5(DL-WLX)	17498	22
Storey 25 to 28	C3	C1100X1100	1.5(DL-WLX)	9680	19775	1.5(DL-WLX)	24935	26
Storey 19 to 24	C3	C1100X1100	1.5(DL-WLX)	9680	28442	1.5(DL-WLX)	33956	19
Storey 13 to 18	C3	C1100X1100	1.5(DL-WLX)	9680	38617	1.5(DL-WLX)	46653	21
Storey 7 to 12	C3	C1100X1100	1.5(DL-WLX)	9680	46342	1.5(DL-WLX)	52952	14
Storey 1 to 6	C3	C1100X1100	1.5(DL-WLX)	9680	43476	1.5(DL-WLX)	53204	22
Storey 50 to 34	C15	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
Storey 29 to 33	C15	C1100X1100	1.5(DL+LL)	9680	13270	1.5(DL-WLY)	17628	33
Storey 25 to 28	C15	C1100X1100	1.5(DL+LL)	9680	18781	1.5(DL-WLY)	23070	23
Storey 19 to 24	C15	C1100X1100	1.5(DL-WLY)	9680	26465	1.5(DL-WLY)	33971	28
Storey 13 to 18	C15	C1100X1100	1.5(DL-WLY)	9680	35848	1.5(DL-WLY)	46472	30
Storey 1 to 12	C15	C1100X1100	1.5(DL-WLY)	9680	41025	1.5(DL-WLY)	52812	29

It can be observed that the governing load combinations in MGLF are majorly the wind combinations. The maximum percentage increase in the reinforcements have been observed in column C15.

Table 4.6: Comparison of Reinforcement for 60 Storey building-Summary

Comparison of Column Reinforcement for 60 storey								
Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
Storey 36 to 60	C1	C1500x1500	0.9DL-1.5EQY	18000	18000	0.9DL-1.5EQY	18000	0
Storey 33 to 35	C1	C1500x1500	1.5(DL-WLX)	18000	33037	1.5(DL-WLY)	37790	14
Storey 28 to 32	C1	C1500x1500	1.5(DL-WLX)	18000	43729	1.5(DL-WLY)	54686	25
Storey 23 to 27	C1	C1500x1500	1.5(DL-WLX)	18000	61560	1.5(DL-WLY)	73603	20
Storey 18 to 22	C1	C1500x1500	1.5(DL-WLX)	18000	79892	1.5(DL-WLY)	94009	18
Storey 15 to 17	C1	C1500x1500	1.5(DL-WLX)	18000	90656	1.5(DL-WLY)	106514	17
Storey 1 to 14	C1	C1500x1500	1.5(DL-WLX)	18000	93892	1.5(DL-WLY)	111087	18
Storey 36 to 60	C3	C1500x1500	0.9DL-1.5EQY	18000	18000	0.9DL-1.5EQY	18000	0
Storey 33 to 35	C3	C1500x1500	1.5(DL-WLX)	18000	31905	1.5(DL-WLY)	35775	12
Storey 28 to 32	C3	C1500x1500	1.5(DL-WLX)	18000	40938	1.5(DL-WLY)	49423	21
Storey 23 to 27	C3	C1500x1500	1.5(DL-WLX)	18000	58078	1.5(DL-WLY)	66091	14
Storey 18 to 22	C3	C1500x1500	1.5(DL-WLX)	18000	73974	1.5(DL-WLY)	85866	16
Storey 15 to 17	C3	C1500x1500	1.5(DL-WLX)	18000	84674	1.5(DL-WLY)	95866	13
Storey 1 to 14	C3	C1500x1500	1.5(DL-WLX)	18000	87895	1.5(DL-WLY)	100458	14
Storey 36 to 60	C15	C1500x1500	0.9DL-1.5EQY	18000	18000	0.9DL-1.5EQY	18000	0
Storey 33 to 35	C15	C1500x1500	1.5(DL-WLX)	18000	30960	1.5(DL-WLY)	36402	18
Storey 28 to 32	C15	C1500x1500	1.5(DL-WLX)	18000	40938	1.5(DL-WLY)	50788	24
Storey 23 to 27	C15	C1500x1500	1.5(DL-WLX)	18000	58078	1.5(DL-WLY)	67212	16
Storey 18 to 22	C15	C1500x1500	1.5(DL-WLX)	18000	73974	1.5(DL-WLY)	87380	18
Storey 15 to 17	C15	C1500x1500	1.5(DL-WLX)	18000	84674	1.5(DL-WLY)	97205	15
Storey 1 to 14	C15	C1500x1500	1.5(DL-WLX)	18000	87895	1.5(DL-WLY)	100790	15

The governing load case in MGLF is DL-WLY for all the three columns. This is mainly because of the fact that MGLF gives higher result for lateral forces in TC 4 also which is Y direction of the building, contrary to the DGLF method where it gives lower result in TC 4. The average percentage increase is in the range of 20-25%.

Storeywise Comparison of Increase in Reinforcement

a. **For 40 Storey Building**

The following tables show the storey wise comparison of increase in the reinforcements for the columns C1, C3 and C15 of all the three buildings. The results have been tabulated in such a way that the effect on the important stories has only been captured. There is no substantial increase in reinforcement for the stories which are not included in the following tables.

It can be seen from Table4.7 that the lower storeys of column C1 have been subjected to maximum percentage increase in the reinforcement i.e. in the 35 - 40% range. The governing load combination has also changed from DL-WLX to DL - WLY for middle stories from storey 18 to 35.

From Table 4.8, which is for column C3, again the lower stories show more increase in steel but the governing load combination remains DL - WLX for both the cases i.e. DGLF and MGLF.

For the case of column C15 which can be reffered from Table 4.9, there is highest increase in the reinforcement is observed. the governing load case has changed for the bottom stories from DL + LL to DL - WLY. Majorly fro the entire building DL - WLY governs. The percentage increase in reinforcement is in the range of 35 - 50% which is a significant increase.

Table 4.7: Reinforcement Comparison for Column C1 - 40 Storey Building

Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
STORY35	C1	C1100X1100	0.9DL-1.5EQY	9680	9680	1.5(DL-WLY)	11495	19
STORY34	C1	C1100X1100	1.5(DL-WLX)	9680	10769	1.5(DL-WLY)	14124	31
STORY33	C1	C1100X1100	1.5(DL-WLX)	9680	13110	1.5(DL-WLY)	16475	26
STORY32	C1	C1100X1100	1.5(DL-WLX)	9680	15383	1.5(DL-WLY)	18589	21
STORY31	C1	C1100X1100	1.5(DL-WLX)	9680	17438	1.5(DL-WLY)	20499	18
STORY30	C1	C1100X1100	1.5(DL-WLX)	9680	19303	1.5(DL-WLY)	22288	15
STORY29	C1	C1100X1100	1.5(DL-WLX)	9680	21002	1.5(DL-WLY)	25658	22
STORY28	C1	C1100X1100	1.5(DL-WLX)	9680	22987	1.5(DL-WLY)	27759	21
STORY27	C1	C1100X1100	1.5(DL-WLX)	9680	25879	1.5(DL-WLY)	29608	14
STORY26	C1	C1100X1100	1.5(DL-WLX)	9680	27568	1.5(DL-WLY)	31421	14
STORY25	C1	C1100X1100	1.5(DL-WLX)	9680	29351	1.5(DL-WLY)	33094	13
STORY24	C1	C1100X1100	1.5(DL-WLX)	9680	31006	1.5(DL-WLY)	34639	12
STORY23	C1	C1100X1100	1.5(DL-WLX)	9680	32540	1.5(DL-WLY)	36064	11
STORY22	C1	C1100X1100	1.5(DL-WLX)	9680	33964	1.5(DL-WLY)	38267	13
STORY21	C1	C1100X1100	1.5(DL-WLX)	9680	35284	1.5(DL-WLY)	40418	15
STORY20	C1	C1100X1100	1.5(DL-WLX)	9680	36746	1.5(DL-WLY)	42419	15
STORY19	C1	C1100X1100	1.5(DL-WLX)	9680	38759	1.5(DL-WLY)	44385	15
STORY18	C1	C1100X1100	1.5(DL-WLX)	9680	40635	1.5(DL-WLY)	46122	14
STORY17	C1	C1100X1100	1.5(DL-WLX)	9680	42502	1.5(DL-WLX)	47736	12
STORY16	C1	C1100X1100	1.5(DL-WLX)	9680	44154	1.5(DL-WLX)	49241	12
STORY15	C1	C1100X1100	1.5(DL-WLX)	9680	45691	1.5(DL-WLX)	50636	11
STORY14	C1	C1100X1100	1.5(DL-WLX)	9680	47118	1.5(DL-WLX)	51927	10
STORY13	C1	C1100X1100	1.5(DL-WLX)	9680	48444	1.5(DL-WLX)	53130	10
STORY12	C1	C1100X1100	1.5(DL-WLX)	9680	49679	1.5(DL-WLX)	55175	11
STORY11	C1	C1100X1100	1.5(DL-WLX)	9680	50826	1.5(DL-WLX)	57389	13
STORY10	C1	C1100X1100	1.5(DL-WLX)	9680	51933	1.5(DL-WLX)	59731	15
STORY9	C1	C1100X1100	1.5(DL-WLX)	9680	53099	1.5(DL-WLX)	61657	16
STORY8	C1	C1100X1100	1.5(DL-WLX)	9680	54853	1.5(DL-WLY)	39823	-27
STORY7	C1	C1100X1100	1.5(DL-WLX)	9680	56983	1.5(DL-WLY)	41546	-27
STORY6	C1	C1100X1100	1.5(DL-WLX)	9680	17726	1.5(DL-WLX)	25345	43
STORY5	C1	C1100X1100	1.5(DL-WLX)	9680	19414	1.5(DL-WLX)	27356	41
STORY4	C1	C1100X1100	1.5(DL-WLX)	9680	20992	1.5(DL-WLX)	29223	39
STORY3	C1	C1100X1100	1.5(DL-WLX)	9680	22571	1.5(DL-WLX)	30970	37
STORY2	C1	C1100X1100	1.5(DL-WLX)	9680	24288	1.5(DL-WLX)	32495	34
STORY1	C1	C1100X1100	1.5(DL-WLX)	9680	26410	1.5(DL-WLX)	34362	30

Table 4.8: Reinforcement Comparison for Column C3 40 Storey Building

Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
STORY35	C3	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
STORY34	C3	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
STORY33	C3	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
STORY32	C3	C1100X1100	0.9DL-1.5EQY	9680	9680	1.5(DL-WLX)	11163	15
STORY31	C3	C1100X1100	1.5(DL-WLX)	9680	10145	1.5(DL-WLX)	14221	40
STORY30	C3	C1100X1100	1.5(DL-WLX)	9680	12093	1.5(DL-WLX)	15922	32
STORY29	C3	C1100X1100	1.5(DL-WLX)	9680	14311	1.5(DL-WLX)	17498	22
STORY28	C3	C1100X1100	1.5(DL-WLX)	9680	15840	1.5(DL-WLX)	18975	20
STORY27	C3	C1100X1100	1.5(DL-WLX)	9680	17276	1.5(DL-WLX)	20304	18
STORY26	C3	C1100X1100	1.5(DL-WLX)	9680	18578	1.5(DL-WLX)	21517	16
STORY25	C3	C1100X1100	1.5(DL-WLX)	9680	19775	1.5(DL-WLX)	22943	16
STORY24	C3	C1100X1100	1.5(DL-WLX)	9680	20871	1.5(DL-WLX)	24935	19
STORY23	C3	C1100X1100	1.5(DL-WLX)	9680	21872	1.5(DL-WLX)	26793	22
STORY22	C3	C1100X1100	1.5(DL-WLX)	9680	23395	1.5(DL-WLX)	28592	22
STORY21	C3	C1100X1100	1.5(DL-WLX)	9680	25106	1.5(DL-WLX)	30353	21
STORY20	C3	C1100X1100	1.5(DL-WLX)	9680	26784	1.5(DL-WLX)	32092	20
STORY19	C3	C1100X1100	1.5(DL-WLX)	9680	28442	1.5(DL-WLX)	33956	19
STORY18	C3	C1100X1100	1.5(DL-WLX)	9680	30211	1.5(DL-WLX)	35612	18
STORY17	C3	C1100X1100	1.5(DL-WLX)	9680	32004	1.5(DL-WLX)	37678	18
STORY16	C3	C1100X1100	1.5(DL-WLX)	9680	33592	1.5(DL-WLX)	40098	19
STORY15	C3	C1100X1100	1.5(DL-WLX)	9680	35065	1.5(DL-WLX)	42588	21
STORY14	C3	C1100X1100	1.5(DL-WLX)	9680	36492	1.5(DL-WLX)	44701	22
STORY13	C3	C1100X1100	1.5(DL-WLX)	9680	38617	1.5(DL-WLX)	46653	21
STORY12	C3	C1100X1100	1.5(DL-WLX)	9680	40924	1.5(DL-WLX)	48459	18
STORY11	C3	C1100X1100	1.5(DL-WLX)	9680	42869	1.5(DL-WLX)	50148	17
STORY10	C3	C1100X1100	1.5(DL-WLX)	9680	44674	1.5(DL-WLX)	51701	16
STORY9	C3	C1100X1100	1.5(DL-WLX)	9680	46342	1.5(DL-WLX)	52952	14
STORY8	C3	C1100X1100	1.5(DL-WLX)	9680	47923	1.5(DL-WLX)	49155	3
STORY7	C3	C1100X1100	1.5(DL-WLX)	9680	49386	1.5(DL-WLX)	50977	3
STORY6	C3	C1100X1100	1.5(DL-WLX)	9680	31507	1.5(DL-WLX)	41241	31
STORY5	C3	C1100X1100	1.5(DL-WLX)	9680	33812	1.5(DL-WLX)	43987	30
STORY4	C3	C1100X1100	1.5(DL-WLX)	9680	35980	1.5(DL-WLX)	46553	29
STORY3	C3	C1100X1100	1.5(DL-WLX)	9680	38580	1.5(DL-WLX)	48942	27
STORY2	C3	C1100X1100	1.5(DL-WLX)	9680	41119	1.5(DL-WLX)	51163	24
STORY1	C3	C1100X1100	1.5(DL-WLX)	9680	43476	1.5(DL-WLX)	53204	22

Table 4.9: Reinforcement Comparison for Column C15 - 40 Storey Building

Storey	Column	Column Section	LC	AsMin	As - DGLF	LC	As - MGLF	% increase
STORY34	C15	C1100X1100	0.9DL-1.5EQY	9680	9680	0.9DL-1.5EQY	9680	0
STORY33	C15	C1100X1100	0.9DL-1.5EQY	9680	9680	1.5(DL-WLY)	9769	1
STORY32	C15	C1100X1100	0.9DL-1.5EQY	9680	9680	1.5(DL-WLY)	11436	18
STORY31	C15	C1100X1100	1.5(DL+LL)	9680	9791	1.5(DL-WLY)	14465	48
STORY30	C15	C1100X1100	1.5(DL+LL)	9680	11221	1.5(DL-WLY)	16068	43
STORY29	C15	C1100X1100	1.5(DL-WLY)	9680	13270	1.5(DL-WLY)	17628	33
STORY28	C15	C1100X1100	1.5(DL-WLY)	9680	14811	1.5(DL-WLY)	19092	29
STORY27	C15	C1100X1100	1.5(DL-WLY)	9680	16254	1.5(DL-WLY)	20405	26
STORY26	C15	C1100X1100	1.5(DL-WLY)	9680	17570	1.5(DL-WLY)	21603	23
STORY25	C15	C1100X1100	1.5(DL-WLY)	9680	18781	1.5(DL-WLY)	23070	23
STORY24	C15	C1100X1100	1.5(DL-WLY)	9680	19893	1.5(DL-WLY)	25047	26
STORY23	C15	C1100X1100	1.5(DL-WLY)	9680	20912	1.5(DL-WLY)	26885	29
STORY22	C15	C1100X1100	1.5(DL-WLY)	9680	21842	1.5(DL-WLY)	28663	31
STORY21	C15	C1100X1100	1.5(DL-WLY)	9680	23237	1.5(DL-WLY)	30403	31
STORY20	C15	C1100X1100	1.5(DL-WLY)	9680	24853	1.5(DL-WLY)	32129	29
STORY19	C15	C1100X1100	1.5(DL-WLY)	9680	26465	1.5(DL-WLY)	33971	28
STORY18	C15	C1100X1100	1.5(DL-WLY)	9680	28160	1.5(DL-WLY)	35604	26
STORY17	C15	C1100X1100	1.5(DL-WLY)	9680	29985	1.5(DL-WLY)	37624	25
STORY16	C15	C1100X1100	1.5(DL-WLY)	9680	31614	1.5(DL-WLY)	40008	27
STORY15	C15	C1100X1100	1.5(DL-WLY)	9680	33129	1.5(DL-WLY)	42465	28
STORY14	C15	C1100X1100	1.5(DL-WLY)	9680	34538	1.5(DL-WLY)	44548	29
STORY13	C15	C1100X1100	1.5(DL-WLY)	9680	35848	1.5(DL-WLY)	46472	30
STORY12	C15	C1100X1100	1.5(DL-WLY)	9680	37514	1.5(DL-WLY)	48252	29
STORY11	C15	C1100X1100	1.5(DL-WLY)	9680	39740	1.5(DL-WLY)	49916	26
STORY10	C15	C1100X1100	1.5(DL-WLY)	9680	41621	1.5(DL-WLY)	51450	24
STORY9	C15	C1100X1100	1.5(DL-WLY)	9680	43384	1.5(DL-WLY)	52679	21
STORY8	C15	C1100X1100	1.5(DL-WLY)	9680	45023	1.5(DL-WLY)	37038	-18
STORY7	C15	C1100X1100	1.5(DL-WLY)	9680	46581	1.5(DL-WLY)	39627	-15
STORY6	C15	C1100X1100	1.5(DL-WLY)	9680	28019	1.5(DL-WLY)	40894	46
STORY5	C15	C1100X1100	1.5(DL+LL)	9680	30546	1.5(DL-WLY)	43623	43
STORY4	C15	C1100X1100	1.5(DL+LL)	9680	33011	1.5(DL-WLY)	46174	40
STORY3	C15	C1100X1100	1.5(DL+LL)	9680	35382	1.5(DL-WLY)	48554	37
STORY2	C15	C1100X1100	1.5(DL+LL)	9680	38126	1.5(DL-WLY)	50772	33
STORY1	C15	C1100X1100	1.5(DL+LL)	9680	41025	1.5(DL-WLY)	52812	29

b. **For 50 Storey Building**

From Table 4.10 and 4.11 it can be seen that the maximum effect is seen in the middle height region of the building from storey 15 to 27. This is maily because the drift in the middle region increases due to application of the MGLF procedure. For column C1, the governing load combination changes from DL + LL to DL - WLX which shows clearly that wind governs the design for MGLF method but the average % increase in case of C1 column is 10 to 12% which is not very much significant. For C3, (Table4.11), again the governing load combination changes entirely to DL - WLX and increase in reinforcement is quite high.

Table 4.10: Reinforcement Comparison for Column C1 - 50 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	AsMin	As - MGLF	%increase
STORY27	C1	C800X800	1.5(DL+LL)	5120	9312	1.5(DL-WLX)	5120	10160	10
STORY26	C1	C800X800	1.5(DL+LL)	5120	10608	1.5(DL-WLX)	5120	11349	7
STORY25	C1	C800X800	1.5(DL+LL)	5120	11795	1.5(DL-WLX)	5120	13169	12
STORY24	C1	C800X800	1.5(DL+LL)	5120	13358	1.5(DL-WLX)	5120	14759	11
STORY23	C1	C800X800	1.5(DL+LL)	5120	14680	1.5(DL-WLX)	5120	15978	9
STORY22	C1	C800X800	1.5(DL+LL)	5120	15873	1.5(DL-WLX)	5120	17149	9
STORY21	C1	C800X800	1.5(DL+LL)	5120	16950	1.5(DL-WLX)	5120	18208	8
STORY20	C1	C800X800	1.5(DL+LL)	5120	17924	1.5(DL-WLX)	5120	19166	7
STORY19	C1	C800X800	1.5(DL+LL)	5120	18838	1.5(DL-WLX)	5120	20678	10
STORY18	C1	C800X800	1.5(DL+LL)	5120	19966	1.5(DL-WLX)	5120	22061	11
STORY17	C1	C800X800	1.5(DL+LL)	5120	21259	1.5(DL-WLX)	5120	23325	10
STORY16	C1	C800X800	1.5(DL+LL)	5120	22515	1.5(DL-WLX)	5120	24545	10
STORY15	C1	C800X800	1.5(DL+LL)	5120	23611	1.5(DL-WLX)	5120	25618	9
STORY1	C1	C800X800	1.5(DL+LL)	5120	19783	1.5(DL+LL)	5120	19783	0

Table 4.11: Reinforcement Comparison for Column C3 - 50 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	AsMin	As - MGLF	%increase
STORY27	C3	C800X800	1.5(DL+LL)	5120	5189	1.5(DL-WLX)	5120	7087	37
STORY26	C3	C800X800	1.5(DL-WLX)	5120	6032	1.5(DL-WLX)	5120	8521	42
STORY25	C3	C800X800	1.5(DL-WLX)	5120	7528	1.5(DL-WLX)	5120	9612	28
STORY24	C3	C800X800	1.5(DL-WLX)	5120	8605	1.5(DL-WLX)	5120	10601	24
STORY23	C3	C800X800	1.5(DL-WLX)	5120	9567	1.5(DL-WLX)	5120	11472	20
STORY22	C3	C800X800	1.5(DL-WLX)	5120	10429	1.5(DL-WLX)	5120	12639	22
STORY21	C3	C800X800	1.5(DL-WLX)	5120	11200	1.5(DL-WLX)	5120	13948	25
STORY20	C3	C800X800	1.5(DL-WLX)	5120	11998	1.5(DL-WLX)	5120	15183	27
STORY19	C3	C800X800	1.5(DL-WLX)	5120	13260	1.5(DL-WLX)	5120	16375	24
STORY18	C3	C800X800	1.5(DL-WLX)	5120	14440	1.5(DL-WLX)	5120	17536	22
STORY17	C3	C800X800	1.5(DL+LL)	5120	15709	1.5(DL-WLX)	5120	18686	19
STORY16	C3	C800X800	1.5(DL+LL)	5120	16919	1.5(DL-WLX)	5120	20193	20
STORY15	C3	C800X800	1.5(DL+LL)	5120	18021	1.5(DL-WLX)	5120	21853	22
STORY1	C3	C800X800	1.5(DL+LL)	5120	32923	1.5(DL+LL)	5120	32923	0

Table 4.12: Reinforcement Comparison for Column C15 - 50 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	AsMin	As - MGLF	%increase
STORY27	C15	C800X800	1.5(DL+LL)	5120	5187	1.5(DL-WLY)	5120	6660	29
STORY26	C15	C800X800	1.5(DL+LL)	5120	5901	1.5(DL-WLY)	5120	8232	40
STORY25	C15	C800X800	1.5(DL+LL)	5120	7041	1.5(DL-WLY)	5120	9331	33
STORY24	C15	C800X800	1.5(DL+LL)	5120	8085	1.5(DL-WLY)	5120	10326	28
STORY23	C15	C800X800	1.5(DL+LL)	5120	8999	1.5(DL-WLY)	5120	11204	25
STORY22	C15	C800X800	1.5(DL+LL)	5120	9809	1.5(DL-WLY)	5120	12168	25
STORY21	C15	C800X800	1.5(DL+LL)	5120	10609	1.5(DL-WLY)	5120	13478	28
STORY20	C15	C800X800	1.5(DL+LL)	5120	11479	1.5(DL-WLY)	5120	14708	29
STORY19	C15	C800X800	1.5(DL+LL)	5120	12869	1.5(DL-WLY)	5120	15893	24
STORY18	C15	C800X800	1.5(DL+LL)	5120	14367	1.5(DL-WLY)	5120	17046	19
STORY17	C15	C800X800	1.5(DL+LL)	5120	15694	1.5(DL-WLY)	5120	18197	16
STORY16	C15	C800X800	1.5(DL+LL)	5120	16901	1.5(DL-WLY)	5120	19396	15
STORY15	C15	C800X800	1.5(DL+LL)	5120	17999	1.5(DL-WLY)	5120	21064	18
STORY1	C15	C800X800	1.5(DL+LL)	5120	32911	1.5(DL+LL)	5120	32911	0

The above Table 4.12 which is fro column C15 shows maximum % increase in reinforcement in the range of 25 - 40%.

c. **For 60 Storey Building**

Table 4.13: Reinforcement Comparison for Column C1 60 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	As - MGLF	% inc.
STORY-35	C1	C1500X1500M40	1.5(DL-WLX)	18000	28389	1.5(DL-WLY)	33476	18
STORY-34	C1	C1500X1500M40	1.5(DL-WLX)	18000	30799	1.5(DL-WLY)	35714	16
STORY-33	C1	C1500X1500M40	1.5(DL-WLX)	18000	33037	1.5(DL-WLY)	37790	14
STORY-32	C1	C1500X1500M40	1.5(DL-WLX)	18000	35120	1.5(DL-WLY)	39722	13
STORY-31	C1	C1500X1500M40	1.5(DL-WLX)	18000	37064	1.5(DL-WLY)	41983	13
STORY-30	C1	C1500X1500M40	1.5(DL-WLX)	18000	38881	1.5(DL-WLY)	46500	20
STORY-29	C1	C1500X1500M40	1.5(DL-WLX)	18000	40582	1.5(DL-WLY)	50726	25
STORY-28	C1	C1500X1500M40	1.5(DL-WLX)	18000	43729	1.5(DL-WLY)	54686	25
STORY-27	C1	C1500X1500M40	1.5(DL-WLX)	18000	47733	1.5(DL-WLY)	58402	22
STORY-26	C1	C1500X1500M40	1.5(DL-WLX)	18000	51500	1.5(DL-WLY)	61895	20
STORY-25	C1	C1500X1500M40	1.5(DL-WLX)	18000	55049	1.5(DL-WLY)	65181	18
STORY-24	C1	C1500X1500M40	1.5(DL-WLX)	18000	58397	1.5(DL-WLY)	68783	18
STORY-23	C1	C1500X1500M40	1.5(DL-WLX)	18000	61560	1.5(DL-WLY)	73603	20
STORY-22	C1	C1500X1500M40	1.5(DL-WLX)	18000	64549	1.5(DL-WLY)	78154	21
STORY-21	C1	C1500X1500M40	1.5(DL-WLX)	18000	67379	1.5(DL-WLY)	82453	22
STORY-20	C1	C1500X1500M40	1.5(DL-WLX)	18000	71723	1.5(DL-WLY)	86519	21
STORY-19	C1	C1500X1500M40	1.5(DL-WLX)	18000	75916	1.5(DL-WLY)	90366	19
STORY-18	C1	C1500X1500M40	1.5(DL-WLX)	18000	79892	1.5(DL-WLY)	94009	18
STORY-17	C1	C1500X1500M40	1.5(DL-WLX)	18000	83667	1.5(DL-WLY)	97459	16
STORY-16	C1	C1500X1500M40	1.5(DL-WLX)	18000	87251	1.5(DL-WLY)	101690	17
STORY-15	C1	C1500X1500M40	1.5(DL-WLX)	18000	90656	1.5(DL-WLY)	106514	17
STORY-14	C1	C1500X1500M40	1.5(DL-WLX)	18000	93892	1.5(DL-WLY)	111087	18

Table 4.14: Reinforcement Comparison for Column C3 60 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	As - MGLF	% inc
STORY-35	C3	C1500X1500M40	1.5(DL-WLX)	18000	27319	1.5(DL-WLX)	31441	15
STORY-34	C3	C1500X1500M40	1.5(DL-WLX)	18000	29696	1.5(DL-WLX)	33688	13
STORY-33	C3	C1500X1500M40	1.5(DL-WLX)	18000	31905	1.5(DL-WLX)	35775	12
STORY-32	C3	C1500X1500M40	1.5(DL-WLX)	18000	33962	1.5(DL-WLX)	37718	11
STORY-31	C3	C1500X1500M40	1.5(DL-WLX)	18000	35882	1.5(DL-WLX)	39530	10
STORY-30	C3	C1500X1500M40	1.5(DL-WLX)	18000	37677	1.5(DL-WLX)	41224	9
STORY-29	C3	C1500X1500M40	1.5(DL-WLX)	18000	39360	1.5(DL-WLX)	45434	15
STORY-28	C3	C1500X1500M40	1.5(DL-WLX)	18000	40938	1.5(DL-WLX)	49423	21
STORY-27	C3	C1500X1500M40	1.5(DL-WLX)	18000	44381	1.5(DL-WLX)	53168	20
STORY-26	C3	C1500X1500M40	1.5(DL-WLX)	18000	48111	1.5(DL-WLX)	56692	18
STORY-25	C3	C1500X1500M40	1.5(DL-WLX)	18000	51626	1.5(DL-WLX)	60010	16
STORY-24	C3	C1500X1500M40	1.5(DL-WLX)	18000	54944	1.5(DL-WLX)	63138	15
STORY-23	C3	C1500X1500M40	1.5(DL-WLX)	18000	58078	1.5(DL-WLX)	66091	14
STORY-22	C3	C1500X1500M40	1.5(DL-WLX)	18000	61043	1.5(DL-WLX)	69780	14
STORY-21	C3	C1500X1500M40	1.5(DL-WLX)	18000	63849	1.5(DL-WLX)	74136	16
STORY-20	C3	C1500X1500M40	1.5(DL-WLX)	18000	66508	1.5(DL-WLX)	78259	18
STORY-19	C3	C1500X1500M40	1.5(DL-WLX)	18000	70025	1.5(DL-WLX)	82164	17
STORY-18	C3	C1500X1500M40	1.5(DL-WLX)	18000	73974	1.5(DL-WLX)	85866	16
STORY-17	C3	C1500X1500M40	1.5(DL-WLX)	18000	77724	1.5(DL-WLX)	89376	15
STORY-16	C3	C1500X1500M40	1.5(DL-WLX)	18000	81287	1.5(DL-WLX)	92706	14
STORY-15	C3	C1500X1500M40	1.5(DL-WLX)	18000	84674	1.5(DL-WLX)	95866	13
STORY-14	C3	C1500X1500M40	1.5(DL-WLX)	18000	87895	1.5(DL-WLY)	100458	14

Table 4.15: Reinforcement Comparison for Column C15 60 Storey Building

Story	ColLine	SecID	LC	AsMin	As - DGLF	LC	As - MGLF	% inc
STORY-35	C15	C1500X1500M40	1.5(DL-WLY)	18000	26334	1.5(DL-WLY)	32126	22
STORY-34	C15	C1500X1500M40	1.5(DL-WLY)	18000	28732	1.5(DL-WLY)	34343	20
STORY-33	C15	C1500X1500M40	1.5(DL-WLY)	18000	30960	1.5(DL-WLY)	36402	18
STORY-32	C15	C1500X1500M40	1.5(DL-WLY)	18000	33035	1.5(DL-WLY)	38318	16
STORY-31	C15	C1500X1500M40	1.5(DL-WLY)	18000	34972	1.5(DL-WLY)	40105	15
STORY-30	C15	C1500X1500M40	1.5(DL-WLY)	18000	36783	1.5(DL-WLY)	42659	16
STORY-29	C15	C1500X1500M40	1.5(DL-WLY)	18000	38480	1.5(DL-WLY)	46855	22
STORY-28	C15	C1500X1500M40	1.5(DL-WLY)	18000	40073	1.5(DL-WLY)	50788	27
STORY-27	C15	C1500X1500M40	1.5(DL-WLY)	18000	42103	1.5(DL-WLY)	54481	29
STORY-26	C15	C1500X1500M40	1.5(DL-WLY)	18000	45863	1.5(DL-WLY)	57954	26
STORY-25	C15	C1500X1500M40	1.5(DL-WLY)	18000	49407	1.5(DL-WLY)	61223	24
STORY-24	C15	C1500X1500M40	1.5(DL-WLY)	18000	52752	1.5(DL-WLY)	64304	22
STORY-23	C15	C1500X1500M40	1.5(DL-WLY)	18000	55911	1.5(DL-WLY)	67212	20
STORY-22	C15	C1500X1500M40	1.5(DL-WLY)	18000	58900	1.5(DL-WLY)	71559	21
STORY-21	C15	C1500X1500M40	1.5(DL-WLY)	18000	61730	1.5(DL-WLY)	75845	23
STORY-20	C15	C1500X1500M40	1.5(DL-WLY)	18000	64412	1.5(DL-WLY)	79901	24
STORY-19	C15	C1500X1500M40	1.5(DL-WLY)	18000	66955	1.5(DL-WLY)	83742	25
STORY-18	C15	C1500X1500M40	1.5(DL-WLY)	18000	70585	1.5(DL-WLY)	87380	24
STORY-17	C15	C1500X1500M40	1.5(DL-WLY)	18000	74369	1.5(DL-WLY)	90830	22
STORY-16	C15	C1500X1500M40	1.5(DL-WLY)	18000	77966	1.5(DL-WLY)	94101	21
STORY-15	C15	C1500X1500M40	1.5(DL-WLX)	18000	81390	1.5(DL-WLY)	97205	19
STORY-14	C15	C1500X1500M40	1.5(DL-WLX)	18000	86908	1.5(DL-WLY)	100790	16

From the Table 4.13, 4.14 and 4.15, which show the reinforcement increase in columns C1, C3 and C15 for 60 storey building, the maximum % increase in the reinforcement is observed in column C15.

On an average, there is 30% increase in the reinforcement demand for all the three buildings.

4.6 Summary

In this section two parts of the methodology have been covered i.e. Part 1: Comparison of IS:875 (Part-III) - 1987 and the Proposed Draft Code and Part 2 Comparison Displacement Based Gust Factor(DGLF) and Moment Based Gust Loading Factor(MGLF). From the results it has been observed that MGLF gives a more realistic and reliable distribution of wind forces i.e. the equivalent static wind load(ESWL) as compared to the present IS 875(III) and draft code.

The potential of MGLF can be more realised for a building having more height as the resonant component of wind force would be more dominating in that case. The response quantities obtained by MGLF method are more than DGLF. The effect on design of the columns is also significant. on an average there is 30% increase in the quantity of reinforcement.

Chapter 5

Application of MGLF to Steel Chimney

5.1 General

Chimneys (or steel stacks), which forms the essential component of a system using fuel as a boiler, plays a vital role in maintaining efficiency, draft, etc. of the system and also minimizing the atmospheric pollution. These are mainly used in sugar factories, food processing industries, thermal plants, vegetable oil factories, rice shellers, chemical industries, etc.

Steel chimneys are preferred for their faster construction, more strength and durability as compared to concrete chimneys. Steel chimneys are lighter than concrete chimneys and hence the effect of seismic forces on the steel chimneys is much lesser. Due to the above precious advantages the concrete chimneys are now going to be replaced by the steel chimneys.

Steel chimneys can be classified into two types depending upon the type of design/construction of the shaft, namely self supporting & guyed. A self supporting chimney is supported on a foundation and the horizontal forces are transferred to it by cantilever action. For very tall chimneys, guys may be used for support.

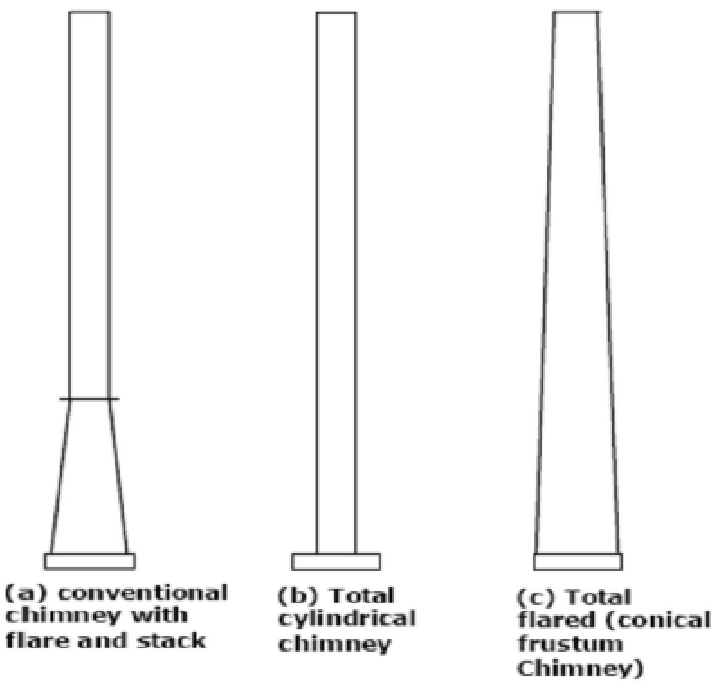


Figure 5.1: Types of Self Supported Chimneys

Chimney is a tall, slender industrial structure which is exposed to various types of loads acting upon it and hence it requires special study for the analysis and design. However, there is some work carried out by researchers and scientists. Of course it is desirable to have a long durability of the structure without less maintenance to withstand different types of loading.

The Indian Standard code of practice for steel chimney is IS 6533(Part 2)-1989. The Dynamic Wind Analysis for the chimney is carried out as per this code. In the present study, a tall steel chimney is considered and it is analysed by IS 6533(Part 2)-1989 and an attempt is made to apply the MGLF procedure to this chimney for its dynamic analysis.

5.2 Problem Formulation

DATA:

Height of chimney	H	90	m
Diameter of chimney	D	2.4	m
Location		Mumbai	
Terrain Category		4	
Topography		Flat	
Thickness of fire brickwork lining		125	mm
Number of breach opening		1	
Bearing capacity of soil		250	kN/m^2

5.3 Analysis of Steel Chimney by IS 6533(Part 2)-1989

5.3.1 Provisions of IS 6533(Part 2)-1989

The following procedure has been followed as per IS 6533(Part-2)-1989. As per code, in case of self supporting chimneys, if T¿ 0.25 seconds, the dynamic effect due to pulsation of wind has to be taken into account in addition to the static wind effect.

Check for Resonance

Strouhal Velocity: $V_{cr} = 5D_t$f
Where, f= natural frequency of the chimney
D_t= diameter of chimney (in m)
If the critical strouhal velocity is within the range i.e.

a. 0.5 to 0.8 times the design wind velocity for lined chimneys and

b. O.33 to 0.8 times the design wind velocity for the unlined chimneys

Checking for resonance is to be carried out.

Time Period

The natural time period of first mode for the chimney is obtained by modelling the chimney in SAP 2000 and performing modal analysis.

Dynamic Inertia Force

The dynamic inertia force (in kgf) acting at the centre of the jth zone (zone height not more than 10 m) for the ith mode of the natural oscillation is obtained from

$$P_{ij} = M_j d s a_{ij} \tag{5.1}$$

Where, M_j = mass of jth zone (kg)
d = dynamic coefficient from (Table 5)
s = height coefficient
a_{ij} =deduced acceleration (m/sec^2)
The dynamic coefficient d depends on parameter ξ = TV_b/1200
Where, V_b = Basic wind speed(m/s)
The height coefficient s is obtained for the first mode from Table 7 of IS 6533. For higher modes s may be taken as unity. Deduced acceleration aij is obtained from,

$$a_{ij} = \frac{y_{ij} \times \Sigma_{k=1}^{r} y_{ik} \times P_{st} \times p_k}{\Sigma_{k=1}^{r} y_{ik}^2 \times M_k} \tag{5.2}$$

M_k = mass of the zone k (kg)
$P_{st,k}$ = wind load on kth zone
r = number of zones into which the chimney is divided
p_k = pulsation coefficient for kth zone
y_{ij},y_{ik}= relative ordinates of mode shape corresponding to j^{th} and k^{th} zones in the i^{th} mode.

It may be noted that the dynamic inertia forces vary along the height of the chimney as per the mode shape oscillation.

5.3.2 Analysis of Steel Chimney

The analysis of chimney is carried out as per the provisions of IS 6533(Part 2).

Height of chimney : H =90 m

Diameter of chimney : D =2.4 m

DIMENSIONING:

Height of Flare = (H/3)	30	m
Diameter of Flare = 1.6D	4	m
No. Of divisions along height to compute wind forces	9	nos.
Length of each division	10	m

CALCULATION OF STATIC WIND LOAD

Basic wind speed	V_b=	44	m/s
Risk Coefficient	k1 =	1	
Topography Factor	k3 =	1	
Drag Coefficient Cd	Cd =	0.7	

The following table contains the calculation of static wind load for the chimney.

Table 5.1: Calculation of Static Wind Load for Steel Chimney

Part	z	D	Class	k_2	p_z	P_{st}	UDL	M
Part	m	m			kN/m^2	kN	kN/m	kN-m
1	90	2.4	C	1.082	1.361	22.86	2.29	114.3231
2	80	2.4	C	1.069	1.327	22.29	2.23	454.4318
3	70	2.4	C	1.053	1.289	21.65	2.17	1014.267
4	60	2.4	C	1.036	1.246	20.93	2.09	1786.993
5	50	2.4	C	1.014	1.195	20.08	2.01	2764.757
6	40	2.4	B	1.055	1.292	21.70	2.17	3951.438
7	30	2.667	B	1.022	1.214	22.66	2.27	5359.904
8	20	3.2	A	1.005	1.172	26.26	2.63	7012.952
9	10	3.733	A	0.926	0.997	26.05	2.60	8927.543
					Total	204.48		

STRESS COMPUTATIONS

Stress due to moment, f_{mo} = (M/250πD^2t) N/mm^2

Stress due to chimney weight, f_{st} = 0.0785h N/mm^2

Stress due to lining, f_{li} = (0.0025h/t) N/mm^2

Let,

h_e = distance from top of chimney to the bottom of every part

t = thickness of shell of chimney

Minimum Thickness of chimney shell = D/500	t_{min} =	4.8	mm
Additional Thickness due to corrosion	t_{corr}=	4	mm
Required thickness	t_{req}=	8.8	mm
Available thickness	t_a =	t-t_{corr}	

Allowable tensile stress, F_t = 0.85 x 150 = 127.5 N/mm^2

Allowable Compressive stress (Table 3 IS 6533(Part 2))

The following table contains the calculation for stresses in the chimney shell.

Table 5.2: Stress Computation for chimney-I

h_e	D	t(assume)	t(available)	D/t_e	h_e/D	fc(allow.)	ft(allow.)	Mass (kg)
m	m	mm	mm			N/mm^2	N/mm^2	
10	2.4	10	6	400	4.17	70	127.50	5918.76
20	2.4	10	6	400	8.33	70.00	127.50	5918.76
30	2.4	12	8	300	12.50	87.00	127.50	7102.51
40	2.4	16	12	200	16.67	112.00	127.50	9470.02
50	2.4	18	14	171.43	20.83	119.00	127.50	10653.77
60	2.4	22	18	133.33	25.00	116.50	127.50	13021.27
70	2.667	22	18	148.17	26.25	115.70	127.50	14469.89
80	3.2	22	18	177.78	25.00	111.00	127.50	17361.70
90	3.733	22	18	207.39	24.11	103.73	127.50	20253.51

Where; Compressive stress, f_c =f_{mo} + f_{st} + f_{li} and

Tensile Stress, f_t = f_{mo} - f_{st} .

Table 5.3: Stress Computation for chimney-II

Part	f_{mo}	f_{st}	f_{li}	f_c	Check	f_t	Check
1	4.21	0.79	4.17	9.16	ok	5.00	ok
2	16.74	1.57	8.33	26.65	ok	18.31	ok
3	28.03	2.36	9.38	39.76	ok	30.38	ok
4	32.92	3.14	8.33	44.39	ok	36.06	ok
5	43.65	3.93	8.93	56.51	ok	47.58	ok
6	48.53	4.71	8.33	61.57	ok	53.24	ok
7	53.30	5.50	9.72	68.52	ok	58.80	ok
8	48.44	6.28	11.11	65.83	ok	54.72	ok
9	45.32	7.07	12.50	64.88	ok	52.38	ok

Dynamic Analysis of Chimney

The chimney is modelled in SAP 2000 using the available template. It is having nine vertical divisions.The Time Period of the chimney has been obtained from this model by performing Modal Analysis.

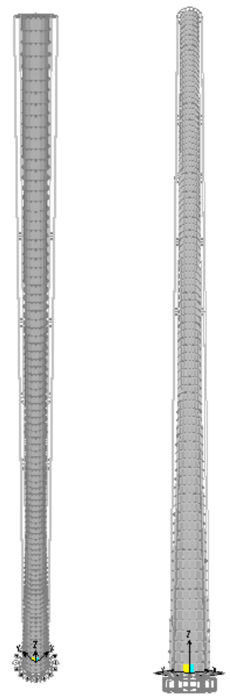


Figure 5.2: 3D view of SAP 2000 Model of Chimney

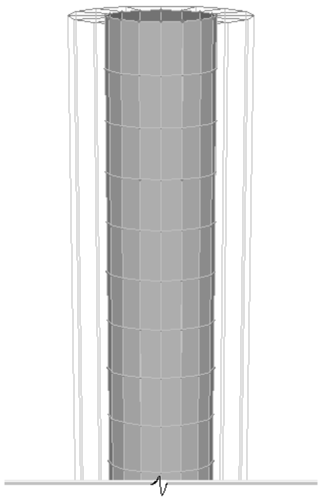


Figure 5.3: 3D Rendered View of Top of Chimney

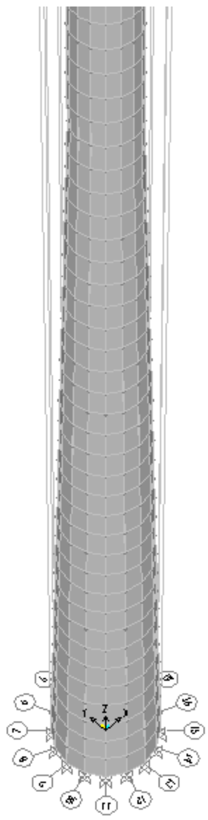


Figure 5.4: 3D Rendered View of Base of Chimney

The Time Period of the chimney which has been obtained from SAP 2000 model by performing Modal Analysis, is as follows.

Time period	T =	1.82	s
Frequency of first mode	f =	0.549	Hz

As Time period is more than 0.25s hence dynamic effect is to be considered.

5.3.3 Calculation of Dynamic Wind Load by IS 6533(Part 2)-1989

Check for Resonance

Design wind velocity	$V_d =$	47.62	m/s	
Strouhal critical velocity, $V_{cr} = 5D_f$	V_{cr}=	6.59	m/s	ok
(Critical range for resonance 0.5 to 0.8 V_d)				
Dynamic Parameter,d1 = T $V_b/1200$	d1 =	0.066		
Dynamic coefficient(Table 5 IS 6533(II)-1989)	d =	2.03		
Height coefficient	s =	0.75		

Let, p = pulsation coefficient; y = mode shape

$\sum y_k * P_{st,k} * p_k = 43.96$

$\sum yk^2 * M_k = 14931.78$

Ratio of $y_k * P_{st,k} * p_k$ and $yk^2 * M_k = 0.0029$

This ratio is obtained to calculate the deduced acceleration of the chimney.

Table 5.4: Calculation of Dynamic Wind Load by IS 6533(Part 2)-1989

Mass Height	Mass	p	y	P_{st}	y_k x $P_{st,k}$ x p_k	yk^2 x M_k	a_{ik}	P_{ik}
m	kg			kN				kN
85	5918.76	0.563	1.000	22.86	12.861	5918.76	0.002944	26.53
75	5918.76	0.578	0.779	22.29	10.023	3587.57	0.002292	20.66
65	7102.51	0.593	0.585	21.65	7.502	2428.79	0.001722	18.62
55	9470.02	0.613	0.419	20.93	5.366	1660.07	0.001233	17.77
45	10653.8	0.638	0.280	20.08	3.588	836.91	0.000825	13.39
35	13021.3	0.675	0.170	21.70	2.484	374.33	0.000499	9.90
25	14469.9	0.725	0.087	22.66	1.421	108.28	0.000255	5.61
15	17361.7	0.790	0.031	26.26	0.646	16.84	0.000092	2.42
5	20253.5	0.830	0.003	26.05	0.075	0.24	0.000010	0.31

5.4 Analysis of Steel Chimney by MGLF Method

5.4.1 Need for applying on chimney

Chimneys are classified in flexible and slender structures. Hence in most cases the governing load is always wind force. As it is extremely flexible, the dynamic wind force should be distributed along the height if chimney in proportion of its mass and mode shape.In the present code for steel chimney, IS 6533(Part 2)-1989, the dynamic method for chimney gives a method in which the forces are obtained by considering mass distribution and mode shape. But the forces are not distributed in proportion of the base bending moment(as in case of MGLF).

It is advocated that distributing wind forces in proportion of base bending moment gives more reliable value, an attempt is made to apply MGLF to a problem of steel chimney and to compare it with the existing method.

5.4.2 Steps for Application of MGLF

An attempt is made to obtain the dynamic wind load by MGLF procefure for the case of chimney structure. Chimney being tall and slender structure, the wind load is more sensitive towards mass distribution and mode shape of the chimney. In case of MGLF method, the dynamic wind load is obtained by distributing the Mean base bending moment along the height of the structure in proportion of its mass and mode shape. In this case, the equation for obtaining the gust factor is the equation given in the draft code of IS 875. Using this equation the combined gust factor is obtained (i.e. it is not split into background and resonant components).

Steps for MGLF Application

The following steps were followed for the application of the MGLF method in case of steel chimney.

- Calculate the static wind load in each vertical part of the chimney.
- Here, the effect of pulse velocity fluctuations is considered by considering the following Gust factor equation from the IS 875 draft code.

$$C_{dyn} = \frac{1 + 2I_h\sqrt{[g_v^2 B_s + \frac{H_s g_r^2 SE}{\beta}]}}{(1 + 2g_v I_h)} \tag{5.3}$$

- The required parameters are calculated and the Cdyn is obtained for the chimney.
- Here, the C_{dyn} / G is not split into two parts as in the case of building.
- Calculate the base overturning moment,

$$M_R = \sum P_{st} Z_i G \tag{5.4}$$

where, G = C_{dyn}

- Assume mode shape function as, where β=2.

$$\phi_i(z) = \left(\frac{z}{H}\right)^{\beta} \tag{5.5}$$

- Obtain dynamic wind load as,

$$P_{Ri} = \frac{m_i \phi_i}{\sqrt{m_i \phi_i Z_i}} \bar{M}_R \tag{5.6}$$

Thus, the MGLF procedure has been applied to the problem of steel chimney.

5.4.3 Calculation of Dynamic Wind Load by MGLF Method

The following calculations for the above mentioned chimney have been done by MGLF method.

CALCULATION BY MGLF FORCES

Total height of structure	h =	90	m
Terrain Category	=	IV	
Average breadth of structure between height s and h	b_{sh} =	2.4	m
Average breadth of the structure between heights 0 and h	b_{oh} =	2.4	m
Integral turbulence length scale at height h = 100 $(h/10)^{0.25}$	L_h =	173.20	m
Time Period of chimney	T =	1.82	sec
Fundamental natural frequency of the structure, $f_o = 1/T$	fo	0.549	Hz
Ratio of structural damping to critical damping(Table 32)	ζ =	0.01	

Calculation of Gust factors for all parts of Chimney

Velocity at height h=90m	V_h	47.626	m/s
Peak Factor	g_R =	3.896	
Peak Factor for Upwind velocity	g_V =	3.5	
Turbulence Intensity	I_h =	0.238	
Size Reduction factor	S =	0.096	

Reduced Frequency	N =	5.32	
Turbulence Spectrum	E =	0.029	
Mass reduction factor	λ =	0	
Mode Shape Coefficient	β =	2	
Resonant BBM	M_R =	9375.67	kN-m
miϕiZi	=	1588134.08	kg-m
1+2$g_v I_h$	=	2.666	

The following Table 5.5 and 5.6 show the calculation of gust or pulse factors for the chimney using the MGLF procedure. The dynamic wind load and the total base shear due to wind is obtained from these tables.

Table 5.5: Calculation of pulse or Gust factor for Chimney

Part	Height	Height factor	Background factor	G_{MB}	G_{MR}	G_M=p_i
9	10	1.012	0.419	0.404	0.338	0.902
8	20	1.049	0.452	0.420	0.344	0.918
7	30	1.111	0.490	0.437	0.354	0.938
6	40	1.198	0.535	0.457	0.367	0.961
5	50	1.309	0.590	0.480	0.384	0.990
4	60	1.444	0.657	0.506	0.403	1.022
3	70	1.605	0.740	0.538	0.425	1.060
2	80	1.790	0.846	0.575	0.449	1.104
1	90	2.000	0.947	0.608	0.474	1.146

Table 5.6: Calculation of Dynamic Wind Load by MGLF Procedure

Height	**Mass**	**Pulse/Gust**	**Static Load**	**Res. Mom.**	**Mode shape**			**Dyn. Load**	**Mover.**
z_i	m_i	p_i	P_{st}	M_R	y_{ik}	$m_i y_{ik}$	$m_i y_{ik} z_i$	P_{Ri}	M_o
m	**kg**		**kN**	**kN-m**	$(zi/H)^2$			**kN**	**kN-m**
85	5918.76	1.146	22.86	2227.24	1.000	5918.76	503094.65	34.94	174.71
75	5918.76	1.104	22.29	1845.82	0.779	4608.03	345602.37	27.20	660.15
65	7102.51	1.06	21.65	1491.87	0.585	4153.37	269969.21	24.52	1404.20
55	9470.02	1.022	20.93	1176.23	0.419	3964.96	218072.53	23.41	2387.90
45	10653.8	0.9896	20.08	894.28	0.280	2986.00	134370.20	17.63	3576.77
35	13021.3	0.9614	21.70	730.23	0.170	2207.76	77271.57	13.03	4918.94
25	14469.9	0.9376	22.66	531.03	0.087	1251.72	31293.01	7.39	6363.24
15	17361.7	0.9177	26.26	361.49	0.031	540.68	8110.14	3.19	7860.44
5	20253.5	0.9019	26.05	117.46	0.003	70.08	350.41	0.41	**9375.67**
				9375.67			**1588134.09**	**151.73**	

Total Base shear due to wind Vw =151.73 kN

Earthquake Forces

The earthquake forces for the chimney are calculated as per IS 1893(Part 4)-2005.

Area of cross section at the base Ao =0.276 m^2

Factor k = $\sqrt{2}$H/r	k =	63.640	
From Table 19.1	C_t =	114.750	
Time period, T = C_t $\sqrt{((WH)/(EAg))}$	T =	2.523	s
Time Period from SAP	T_{sap} =	1.820	s

Considering lower time period as in case of earthquake lower time period would give more base shear.

Time Period		T =	1.820	s
Equivalent thickness t_e,		t_e=	17.12	mm
Weight of steel		Ws =	1215.95	kN
Weight of lining		Wl =	1696.46	kN
Total weight	W =	Total	2912.41	kN
Hence for 2% damping,	Sa/g	α =	0.080	
For medium soil with isolated footing		β =	1.200	
Importance Factor		I=	1.000	
Seismic Zone Factor, Z = III		F =	0.160	
$A_h = \alpha * \beta *$ I * Z		A_h =	0.015	
Coefficient	C_v	=	1.500	
Earthquake Base Shear,		V =	67.10	kN

Hence, by comparing the Base shear it can be clearly seen that wind is governing the design.

From the analysis results it can be seen clearly that the MGLF is giving more value of dynamic wind forces than the method given in the IS 6533(Part 2)-1989. Hence, for the design of the chimney the MGLF forces are considered as the result of the dynamic analysis.

5.5 Design of Steel Chimney

The chimney is designed as a welded steel chimney. For the purpose of design the provisions of IS 6533 (Part 2) are used. The design of footing is done as per IS 456-2000.

Check for Shell Thickness

As per the code, the shell stack must be checked for the combined lateral force i.e. combination of static and dynamic load.This check has been performed by checking the combined compressive stress in the shell with the permissible compressive stress value. The calculation is tabulated in the following table.

Table 5.7: Check for shell thickness for combined static and dynamic loads

Part	f_c,static	$f_{c,dyn}$	Total, f_c	permi. F_c	Check
				(x 1.33)	
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	
1	9.16349	14.004	23.1672	93.1	ok
2	26.6452	38.707	65.3525	93.1	ok
3	39.7553	55.039	94.7945	115.71	ok
4	44.391	59.318	103.709	148.96	ok
5	56.5068	73.103	129.61	158.27	ok
6	61.5689	76.644	138.213	154.945	ok
7	68.5198	81.346	149.866	153.881	ok
8	65.8349	73.791	139.626	147.63	ok
9	64.8812	68.138	133.019	137.9609	ok

Hence, the thicknesses provided are sufficient.

BASE PLATE DESIGN

Diameter at top	D_{top}=	2.4	m
Diameter at the base	D_{base} =	4	m
Bearing capacity of soil	f_{bc} =	250	N/mm^2
Considering moment at the base	M_{base} =	9375.67	kN-m
Force due to moment(inc. by 25%)=[4M/π D^2]*1.25	Fm =	932.62	kN/m
Calculation on weight:			
Equivalent thickness te,	t_e =	17.12	mm
Weight of steel	Ws =	1215.95	kN
Weight of lining	Wl =	1696.46	kN
	Total =	2912.41	kN
Force due to gravity(increased by 10%)=(W*1.1)/πD)	Fg =	254.94	kN/m
Total Force	F_m+F_g=	1187.55	kN/m
Grade of Concrete	f_{ck} =	20.00	MPa
Allowable bearing pressure for concrete	f_b =	9.00	N/mm_2
Width of base required	w =	131.95	mm

Provide width of		300.00	mm
Pressure under base plate		3.96	N/mm^2
Thickness of base plate=0.866*b*sqrt(fb/fbc)	=	32.69	mm

Use base plate of 300 x 40 mm .

HOLDING DOWN BOLTS

Try 45mm high tensile bolts	Bolt dia.=	45	mm
	f_u =	340	N/mm^2
Tensile strength of bolts	f_y =	204	N/mm^2
Bolt strength in tension	R_t =	260	kN
Diameter of bolt ring	D_1 =	4300	mm
Number of bolts,n = (4M/$R_t D_1$)-(Ws/R_t)	n =	46	nos.

Use 50-45mm dia. Bolts.

DESIGN OF JOINTS

Thickness of plates	t =	10	mm	
Use bolts of dia.	=	18	mm	
Bolt Value	Bv =	36.67	kN	
Using double bolted lap joint,				
Required strength of plate=0.7*0.6*fy	=	105	N/mm^2	
Strength per unit length	=	1050	N/mm	
Pitch of rivet = Bv * 2 * 10^3/strength per unit length.	=	69.85	mm	
Maximum pitch=10t	=	100	mm	ok
Provided pitch	=	65	mm	

Provide double bolted lap joint using 18mm dia. Bolts at a pitch of 65mm.

Thickness of plates	t =	12	mm	
Use bolts of dia	=	18	mm	
Bolt Value	Bv =	36.67	kN	
Using double bolted lap joint,				
Required strength of plate=0.7*0.6*fy	=	105	N/mm^2	
Strength per unit length	=	1260	N/mm	
Pitch of rivet = Bv * 2 * 10^3strength per unit length.	=	58.21	mm	
Maximum pitch=10t	=	120	mm	ok
Provided pitch	=	55	mm	

Provide double bolted lap joint using 18mm dia. Bolts at a pitch of 55mm.

Thickness of plates	t =	16	mm	
Use bolts of dia	=	20	mm	
Bolt Value	Bv =	45.27	kN	
Using double bolted lap joint,				
Required strength of plate=0.7*0.6*fy	=	105	N/mm^2	
Strength per unit length	=	1680	N/mm	
Pitch of rivet = Bv * 2 * 10^3strength per unit length.	=	53.89	mm	
Maximum pitch=10t	=	160	mm	ok
Provided pitch	=	50	mm	

Provide double bolted lap joint using 20mm dia. Bolts at a pitch of 50mm.

Thickness of plates	t =	18	mm	
Use bolts of dia	=	20	mm	
Bolt Value	Bv =	45.27	kN	
Using triple bolted lap joint,				
Required strength of plate=0.7*0.6*fy	=	105	N/mm^2	
Strength per unit length	=	1890	N/mm	
Pitch of rivet = Bv * 3 * 10^3strength per unit length.	=	71.86	mm	
Maximum pitch=10t	=	180	mm	ok

Provided pitch	=	70	mm

Provide triple bolted lap joint using 20mm dia. Bolts at a pitch of 70mm.

Thickness of plates	t =	22	mm	
Use bolts of dia	=	22	mm	
Bolt Value	Bv =	54.77	kN	
Using triple bolted lap joint,				
Required strength of plate=0.7*0.6*fy	=	105	N/mm^2	
Strength per unit length	=	2310	N/mm	
Pitch of rivet = Bv * 3 * 10^3strength per unit length.	=	71.13	mm	
Maximum pitch=10t	=	220	mm	ok
Provided pitch	=	70	mm	

Provide double bolted lap joint using 22mm dia. Bolts at a pitch of 70mm.

DESIGN OF FLUE OPENING

Diameter of chimney in flue portion	D =	2.4	m
Radius	R =	1.2	m
Area of cross section of chimney	Ao =	4.52	m^2
Therefore, Area of breach opening	1.2Ao =	5.42	m^2
Maximum width of opening = 2/3 * D	=	1.6	m
Depth of opening	=	3.39	m
Width of opening	B =	1.6	m
Depth of opening	D =	3.2	m
Actual area provided of the opening	A =	5.12	m^2
Thickness in Part 6	t =	22	mm
Area of stack plates removed = t*width	=	35200	mm^2
Angle subtended at the center	=	41.8	degrees
Length of chord = R+Rcosθ	=	2.09	m

Diameter/chord length	=	1.14	
Area of reinforcement	=	40332.84	mm^2
Provide @L 200 x 200 x 18 @ 6881 x 2	=	13762	mm^2
Plate section PL 300 x 22	=	6600	mm^2
	Total	20362	mm^2

The same reinforcement is provided at the top and bottom of the breach opening.

Tensile stress in stack plates = 150*0.7	=	105	N/mm^2
Force in each side	=	2117.474	kN
Select bolt of diameter	=	22	kN
Bolt Value	Bv =	54.77	kN
Strength in double shear	=	109.54	kN
No. Of bolts	n =	20	nos

Provide 2 rows of 10 bolts on each vertical side at a pitch of 80mm in each of the extended portion of the vertical reinforcement. Thus, the vertical reinforcement will extend above and below the opening by a distance of 10 x 80 = 800mm. In the vertical and the horizontal reinforcement, use 22mm bolts at a pitch of 160mm.

DESIGN OF FOUNDATION BLOCK

Try a circular slab (Raft) foundation.

Diameter of foundation	D	9	m
Depth of foundation	d	2	m
Weight of foundation	Wf	3180.86	kN
Weight of chimney and lining	Ws	2912.41	kN
Total	W	6093.273	kN
Area of foundation	A	63.61	m^2
Direct pressure,	F = W/A	95.78	kN/m^2
Total Lateral force(greater of static and dyn. wind)	P =	204.48	kN
Total moment at the base of foundation	M =	9784.64	kN-m
Eccentricity	e=M/W =	1.605	m

e/D	e/D=	0.178423	<0.255	ok
	K/D	0.75	>0.6	ok
Maximum base pressure = (P/A)+(M/Z)	=	232.49	kN/m^2	ok

CHECK AGAINST OVERTURNING

Overturning moment	=	9784.64	kN-m	
Weight of stack	Ws =	1215.95	kN	
Restoring moment	=	19785.66	kN-m	
Factor of safety	FOS =	2.022	>1.5	ok

CHECK AGAINST SLIDING

Let coefficient of friction	μ	0.35		
Frictional force > Total lateral force than ok.	μN	1538.884	kN	ok

Hence the design is safe.

5.6 Results and Discussion

From the calculations it can be observed that the value of forces obtained by MGLF procedure is more than the IS 6533 procedure. Hence, the design of the chimney would be affected.

The comparison is carried out between the MGLF and IS 6533 procedure, by comparing Lateral forces and the quantity of steel required for chimney stack. the results have been tabulated. The following tables, Table 5.8 and 5.9 show the tabulated comparison between IS method and MGLF method.

Table 5.8: Comparison of Lateral Forces

Mass Height	**Mass**	**t**	P_{static}	P_{dyn}	P_{MGLF}	P_{design}	P_{design}
m	kg	mm	kN	kN	kN	kN	kN
			(IS Method)	(IS Method)	(MGLF)	(IS Method)	(MGLF)
85	5919	10	22.86	26.53	34.94	49.4	57.81
75	5919	10	22.29	20.66	27.2	42.95	49.5
65	7103	12	21.65	18.62	24.52	40.27	46.17
55	9470	16	20.93	17.77	23.41	38.7	44.33
45	10654	18	20.08	13.39	17.63	33.47	37.71
35	13021	22	21.7	9.9	13.03	31.6	34.74
25	14470	22	22.66	5.61	7.39	28.27	30.05
15	17362	22	26.26	2.42	3.19	28.68	29.45
5	20254	22	26.05	0.31	0.41	26.36	26.46

Overall there is about 10% increase in the dynamic wind load obtained by MGLF procedure.

Table 5.9: Comparison of Plate Thickness

Part	Height	Mass	$t_{(IS)}$	Mass	$t_{(MGLF)}$
	m	kg	mm	kg	mm
1	85	5919	10	5919	10
2	75	5919	10	5919	10
3	65	5919	10	7103	12
4	55	9470	16	9470	16
5	45	9470	16	10654	18
6	35	11838	20	13021	22
7	25	13154	20	14470	22
8	15	15783	20	17362	22
9	5	20254	22	20254	22
Sum		**97725kg**		**104170kg**	

The increase in total quantity of steel is 5%.

5.7 Summary

The MGLF procedure gives a higher value of force for the chimney considered. The results show an increase in force by 10%. The MGLF procedure is giving more realistic value of load and would result in higher safety of the structure. Moreover, it also affects the design as it increases the steel demand by 5%.

Chapter 6

Summary and Conclusion

6.1 Summary

In the present study, various methods of calculating the equivalent static wind load on building and steel chimneys have been studied. Comparison has been carried out between the dynamic method of present IS 875(III), the proposed draft code and the new concept of MGLF method for a 30 storey RC building and the results have been compared for various response quantities like lateral forces, storey shear, overturning moment, displacements and storey drifts. Thereafter, a parametric study has been carried out by varying the height of building considering 40,50 and 60 storey building and the effect of MGLF on design of building has been has been studied by comparing the column reinforcements.

Also, an attempt has been made to apply the MGLF method to a problem of steel chimney and the effect on design has been studied.

6.2 Conclusion

Based on the current study, following set of conclusions have been made:

- MGLF is a more realistic method of determining the ESWL on a building.

- The MGLF method gives the maximum value of lateral forces compared to present code and draft code.

- The method of distributing the ESWL in proportion of mass and mode shape of the building has not been put forward in the present IS code and draft code for wind effects. But, as the height of the building increases, it becomes more slender and flexible and the distribution of the ESWL would depend on the mass and the mode shape of the building also.

- The base shear values in case of TC 1 are obtained nearly same in DGLF and MGLF Method but there is significant difference for the values in TC 4.

- In case of MGLF method, the terrain category wise variation observed in calculation of lateral forces is very less.

- The resonant component of wind force becomes more dominant with increase in height of building which can be realized from the plots of ESWL for the three buildings considered.

- The curves for the resonant component overlap the ones for the background component.

- From the four cases considered, it can be said that the effect of non uniform mass and non linear mode shape is very less in case of regular buildings with square or rectangular cross section. But, this effect would be important in case of different structural systems like outrigger, braced structures, space and hybrid structures, etc.

- Upto 30 storeys or 100m high building the effect of MGLF forces is not so predominant that it affects the design of the building.

- From the parametric study, it can be said that the wind forces go on increasing with increase in the height of building.

- The effect of consideration of the non linear mode shape can be seen more in case 2 i.e. considering non linear mode shape and for 60 storey building.
- The effect of MGLF in increasing the column reinforcement is on an average 30% and would result in higher safety of the structure.
- In case of steel chimney considered, the MGLF method gives higher results for dynamic wind forces and hence would result in more safer design.
- As a result of increase in the forces, the thickness of the stack plates also increase in some parts of the chimney stack.

Overall it can be said that MGLF gives higher results for forces. Hence, it is more safe.

6.3 Future Scope

- Comparison of IS code with codes of different countries and to understand their characterization of wind.
- Application of MGLF to tall building with outrigger structural system; or any other structural system involving mass variation.
- Application of MGLF to different types of structures like tall steel buildings, silos, cooling towers, lattice towers etc.
- Incorporation of cross wind effects of wind on a tall building along with the along wind MGLF components and study the effect.
- Parametric study for comparison of cost for different structures like RCC chimneys, silos, lattice towers etc.

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Appendix A

Calculation of Wind Forces

The calculation of wind load by Static Method, Dynamic method , Draft Code method and MGLF Procedure is tabulated in this section. All the calculations of the ESWL for the buildings have been done in Excel. The Excel sheet calculation for 30,40,50 and 60 storey building are presented in the report.

Calculation of k2 Factor

The k2 factor is given in the code in the form of a Table. Here it is converted in the form of best fit curves according to the Terrain Category. The following figure shows the variation with heightand the Table shows the equation of best fit curves considerd for the calculation of Vz.

Table A.1: Effect of Terrain Category on k2 Factor

Terrain Category	Class	Equation for best fit curve
1	A	y = 0.0884ln(x) + 0.8512
	B	y = 0.0888ln(x) + 0.83
	C	y = 0.0888ln(x) + 0.79
2	A	y = 0.0985ln(x) + 0.7801
	B	y = 0.0996ln(x) + 0.7546
	C	y = 0.1009ln(x) + 0.6998
3	A	y = 0.1129ln(x) + 0.6664
	B	y = 0.1127ln(x) + 0.6388
	C	y = 0.1157ln(x) + 0.5618
4	A	y = 0.1552ln(x) + 0.4122
	B	y = 0.1522ln(x) + 0.3917
	C	y = 0.1555ln(x) + 0.2869

The figure A.1 shows the variation of k2 factor with height of building.

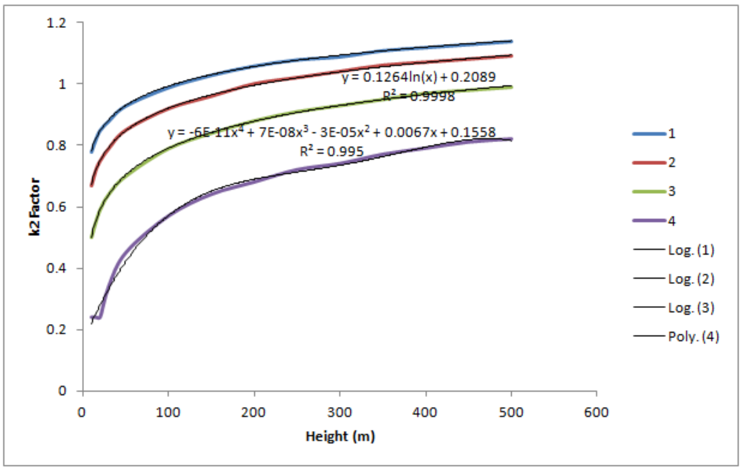

Figure A.1: Variation of k2 Factor with height

CALCULATION OF 30 STOREY BUILDING

The sample calculation of Static Wind Load by IS 875(Part 3)-1987 for the 30 storey building example is shown here.

CALCULATION OF STATIC WIND LOAD:

Location of building Mumbai Plan Dimensions of building w =24 m

d =24 m

Basic wind speed Vb= 44 m/s

terrain catagory TC =1

Number of Storeys n 30

Height of building H 90 m

Risk coefficient factor, K1 = 1

Topography factor, K3 = 1

Storey height h =3 m

Class C

Design wind speed, Vz = k1 k2 k3 Vb = 44 *k2 m/s

Wind pressure at height ,z pz = 0.6 x Vz^2 pz 1161.6 *k2 N/m^2

Force Coefficients:

(a) Wind at 0:(Along X- Direction)

a= 24 m a/b= 1 Cf= 1.4

b= 24 m h/b =3.75

h= 90 m

(b)Wind at 90: (Along Y- Direction)

a =24 m a/b =1 Cf= 1.4

b =24 m h/b =3.75

h =90 m

Table A.2: Static Wind Force at each Storey(In X-Direction)-30 Storey

Storey	Ht	K2	Pd	cf	b	d	Fx
Base	0			1.4	24	1.5	52.05
1	3	0.888	1.032	1.4	24	3	104.1
2	6	0.95	1.104	1.4	24	3	111.3
3	9	0.986	1.146	1.4	24	3	115.6
4	12	1.011	1.175	1.4	24	3	118.5
5	15	1.031	1.198	1.4	24	3	120.8
6	18	1.047	1.217	1.4	24	3	122.7
7	21	1.061	1.233	1.4	24	3	124.3
8	24	1.073	1.247	1.4	24	3	125.7
9	27	1.083	1.259	1.4	24	3	127
10	30	1.093	1.27	1.4	24	3	128.1
11	33	1.101	1.279	1.4	24	3	129
12	36	1.109	1.289	1.4	24	3	130
13	39	1.116	1.297	1.4	24	3	130.8
14	42	1.122	1.304	1.4	24	3	131.5
15	45	1.129	1.312	1.4	24	3	132.3
16	48	1.134	1.318	1.4	24	3	132.9
17	51	1.14	1.325	1.4	24	3	133.6
18	54	1.145	1.331	1.4	24	3	134.2
19	57	1.15	1.336	1.4	24	3	134.7
20	60	1.154	1.341	1.4	24	3	135.2
21	63	1.158	1.346	1.4	24	3	135.7
22	66	1.163	1.351	1.4	24	3	136.2
23	69	1.166	1.355	1.4	24	3	136.6
24	72	1.17	1.36	1.4	24	3	137.1
25	75	1.174	1.364	1.4	24	3	137.5
26	78	1.177	1.368	1.4	24	3	137.9
27	81	1.181	1.372	1.4	24	3	138.3
28	84	1.184	1.376	1.4	24	3	138.8
29	87	1.187	1.379	1.4	24	3	139.1
30	90	1.19	1.383	1.4	24	3	139.5
						Total	3945.924

Table A.3: Static Wind Force at each Storey(In Y-Direction)-30 Storey

Storey	Ht	K2	Pd	cf	b	d	Fx
Base	0			1.4	24	1.5	26.80
1	3	0.458	0.532	1.4	24	3	53.60
2	6	0.566	0.657	1.4	24	3	66.22
3	9	0.629	0.730	1.4	24	3	73.60
4	12	0.673	0.782	1.4	24	3	78.84
5	15	0.708	0.822	1.4	24	3	82.90
6	18	0.736	0.855	1.4	24	3	86.22
7	21	0.760	0.883	1.4	24	3	89.03
8	24	0.781	0.907	1.4	24	3	91.46
9	27	0.799	0.929	1.4	24	3	93.60
10	30	0.816	0.948	1.4	24	3	95.52
11	33	0.831	0.965	1.4	24	3	97.26
12	36	0.844	0.981	1.4	24	3	98.84
13	39	0.857	0.995	1.4	24	3	100.30
14	42	0.868	1.008	1.4	24	3	101.65
15	45	0.879	1.021	1.4	24	3	102.90
16	48	0.889	1.033	1.4	24	3	104.08
17	51	0.898	1.043	1.4	24	3	105.18
18	54	0.907	1.054	1.4	24	3	106.22
19	57	0.916	1.064	1.4	24	3	107.21
20	60	0.924	1.073	1.4	24	3	108.14
21	63	0.931	1.082	1.4	24	3	109.03
22	66	0.938	1.090	1.4	24	3	109.88
23	69	0.945	1.098	1.4	24	3	110.68
24	72	0.952	1.106	1.4	24	3	111.46
25	75	0.958	1.113	1.4	24	3	112.20
26	78	0.964	1.120	1.4	24	3	112.92
27	81	0.970	1.127	1.4	24	3	113.60
28	84	0.976	1.134	1.4	24	3	114.27
29	87	0.981	1.140	1.4	24	3	114.91
30	90	0.987	1.146	1.4	24	3	115.52
						Total	2994.00

CALCULATION OF DYNAMIC WIND LOAD(IS 875(III)-1987:

(a)Building Configuration:

Number of Storeys n= 60

Typical Storey Height h =3 m

Height of the building H =180 m

Plan Dimensions of the building Length L =24 m

Width W= 24 m

Building Location : Mumbai

Regional Basic wind speed Vb =44 m/s

Terrain Category :1

Class :C

Probability Factor k1= 1

Topography factor k3 =1

(b) Calculation of Force Coefficient

(a) Wind at 0:(Along X- Direction)

a= 24 m a/b= 1 Cf= 1.4

b= 24 m h/b =7.5

h= 90 m

(b)Wind at 90: (Along Y- Direction)

a =24 m a/b =1 Cf= 1.4

b =24 m h/b =7.5

h =90 m

The calculation of Gust Factor is Tabulated in the following tables. The gust factor is calculated as per IS 875(Part 3)-1987 Gust factor method.

Table A.4: Calculation of Gust Factor: (Category 1)-30 Storey

Fundamental natural period	Tx	1.653	s
	Ty	1.653	s
Natural frequency of building in Hz	fx	0.604	Hz
	fy	0.604	Hz
Lateral Correlation Constant	Cy	10.000	
Longitudinal Corelation constant	Cz	12.000	
a Hourly mean wind speed Vz = k1 k2 k3 Vb‘	Vz	44.000	x k2 m/s
Hourly mean wind speed at height H	Vh	43.264	
gf.r (From Fig. 8 IS 875(III))	gf.r	0.710	
L(h)(From Fig. 8 IS 875(III))	L(h)	2070.000	
Cz.h/L(h)		0.5217	
fo.L(h)/Vh		28.937	
λ = (Cy b)/(Cz H)	λ	0.222	
Reduced frequency, Fo = Czfoh/Vh	Fo	15.098	
Background Factor from Fig. 9, IS 875(III)	B	0.920	
Size Reduction Factor from Fig. 10 IS 875(III)	S	0.098	
Gust Energy Factor from Fig. 11 IS 875(III)	E	0.060	
Damping Coefficient for RC structure from Table 34.	β	0.020	
Gust factor,	G	1.782	
ϕ = gf.r x sqrt(B)/4	ϕ	0.000	
Background GLF	GB	0.681	
Resonant GLF	GR	0.385	

Table A.5: Calculation of Gust Factor: (Category 4)-30 Storey

Fundamental natural period	Ty	1.653	s
Natural frequency of building in Hz	fy	0.604	Hz
Lateral Correlation Constant	Cy	10	
Longitudinal Corelation constant	Cz	12	
Hourly mean wind speed Vz = k1 k2 k3 Vb‘	Vz	44	x k2 m/s
Hourly mean wind speed at height H	Vh	24.388	m/s
gf.r (From Fig. 8 IS 875(III))	gf.r	2	
L(h)(From Fig. 8 IS 875(III))	L(h)	1250	
Cz.h/L(h)		0.864	
fo.L(h)/Vh		30.998	
λ = (Cy b)/(Cz H)	λ	0.222	
Reduced frequency, Fo = Czfoh/Vh	Fo	26.78282	
Background Factor from Fig. 9, IS 875(III)	B	0.66	
Size Reduction Factor from Fig. 10 IS 875(III)	S	0.045	
Gust Energy Factor from Fig. 11 IS 875(III)	E	0.051	
Damping Coefficient for RC structure from Table 34.	β	0.02	
Gust factor,	G	2.760	
ϕ= gf.r x sqrt(B)/4	ϕ	0	
Background GLF	GB	1.6248	2.7603
Resonant GLF	GR	0.677	

Table A.6: Calculation of Forces at each Storey Level (TC 1)-30 Storey

Storey	Height	k2	Vz = k1k2k3Vb	pz=0.6Vz^2	Fz=Cf.Ae.pz.G	Background	Resonant
						ESWL	ESWL
	(m)		m/s	kN/m2	kN	kN	kN
0	0			0	47.082	0	0
1	3	0.672	29.557	0.525	94.165	35.981	20.340
2	6	0.736	32.350	0.628	112.807	43.104	24.367
3	9	0.773	33.985	0.693	124.492	47.569	26.891
4	12	0.799	35.144	0.742	133.132	50.870	28.757
5	15	0.820	36.043	0.780	140.033	53.507	30.248
6	18	0.836	36.778	0.812	145.801	55.711	31.494
7	21	0.850	37.400	0.840	150.769	57.609	32.567
8	24	0.863	37.938	0.864	155.140	59.279	33.511
9	27	0.873	38.412	0.886	159.046	60.772	34.354
10	30	0.883	38.837	0.905	162.582	62.123	35.118
11	33	0.892	39.221	0.923	165.815	63.358	35.816
12	36	0.900	39.572	0.940	168.793	64.496	36.460
13	39	0.907	39.895	0.955	171.556	65.552	37.057
14	42	0.914	40.193	0.970	174.135	66.537	37.614
15	45	0.920	40.471	0.983	176.553	67.461	38.136
16	48	0.926	40.731	0.996	178.829	68.331	38.628
17	51	0.932	40.976	1.008	180.981	69.153	39.092
18	54	0.937	41.206	1.019	183.022	69.933	39.533
19	57	0.942	41.424	1.030	184.963	70.674	39.952
20	60	0.947	41.631	1.040	186.814	71.381	40.352
21	63	0.951	41.827	1.050	188.583	72.057	40.734
22	66	0.955	42.015	1.060	190.277	72.705	41.100
23	69	0.959	42.194	1.069	191.904	73.326	41.452
24	72	0.963	42.366	1.077	193.467	73.924	41.789
25	75	0.967	42.530	1.086	194.973	74.499	42.114
26	78	0.971	42.688	1.094	196.425	75.054	42.428
27	81	0.974	42.840	1.102	197.827	75.590	42.731
28	84	0.977	42.987	1.109	199.183	76.108	43.024
29	87	0.981	43.128	1.117	200.496	76.609	43.308
30	90	0.984	43.265	1.124	201.768	77.095	43.582
				Total	5151.403		

Table A.7: Calculation of Forces at each Storey Level (TC 4)-30 Storey

Storey	Height	k2	Vz = k1k2k3Vb	pz=0.6Vz^2	Fz=Cf.Ae.pz.G	Backgrnd	Resonant
						ESWL	ESWL
	(m)		m/s	kN/m2	kN	kN	kN
0	0	0.176	7.728	0.036	4.985	0.000	0.000
1	3	0.176	7.728	0.036	9.970	2.934	1.223
2	6	0.195	8.577	0.044	12.282	3.615	1.507
3	9	0.214	9.404	0.053	14.763	4.345	1.812
4	12	0.232	10.208	0.063	17.397	5.120	2.135
5	15	0.250	10.990	0.072	20.166	5.935	2.475
6	18	0.267	11.752	0.083	23.056	6.785	2.829
7	21	0.284	12.492	0.094	26.052	7.667	3.197
8	24	0.300	13.212	0.105	29.141	8.576	3.576
9	27	0.316	13.912	0.116	32.311	9.509	3.965
10	30	0.332	14.592	0.128	35.549	10.462	4.362
11	33	0.347	15.254	0.140	38.845	11.432	4.767
12	36	0.361	15.897	0.152	42.188	12.416	5.177
13	39	0.375	16.521	0.164	45.569	13.411	5.592
14	42	0.389	17.128	0.176	48.979	14.415	6.011
15	45	0.403	17.718	0.188	52.410	15.425	6.432
16	48	0.416	18.291	0.201	55.854	16.438	6.854
17	51	0.428	18.847	0.213	59.304	17.454	7.278
18	54	0.441	19.388	0.226	62.754	18.469	7.701
19	57	0.453	19.913	0.238	66.197	19.482	8.124
20	60	0.464	20.422	0.250	69.629	20.492	8.545
21	63	0.475	20.917	0.263	73.044	21.497	8.964
22	66	0.486	21.397	0.275	76.438	22.496	9.380
23	69	0.497	21.864	0.287	79.806	23.488	9.794
24	72	0.507	22.317	0.299	83.145	24.470	10.203
25	75	0.517	22.756	0.311	86.452	25.444	10.609
26	78	0.527	23.183	0.322	89.724	26.406	11.011
27	81	0.536	23.597	0.334	92.958	27.358	11.407
28	84	0.545	23.999	0.346	96.151	28.298	11.799
29	87	0.554	24.389	0.357	99.302	29.225	12.186
30	90	0.563	24.767	0.368	102.410	30.140	12.567
					1646.832		

CALCULATION OF WIND LOAD BY DRAFT CODE (IS 875(III)):

The calculation of dynamic wind load is done as per IS 875(III) Draft Code.

CALCULATION OF WIND LOAD:

Location of building : Mumbai

Plan Dimensions of building w =24 m

d =24 m

Wind Zone Z= III

Basic Wind Speed Vb =44 m/s

Average storey height h =3 m

Frame spacing in X-Direction sx =8 m

Frame spacing in Y-Direction sy =8 m

Number of storeys n =30 nos.

Total height of the building H =90 m

Aspect ratio h/d =3.75

Table A.8: Wind Parameters-30 Storey

Risk coefficient factor, k1	k1	1	
Topography factor, k3	k3	1	
Importance factor, k4	k4	1	
Wind directionality factor, Kd	kd	0.9	
Area averaging factor, Ka	ka	1	
Combination Factor, Kc	kc	1	
Design wind speed, Vz = k1 k2 k3 k4 Vb	Vz	44	*k2 m/s
Wind pressure at height ,z pz = 0.6*Vz^2	pz	1161.6	*k_2 N/m^2
Design wind pressure , pd = ka kd kc pz	pd	1045.44	*k_2 N/m^2

Table A.9: Calculation of Design Pressures in X- and Y- Direction-30 Storey

Height	k2	k2	Vz(m/s)	Vz(m/s)	pz(kN/m^2)	pz(kN/m^2)	pd(kN/m^2)	pd(kN/m^2)
	sea face	other face	sea face	other face	sea face	other face	sea face	other face
Category	1	4	1	4	1	4	1	4
0	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
3	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
6	1.010	0.740	44.422	32.542	1.184	0.635	1.066	0.572
9	1.045	0.765	45.999	33.668	1.270	0.680	1.143	0.612
12	1.071	0.790	47.118	34.751	1.332	0.725	1.199	0.652

Height	k2	k2	Vz(m/s)	Vz(m/s)	pz(kN/m^2)	pz(kN/m^2)	pd(kN/m^2)	pd(kN/m^2)
	sea face	other face	sea face	other face	sea face	other face	sea face	other face
15	1.091	0.813	47.986	35.792	1.382	0.769	1.243	0.692
18	1.107	0.836	48.695	36.793	1.423	0.812	1.280	0.731
21	1.120	0.858	49.295	37.754	1.458	0.855	1.312	0.770
24	1.132	0.879	49.814	38.676	1.489	0.898	1.340	0.808
27	1.143	0.899	50.272	39.562	1.516	0.939	1.365	0.845
30	1.152	0.918	50.682	40.412	1.541	0.980	1.387	0.882
33	1.160	0.937	51.053	41.228	1.564	1.020	1.407	0.918
36	1.168	0.955	51.391	42.010	1.585	1.059	1.426	0.953
39	1.175	0.972	51.703	42.760	1.604	1.097	1.444	0.987
42	1.182	0.988	51.991	43.479	1.622	1.134	1.460	1.021
45	1.188	1.004	52.259	44.169	1.639	1.171	1.475	1.053
48	1.193	1.019	52.510	44.829	1.654	1.206	1.489	1.085
51	1.199	1.033	52.746	45.461	1.669	1.240	1.502	1.116
54	1.204	1.047	52.968	46.067	1.683	1.273	1.515	1.146
57	1.209	1.060	53.179	46.647	1.697	1.306	1.527	1.175
60	1.213	1.073	53.378	47.202	1.710	1.337	1.539	1.203
63	1.217	1.085	53.568	47.733	1.722	1.367	1.550	1.230
66	1.222	1.096	53.749	48.241	1.733	1.396	1.560	1.257
69	1.225	1.107	53.922	48.728	1.745	1.425	1.570	1.282
72	1.229	1.118	54.087	49.194	1.755	1.452	1.580	1.307
75	1.233	1.128	54.246	49.639	1.766	1.478	1.589	1.331
78	1.236	1.138	54.399	50.065	1.776	1.504	1.598	1.354
81	1.240	1.147	54.545	50.473	1.785	1.529	1.607	1.376
84	1.243	1.156	54.687	50.863	1.794	1.552	1.615	1.397
87	1.246	1.164	54.823	51.237	1.803	1.575	1.623	1.418
90	1.249	1.173	54.955	51.594	1.812	1.597	1.631	1.437

Table A.10: Calculation of Cdyn in X-Direction-30 Storey)

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	1	
Peak Factor	gR	3.920676	
Peak Factor for Upwind velocity	gV	3.5	
Turbulence Intensity	Ih	0.109	
Size Reduction factor	S	0.063218	
Reduced Frequency	N	2.621462	
Turbulence Spectrum	E	0.04784	

Table A.11: Calculation of Cdyn in Y-Direction-30 Storey)

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	4	
Peak Factor	gR	3.920	
Peak Factor for Upwind velocity	gV	3.5	
Turbulence Intensity	Ih	0.238	
Size Reduction factor	S	0.0381	
Reduced Frequency	N	3.6739	
Turbulence Spectrum	E	0.0382	

Table A.12: Wind Forces in X-Direction-30 Storey

Height	Background Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
0	0.377	1.000	0.893	0.940	42.312	47.385
3	0.384	1.001	0.895	0.940	84.822	94.769
6	0.391	1.004	0.897	1.066	96.380	107.412
9	0.399	1.010	0.900	1.143	103.625	115.174
12	0.406	1.018	0.902	1.199	109.043	120.845
15	0.415	1.028	0.905	1.243	113.445	125.338
18	0.423	1.040	0.908	1.280	117.203	129.070
21	0.432	1.054	0.911	1.312	120.518	132.268
24	0.440	1.071	0.914	1.340	123.514	135.070
27	0.450	1.090	0.918	1.365	126.269	137.566
30	0.459	1.111	0.921	1.387	128.838	139.818
33	0.469	1.134	0.925	1.407	131.261	141.871
36	0.479	1.160	0.929	1.426	133.567	143.758
39	0.490	1.188	0.933	1.444	135.777	145.505
42	0.500	1.218	0.937	1.460	137.909	147.132
45	0.511	1.250	0.942	1.475	139.974	148.655
48	0.522	1.284	0.946	1.489	141.983	150.087
51	0.534	1.321	0.951	1.502	143.943	151.438
54	0.545	1.360	0.955	1.515	145.859	152.717
57	0.557	1.401	0.960	1.527	147.735	153.932
60	0.568	1.444	0.964	1.539	149.572	155.089
63	0.580	1.490	0.969	1.550	151.370	156.194
66	0.591	1.538	0.974	1.560	153.129	157.251
69	0.601	1.588	0.978	1.570	154.844	158.264
72	0.611	1.640	0.983	1.580	156.512	159.237
75	0.620	1.694	0.987	1.589	158.127	160.174
78	0.628	1.751	0.991	1.598	159.683	161.076
81	0.635	1.810	0.995	1.607	161.173	161.946
84	0.639	1.871	0.999	1.615	162.592	162.787
87	0.642	1.934	1.002	1.623	163.935	163.601
90	0.643	2.000	1.005	1.631	165.199	164.389
					4160.110	

Table A.13: Wind Forces in Y-Direction-30 Storey

Height	Background Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
0	0.377	1.000	0.803	0.531	21.499	26.783
3	0.384	1.001	0.806	0.531	43.172	53.567
6	0.391	1.004	0.809	0.572	46.654	57.641
9	0.399	1.010	0.813	0.612	50.162	61.701
12	0.406	1.018	0.817	0.652	53.690	65.734
15	0.415	1.028	0.821	0.692	57.231	69.732
18	0.423	1.040	0.825	0.731	60.779	73.684
21	0.432	1.054	0.829	0.770	64.329	77.583
24	0.440	1.071	0.834	0.808	67.877	81.422
27	0.450	1.090	0.838	0.845	71.417	85.195
30	0.459	1.111	0.843	0.882	74.946	88.896
33	0.469	1.134	0.848	0.918	78.461	92.521
36	0.479	1.160	0.853	0.953	81.958	96.065
39	0.490	1.188	0.858	0.987	85.434	99.526
42	0.500	1.218	0.864	1.021	88.887	102.902
45	0.511	1.250	0.869	1.053	92.313	106.189
48	0.522	1.284	0.875	1.085	95.708	109.388
51	0.534	1.321	0.881	1.116	99.071	112.496
54	0.545	1.360	0.886	1.146	102.396	115.513
57	0.557	1.401	0.892	1.175	105.679	118.439
60	0.568	1.444	0.898	1.203	108.914	121.275
63	0.580	1.490	0.904	1.230	112.096	124.020
66	0.591	1.538	0.910	1.257	115.216	126.676
69	0.601	1.588	0.915	1.282	118.265	129.244
72	0.611	1.640	0.920	1.307	121.232	131.726
75	0.620	1.694	0.925	1.331	124.107	134.122
78	0.628	1.751	0.930	1.354	126.876	136.435
81	0.635	1.810	0.934	1.376	129.527	138.666
84	0.639	1.871	0.938	1.397	132.048	140.819
87	0.642	1.934	0.941	1.418	134.428	142.895
90	0.643	2.000	0.943	1.437	136.660	144.897
					2801.032	

CALCULATION OF MGLF FORCES

The calculation of wind forces as per MGLF method is tabulated as follows:

Table A.14: Calculation of MGLF Forces in X- Direction-30 Storey

Terrain Category	TC	1	
No. of Storeys	N	30.00	nos.
Peak Factor	gR	3.92	
Peak Factor for Upwind velocity	gV	3.50	
Turbulence Intensity	Ih	0.11	
Size Reduction factor	S	0.06	
Reduced Frequency	N	2.62	
Turbulence Spectrum	E	0.05	
Damping Coefficient	ζ	0.02	
Mass at each storey	mo	481855.25	kg
Mass reduction factor	λ	0.00	
Mode Shape Coefficient	β	1.00	
Total height of the building	H	180.00	m
Storey Height	h	3.00	m
Mean BBM	$\dot{M}$	49798.28	kN-m
Res. extreme BBM component	M_R	9388.15	kN-m
$\sum$miϕiZi	$\sum$miϕiZi	37966178.00	kg-m

Table A.15: Calculation of MGLF Forces in Y- Direction-30 Storey

Terrain Category		4	
No. of Storeys	N	30.00	nos.
Peak Factor	gR	3.92	
Peak Factor for Upwind velocity	gV	3.50	
Turbulence Intensity	Ih	0.24	
Size Reduction factor	S	0.04	
Reduced Frequency	N	3.67	
Turbulence Spectrum	E	0.04	
Damping Coefficient	ζ	0.02	
Mass at each storey	mo	481855.25	kg
Mass reduction factor	λ	0.00	
Mode Shape Coefficient	β	1.00	
Total height of the building	H	180.00	m
Storey height	h	3.00	m
Mean BBM	$\dot{M}$	39416.28	kN-m
Res. extreme BBM component	M_R	7449.88	kN-m
$\sum$miϕiZi	$\sum$miϕiZi	37966178.00	kg-m

Table A.16: Wind Forces in X-Direction by MGLF Method-30 Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd ESWL	miϕiZi	Res. ESWL
	Zi		Hs					ϕi	P_{Bi}		P_{Ri}	
	0	47.385	1.000	0.000	0.377	0.266	0.189	0.893	0.000	12.59	0.00	0.00
1	3	94.769	1.001	53.628	0.384	0.268	0.189	0.895	0.017	25.41	4015.46	1.76
2	6	107.412	1.004	121.767	0.391	0.271	0.189	0.897	0.033	29.07	16061.84	3.51
3	9	115.174	1.010	196.391	0.399	0.273	0.189	0.900	0.050	31.47	36139.14	5.27
4	12	120.845	1.018	275.806	0.406	0.276	0.190	0.902	0.067	33.34	64247.37	7.02
5	15	125.338	1.028	359.328	0.415	0.279	0.191	0.905	0.083	34.93	100386.50	8.78
6	18	129.070	1.040	446.664	0.423	0.281	0.192	0.908	0.100	36.33	144556.60	10.53
7	21	132.268	1.054	537.716	0.432	0.284	0.194	0.911	0.117	37.60	196757.60	12.29
8	24	135.070	1.071	632.491	0.440	0.287	0.195	0.914	0.133	38.80	256989.50	14.04
9	27	137.566	1.090	731.062	0.450	0.290	0.197	0.918	0.150	39.92	325252.30	15.80
10	30	139.818	1.111	833.545	0.459	0.293	0.199	0.921	0.167	41.00	401546.00	17.56
11	33	141.871	1.134	940.080	0.469	0.296	0.201	0.925	0.183	42.05	485870.70	19.31
12	36	143.758	1.160	1050.824	0.479	0.300	0.203	0.929	0.200	43.06	578226.30	21.07
13	39	145.505	1.188	1165.941	0.490	0.303	0.205	0.933	0.217	44.06	678612.80	22.82
14	42	147.132	1.218	1285.603	0.500	0.306	0.208	0.937	0.233	45.04	787030.20	24.58
15	45	148.655	1.250	1409.980	0.511	0.309	0.211	0.942	0.250	46.00	903478.60	26.33
16	48	150.087	1.284	1539.241	0.522	0.313	0.214	0.946	0.267	46.94	1027958.00	28.09
17	51	151.438	1.321	1673.552	0.534	0.316	0.217	0.951	0.283	47.88	1160468.00	29.85
18	54	152.717	1.360	1813.076	0.545	0.320	0.220	0.955	0.300	48.80	1301009.00	31.60
19	57	153.932	1.401	1957.969	0.557	0.323	0.223	0.960	0.317	49.71	1449581.00	33.36
20	60	155.089	1.444	2108.380	0.568	0.326	0.227	0.964	0.333	50.60	1606184.00	35.11
21	63	156.194	1.490	2264.454	0.580	0.329	0.230	0.969	0.350	51.47	1770818.00	36.87
22	66	157.251	1.538	2426.328	0.591	0.333	0.234	0.974	0.367	52.31	1943483.00	38.62
23	69	158.264	1.588	2594.134	0.601	0.336	0.238	0.978	0.383	53.11	2124179.00	40.38
24	72	159.237	1.640	2767.995	0.611	0.338	0.241	0.983	0.400	53.88	2312905.00	42.13
25	75	160.174	1.694	2948.030	0.620	0.341	0.245	0.987	0.417	54.60	2509663.00	43.89
26	78	161.076	1.751	3134.352	0.628	0.343	0.249	0.991	0.433	55.25	2714451.00	45.65
27	81	161.946	1.810	3327.065	0.635	0.345	0.254	0.995	0.450	55.83	2927271.00	47.40
28	84	162.787	1.871	3526.271	0.639	0.346	0.258	0.999	0.467	56.34	3148121.00	49.16
29	87	163.601	1.934	3732.065	0.642	0.347	0.262	1.002	0.483	56.75	3377002.00	50.91
30	90	164.389	2.000	3944.536	0.643	0.347	0.267	1.005	0.500	57.07	3613914.00	52.67

Table A.17: Calculation of Single Lateral Force for Design Input in X- Direction-30 Storey

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
30	90	164.39	57.07	52.67	164.39	0.00	57.07	0.00	52.67	0.00	242.06	242.06
29	87	163.61	56.75	50.92	327.99	493.17	113.82	171.20	103.58	158.01	481.89	239.84
28	84	162.79	56.34	49.16	490.78	1477.14	170.15	512.65	152.74	468.76	719.43	237.55
27	81	161.95	55.84	47.41	652.72	2949.47	225.99	1023.11	200.14	926.97	954.60	235.17
26	78	161.08	55.26	45.65	813.80	4907.65	281.24	1701.07	245.79	1527.40	1187.31	232.72
25	75	160.18	54.60	43.90	973.97	7349.05	335.83	2544.78	289.68	2264.76	1417.48	230.17
24	72	159.24	53.89	42.14	1133.21	10270.96	389.71	3552.27	331.81	3133.79	1645.05	227.57
23	69	158.27	53.12	40.38	1291.48	13670.60	442.83	4721.42	372.19	4129.23	1869.95	224.91
22	66	157.26	52.31	38.63	1448.73	17545.02	495.14	6049.90	410.82	5245.81	2092.11	222.17
21	63	156.20	51.47	36.87	1604.92	21891.20	546.60	7535.31	447.68	6478.26	2311.46	219.35
20	60	155.09	50.60	35.12	1760.01	26705.96	597.20	9175.12	482.80	7821.31	2527.96	216.51
19	57	153.94	49.71	33.36	1913.94	31985.99	646.91	10966.71	516.15	9269.70	2741.53	213.58
18	54	152.72	48.81	31.61	2066.66	37727.82	695.71	12907.43	547.75	10818.16	2952.13	210.60
17	51	151.44	47.88	29.85	2218.10	43927.79	743.59	14994.55	577.60	12461.42	3159.67	207.55
16	48	150.09	46.95	28.09	2368.18	50582.08	790.53	17225.32	605.69	14194.22	3364.08	204.41
15	45	148.66	46.00	26.34	2516.84	57686.63	836.53	19596.91	632.02	16011.29	3565.29	201.22
14	42	147.14	45.04	24.58	2663.97	65237.14	881.56	22106.49	656.60	17907.37	3763.19	197.91
13	39	145.51	44.06	22.83	2809.48	73229.05	925.62	24751.18	679.43	19877.18	3957.70	194.52
12	36	143.76	43.07	21.07	2953.23	81657.47	968.69	27528.05	700.49	21915.45	4148.66	190.97
11	33	141.88	42.05	19.32	3095.10	90517.17	1010.74	30434.11	719.81	24016.94	4335.96	187.30
10	30	139.82	41.01	17.56	3234.92	99802.49	1051.74	33466.31	737.36	26176.35	4519.39	183.44
9	27	137.57	39.93	15.81	3372.49	109507.30	1091.66	36621.53	753.16	28388.44	4698.76	179.37
8	24	135.08	38.80	14.05	3507.56	119624.70	1130.46	39896.52	767.21	30647.93	4873.78	175.03
7	21	132.27	37.61	12.29	3639.83	130147.40	1168.06	43287.89	779.50	32949.55	5044.11	170.33
6	18	129.08	36.33	10.54	3768.90	141066.90	1204.39	46792.08	790.03	35288.04	5209.29	165.18
5	15	125.34	34.93	8.78	3894.24	152373.60	1239.31	50405.24	798.81	37658.14	5368.69	159.41
4	12	120.85	33.35	7.03	4015.08	164056.30	1272.66	54123.18	805.83	40054.56	5521.41	152.73
3	9	115.18	31.48	5.27	4130.25	176101.50	1304.13	57941.14	811.10	42472.06	5666.04	144.63
2	6	107.42	29.08	3.52	4237.67	188492.30	1333.20	61853.52	814.61	44905.35	5800.05	134.01
1	3	94.77	25.41	1.76	4332.44	201205.30	1358.61	65853.12	816.37	47349.18	5917.46	117.42
0	0	47.39	12.59	0.00	4379.83	214202.60	1371.20	69928.95	816.37	49798.29	**5975.65**	58.19

Table A.18: Wind Forces in Y-Direction by MGLF Method-30 Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd ESWL	miϕiZi	Res. ESWL
	Zi		Hs					ϕi	P_{Bi}		P_{Ri}	
	0	0.000	1.000	0.000	0.377	0.384	0.189	0.803	0.000	0.000	0.000	0.000
1	3	53.567	1.001	30.390	0.384	0.387	0.189	0.806	0.017	20.738	4015.460	1.390
2	6	57.641	1.004	65.512	0.391	0.391	0.189	0.809	0.033	22.526	16061.840	2.779
3	9	61.701	1.010	105.480	0.399	0.395	0.190	0.813	0.050	24.345	36139.140	4.169
4	12	65.734	1.018	150.409	0.406	0.398	0.191	0.817	0.067	26.189	64247.370	5.558
5	15	69.732	1.028	200.423	0.415	0.402	0.192	0.821	0.083	28.056	100386.500	6.948
6	18	73.684	1.040	255.645	0.423	0.406	0.193	0.825	0.100	29.943	144556.600	8.338
7	21	77.583	1.054	316.209	0.432	0.411	0.194	0.829	0.117	31.848	196757.600	9.727
8	24	81.422	1.071	382.249	0.440	0.415	0.196	0.834	0.133	33.768	256989.500	11.117
9	27	85.195	1.090	453.905	0.450	0.419	0.197	0.838	0.150	35.700	325252.300	12.506
10	30	88.896	1.111	531.319	0.459	0.423	0.199	0.843	0.167	37.643	401546.000	13.896
11	33	92.521	1.134	614.635	0.469	0.428	0.201	0.848	0.183	39.595	485870.700	15.286
12	36	96.065	1.160	703.997	0.479	0.433	0.204	0.853	0.200	41.553	578226.300	16.675
13	39	99.526	1.188	799.547	0.490	0.437	0.206	0.858	0.217	43.515	678612.800	18.065
14	42	102.902	1.218	901.426	0.500	0.442	0.209	0.864	0.233	45.479	787030.200	19.455
15	45	106.189	1.250	1009.770	0.511	0.447	0.211	0.869	0.250	47.443	903478.600	20.844
16	48	109.388	1.284	1124.712	0.522	0.452	0.214	0.875	0.267	49.403	1027958.000	22.234
17	51	112.496	1.321	1246.378	0.534	0.457	0.217	0.881	0.283	51.356	1160468.000	23.623
18	54	115.513	1.360	1374.890	0.545	0.461	0.220	0.886	0.300	53.298	1301009.000	25.013
19	57	118.439	1.401	1510.361	0.557	0.466	0.224	0.892	0.317	55.225	1449581.000	26.403
20	60	121.275	1.444	1652.898	0.568	0.471	0.227	0.898	0.333	57.130	1606184.000	27.792
21	63	124.020	1.490	1802.602	0.580	0.476	0.231	0.904	0.350	59.005	1770818.000	29.182
22	66	126.676	1.538	1959.565	0.591	0.480	0.234	0.910	0.367	60.842	1943483.000	30.571
23	69	129.244	1.588	2123.875	0.601	0.485	0.238	0.915	0.383	62.631	2124179.000	31.961
24	72	131.726	1.640	2295.609	0.611	0.489	0.242	0.920	0.400	64.358	2312905.000	33.351
25	75	134.122	1.694	2474.842	0.620	0.492	0.246	0.925	0.417	66.011	2509663.000	34.740
26	78	136.435	1.751	2661.641	0.628	0.495	0.250	0.930	0.433	67.573	2714451.000	36.130
27	81	138.666	1.810	2856.069	0.635	0.498	0.254	0.934	0.450	69.030	2927271.000	37.519
28	84	140.819	1.871	3058.185	0.639	0.500	0.259	0.938	0.467	70.367	3148121.000	38.909
29	87	142.895	1.934	3268.041	0.642	0.501	0.263	0.941	0.483	71.570	3377002.000	40.299
30	90	144.897	2.000	3485.691	0.643	0.501	0.267	0.943	0.500	72.629	3613914.000	41.688

Table A.19: Calculation of Single Lateral Force for Design Input in Y- Direction-30 Storey

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
30	90	144.90	72.63	41.69	144.90	0.00	72.63	0.00	41.69	0.00	228.64	228.64
29	87	142.89	71.57	40.30	287.79	434.69	144.20	217.89	81.99	125.07	453.67	225.02
28	84	140.82	70.37	38.91	428.61	1298.06	214.57	650.49	120.90	371.03	674.90	221.23
27	81	138.67	69.03	37.52	567.28	2583.90	283.60	1294.18	158.42	733.71	892.13	217.23
26	78	136.43	67.57	36.13	703.71	4285.73	351.17	2144.98	194.55	1208.96	1105.17	213.04
25	75	134.12	66.01	34.74	837.83	6396.86	417.18	3198.49	229.29	1792.60	1313.87	208.70
24	72	131.73	64.36	33.35	969.56	8910.36	481.54	4450.03	262.64	2480.45	1518.07	204.20
23	69	129.24	62.63	31.96	1098.80	11819.03	544.17	5894.64	294.60	3268.36	1717.60	199.53
22	66	126.68	60.84	30.57	1225.48	15115.44	605.01	7527.15	325.17	4152.15	1912.34	194.74
21	63	124.02	59.01	29.18	1349.50	18791.88	664.02	9342.19	354.35	5127.66	2102.15	189.82
20	60	121.27	57.13	27.79	1470.77	22840.38	721.15	11334.24	382.14	6190.71	2286.91	184.76
19	57	118.44	55.23	26.40	1589.21	27252.70	776.37	13497.68	408.55	7337.14	2466.51	179.60
18	54	115.51	53.30	25.01	1704.73	32020.34	829.67	15826.79	433.56	8562.77	2640.85	174.34
17	51	112.50	51.36	23.62	1817.22	37134.52	881.03	18315.80	457.18	9863.45	2809.81	168.95
16	48	109.39	49.40	22.23	1926.61	42586.19	930.43	20958.88	479.42	11234.99	2973.29	163.49
15	45	106.19	47.44	20.84	2032.80	48366.02	977.87	23750.17	500.26	12673.24	3131.20	157.91
14	42	102.90	45.48	19.45	2135.70	54464.42	1023.35	26683.78	519.71	14174.02	3283.46	152.25
13	39	99.53	43.51	18.06	2235.23	60871.52	1066.87	29753.83	537.78	15733.16	3429.98	146.52
12	36	96.07	41.55	16.68	2331.29	67577.21	1108.42	32954.43	554.45	17346.50	3570.65	140.67
11	33	92.52	39.59	15.29	2423.81	74571.09	1148.01	36279.68	569.74	19009.86	3705.42	134.77
10	30	88.90	37.64	13.90	2512.71	81842.53	1185.66	39723.72	583.64	20719.08	3834.23	128.81
9	27	85.20	35.70	12.51	2597.90	89380.66	1221.36	43280.69	596.14	22469.99	3956.98	122.75
8	24	81.42	33.77	11.12	2679.33	97174.37	1255.12	46944.76	607.26	24258.41	4073.64	116.65
7	21	77.58	31.85	9.73	2756.91	105212.36	1286.97	50710.13	616.99	26080.19	4184.13	110.50
6	18	73.68	29.94	8.34	2830.60	113483.09	1316.92	54571.04	625.32	27931.15	4288.44	104.31
5	15	69.73	28.06	6.95	2900.33	121974.87	1344.97	58521.79	632.27	29807.13	4386.50	98.06
4	12	65.73	26.19	5.56	2966.06	130675.85	1371.16	62556.71	637.83	31703.94	4478.31	91.81
3	9	61.70	24.34	4.17	3027.76	139574.04	1395.51	66670.19	642.00	33617.44	4563.86	85.55
2	6	57.64	22.53	2.78	3085.40	148657.33	1418.03	70856.71	644.78	35543.43	4643.14	79.28
1	3	53.57	20.74	1.39	3138.97	157913.54	1438.77	75110.80	646.17	37477.77	4716.18	73.04
0	0	26.78	10.27	0.00	3165.75	167330.45	1449.04	79427.11	646.17	39416.28	**4716.18**	73.04

CALCULATION OF 40 STOREY BUILDING

Calculation of DGLF Method

CALCULATION OF WIND LOAD:

Location of building Mumbai

Plan Dimensions of building w =24 m; d =24 m

Wind Zone Z =III

Basic Wind Speed Vb =44 m/s

Average storey height h =3 m

Frame spacing in X-Direction sx= 8 m

Frame spacing in Y-Direction sy =8 m

Number of storeys n 40 =nos.

Total height of the building H =120 m

Table A.20: Wind Parameters - 40 Storey

Risk coefficient factor, k1	k1	1	
Topography factor, k3	k3	1	
Importance factor, k4	k4	1	
Wind directionality factor, Kd	kd	0.9	
Area averaging factor, Ka	ka	1	
Combination Factor, Kc	kc	1	
Design wind speed, Vz = k1 k2 k3 k4 Vb	Vz	44	*k2 m/s
Wind pressure at height ,z pz = 0.6*Vz^2	pz	1161.6	*k2 N/m^2
Design wind pressure , pd = ka kd kc pz	pd	1045.44	*k2 N/m^2

Table A.21: Calculation of Design Pressures in X- and Y- Direction-40 Storey

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
0	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
3	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
6	1.010	0.740	44.422	32.542	1.184	0.635	1.066	0.572
9	1.045	0.765	45.999	33.668	1.270	0.680	1.143	0.612
12	1.071	0.790	47.118	34.751	1.332	0.725	1.199	0.652
15	1.091	0.813	47.986	35.792	1.382	0.769	1.243	0.692

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
18	1.107	0.836	48.695	36.793	1.423	0.812	1.280	0.731
21	1.120	0.858	49.295	37.754	1.458	0.855	1.312	0.770
24	1.132	0.879	49.814	38.676	1.489	0.898	1.340	0.808
27	1.143	0.899	50.272	39.562	1.516	0.939	1.365	0.845
30	1.152	0.918	50.682	40.412	1.541	0.980	1.387	0.882
33	1.160	0.937	51.053	41.228	1.564	1.020	1.407	0.918
36	1.168	0.955	51.391	42.010	1.585	1.059	1.426	0.953
39	1.175	0.972	51.703	42.760	1.604	1.097	1.444	0.987
42	1.182	0.988	51.991	43.479	1.622	1.134	1.460	1.021
45	1.188	1.004	52.259	44.169	1.639	1.171	1.475	1.053
48	1.193	1.019	52.510	44.829	1.654	1.206	1.489	1.085
51	1.199	1.033	52.746	45.461	1.669	1.240	1.502	1.116
54	1.204	1.047	52.968	46.067	1.683	1.273	1.515	1.146
57	1.209	1.060	53.179	46.647	1.697	1.306	1.527	1.175
60	1.213	1.073	53.378	47.202	1.710	1.337	1.539	1.203
63	1.217	1.085	53.568	47.733	1.722	1.367	1.550	1.230
66	1.222	1.096	53.749	48.241	1.733	1.396	1.560	1.257
69	1.225	1.107	53.922	48.728	1.745	1.425	1.570	1.282
72	1.229	1.118	54.087	49.194	1.755	1.452	1.580	1.307
75	1.233	1.128	54.246	49.639	1.766	1.478	1.589	1.331
78	1.236	1.138	54.399	50.065	1.776	1.504	1.598	1.354
81	1.240	1.147	54.545	50.473	1.785	1.529	1.607	1.376
84	1.243	1.156	54.687	50.863	1.794	1.552	1.615	1.397
87	1.246	1.164	54.823	51.237	1.803	1.575	1.623	1.418
90	1.249	1.173	54.955	51.594	1.812	1.597	1.631	1.437
93	1.252	1.180	55.083	51.937	1.820	1.618	1.638	1.457
96	1.255	1.188	55.206	52.265	1.829	1.639	1.646	1.475
99	1.257	1.195	55.326	52.579	1.837	1.659	1.653	1.493
102	1.260	1.202	55.442	52.881	1.844	1.678	1.660	1.510
105	1.263	1.208	55.555	53.170	1.852	1.696	1.667	1.527
108	1.265	1.215	55.664	53.448	1.859	1.714	1.673	1.543
111	1.268	1.221	55.771	53.715	1.866	1.731	1.680	1.558
114	1.270	1.227	55.875	53.972	1.873	1.748	1.686	1.573
117	1.272	1.232	55.976	54.219	1.880	1.764	1.692	1.587
120	1.274	1.238	56.074	54.457	1.887	1.779	1.698	1.601

Table A.22: Building Parameters in X- and Y- Direction-40 Storey

Total height of structure	h	120.000	m
Average breadth of the structure between heights 0 and h	boh	24.000	m
Depth of structure	d	24.000	m
Measure of the integral turbulence length scale at height h = 100 $(h/10)^{0.25}$	Lh	186.121	m
Time Period of building, T = 0.09h/sqrt(d)	T	2.205	seconds
Fundamental natural frequency of the structure, fo = 1/T	fo	0.454	Hz
Ratio of structural damping to critical damping of the structure, β(Table 32)	β	0.020	

Table A.23: Calculation of Cdyn in X-Direction-40 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	1	
Peak Factor	gR	3.847	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.102	
Size Reduction factor	S	0.076	
Reduced Frequency	N	2.075	
Turbulence Spectrum	E	0.056	

Table A.24: Calculation of Cdyn in Y-Direction-40 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	4	
Peak Factor	gR	3.847	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.222	
Size Reduction factor	S	0.048	
Reduced Frequency	N	2.870	
Turbulence Spectrum	E	0.045	

Table A.25: Wind Forces in X- Direction-40 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.333	1.000	0.903	0.940	42.802	47.385
3	0.338	1.001	0.905	0.940	85.743	94.769
6	0.344	1.003	0.906	1.066	97.352	107.412
9	0.349	1.006	0.908	1.143	104.585	115.174
12	0.355	1.010	0.910	1.199	109.957	120.845
15	0.361	1.016	0.912	1.243	114.290	125.338
18	0.367	1.023	0.914	1.280	117.961	129.070
21	0.374	1.031	0.916	1.312	121.175	132.268
24	0.380	1.040	0.918	1.340	124.055	135.070
27	0.387	1.051	0.921	1.365	126.683	137.566
30	0.394	1.063	0.923	1.387	129.115	139.818
33	0.401	1.076	0.926	1.407	131.391	141.871
36	0.408	1.090	0.929	1.426	133.541	143.758
39	0.416	1.106	0.932	1.444	135.589	145.505
42	0.424	1.123	0.935	1.460	137.551	147.132
45	0.432	1.141	0.938	1.475	139.443	148.655
48	0.441	1.160	0.941	1.489	141.276	150.087
51	0.449	1.181	0.945	1.502	143.060	151.438
54	0.458	1.203	0.948	1.515	144.801	152.717
57	0.468	1.226	0.952	1.527	146.508	153.932
60	0.477	1.250	0.955	1.539	148.184	155.089
63	0.487	1.276	0.959	1.550	149.835	156.194
66	0.497	1.303	0.963	1.560	151.464	157.251
69	0.507	1.331	0.967	1.570	153.074	158.264

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
72	0.518	1.360	0.971	1.580	154.667	159.237
75	0.529	1.391	0.975	1.589	156.246	160.174
78	0.540	1.423	0.980	1.598	157.810	161.076
81	0.552	1.456	0.984	1.607	159.361	161.946
84	0.563	1.490	0.988	1.615	160.899	162.787
87	0.574	1.526	0.993	1.623	162.421	163.601
90	0.586	1.563	0.997	1.631	163.926	164.389
93	0.597	1.601	1.002	1.638	165.412	165.153
96	0.608	1.640	1.006	1.646	166.875	165.894
99	0.618	1.681	1.010	1.653	168.310	166.614
102	0.628	1.723	1.014	1.660	169.712	167.314
105	0.637	1.766	1.018	1.667	171.073	167.996
108	0.645	1.810	1.022	1.673	172.389	168.659
111	0.651	1.856	1.026	1.680	173.651	169.305
114	0.656	1.903	1.029	1.686	174.853	169.936
117	0.659	1.951	1.032	1.692	175.991	170.551
120	0.660	2.000	1.035	1.698	177.061	171.152
					5860.093	

Table A.26: Wind Forces in Y- Direction-40 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.333	1.000	0.806	0.531	21.583	26.783
3	0.338	1.001	0.808	0.531	43.294	53.567
6	0.344	1.003	0.811	0.572	46.732	57.641
9	0.349	1.006	0.813	0.612	50.186	61.701
12	0.355	1.010	0.816	0.652	53.649	65.734
15	0.361	1.016	0.819	0.692	57.114	69.732
18	0.367	1.023	0.822	0.731	60.574	73.684
21	0.374	1.031	0.825	0.770	64.025	77.583
24	0.380	1.040	0.829	0.808	67.461	81.422
27	0.387	1.051	0.832	0.845	70.879	85.195
30	0.394	1.063	0.836	0.882	74.274	88.896
33	0.401	1.076	0.839	0.918	77.644	92.521
36	0.408	1.090	0.843	0.953	80.986	96.065
39	0.416	1.106	0.847	0.987	84.298	99.526
42	0.424	1.123	0.851	1.021	87.578	102.902
45	0.432	1.141	0.855	1.053	90.825	106.189
48	0.441	1.160	0.860	1.085	94.037	109.388
51	0.449	1.181	0.864	1.116	97.214	112.496
54	0.458	1.203	0.869	1.146	100.355	115.513
57	0.468	1.226	0.874	1.175	103.459	118.439
60	0.477	1.250	0.878	1.203	106.527	121.275
63	0.487	1.276	0.883	1.230	109.558	124.020
66	0.497	1.303	0.888	1.257	112.551	126.676
69	0.507	1.331	0.894	1.282	115.508	129.244
72	0.518	1.360	0.899	1.307	118.426	131.726
75	0.529	1.391	0.904	1.331	121.306	134.122
78	0.540	1.423	0.910	1.354	124.147	136.435

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
81	0.552	1.456	0.915	1.376	126.947	138.666
84	0.563	1.490	0.921	1.397	129.705	140.819
87	0.574	1.526	0.927	1.418	132.418	142.895
90	0.586	1.563	0.932	1.437	135.082	144.897
93	0.597	1.601	0.938	1.457	137.692	146.826
96	0.608	1.640	0.943	1.475	140.243	148.687
99	0.618	1.681	0.948	1.493	142.727	150.482
102	0.628	1.723	0.954	1.510	145.136	152.213
105	0.637	1.766	0.958	1.527	147.460	153.883
108	0.645	1.810	0.963	1.543	149.689	155.495
111	0.651	1.856	0.967	1.558	151.811	157.052
114	0.656	1.903	0.970	1.573	153.817	158.558
117	0.659	1.951	0.973	1.587	155.698	160.014
120	0.660	2.000	0.975	1.601	157.451	161.424
					4240.069	

Table A.27: Calculation of MGLF Forces in X- and Y- Direction-40 Storey

CALCULATION OF MGLF FORCES X- Direction			
Terrain Category		I	
No. of Storeys	N	40	nos.
Peak Factor	gR	3.847	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.102	
Size Reduction factor	S	0.076	
Reduced Frequency	N	2.075	
Turbulence Spectrum	E	0.056	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	907543.323	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	120.000	m
Storey Height	h	3.000	m
Mean BBM		**102233.123**	
Res. extreme BBM component	M_R	21566.876	
miiZi	miϕiZi	502325229.358	
CALCULATION OF MGLF FORCES Y- Direction			
Terrain Category		IV	
No. of Storeys	N	40	nos.
Peak Factor	gR	3.847	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.222	
Size Reduction factor	S	0.048	
Reduced Frequency	N	2.870	
Turbulence Spectrum	E	0.045	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	907543.323	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	120.000	m
Storey Height	h	3.000	m
Mean BBM		**90854.959**	
Res. extreme BBM component	M_R	19971.075	
miiZi	miϕiiZi	502325229.358	

Table A.28: Wind Forces in X-Direction by MGLF Method-40Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_Ri
	m	kN		kN-m						kN	kg-m	kN
	0	47.38	1.000	0.000	0.333	0.240	0.211	0.903	0.000	11.39	0.00	0.00
1	3	94.77	1.001	59.996	0.338	0.242	0.211	0.905	0.025	22.96	22688.58	1.54
2	6	107.41	1.003	136.126	0.344	0.244	0.211	0.906	0.050	26.24	90754.33	3.08
3	9	115.17	1.006	219.285	0.349	0.246	0.212	0.908	0.075	28.36	204197.25	4.62
4	12	120.85	1.010	307.445	0.355	0.248	0.212	0.910	0.100	30.00	363017.33	6.16
5	15	125.34	1.016	399.703	0.361	0.250	0.213	0.912	0.125	31.38	567214.58	7.70
6	18	129.07	1.023	495.594	0.367	0.252	0.213	0.914	0.150	32.58	816788.99	9.24
7	21	132.27	1.031	594.869	0.374	0.255	0.214	0.916	0.175	33.68	1111740.57	10.77
8	24	135.07	1.040	697.402	0.380	0.257	0.215	0.918	0.200	34.69	1452069.32	12.31
9	27	137.57	1.051	803.147	0.387	0.259	0.216	0.921	0.225	35.64	1837775.23	13.85
10	30	139.82	1.063	912.105	0.394	0.261	0.217	0.923	0.250	36.55	2268858.31	15.39
11	33	141.87	1.076	1024.315	0.401	0.264	0.219	0.926	0.275	37.42	2745318.55	16.93
12	36	143.76	1.090	1139.841	0.408	0.266	0.220	0.929	0.300	38.27	3267155.96	18.47
13	39	145.51	1.106	1258.760	0.416	0.269	0.222	0.932	0.325	39.09	3834370.54	20.01
14	42	147.13	1.123	1381.167	0.424	0.271	0.224	0.935	0.350	39.91	4446962.28	21.55
15	45	148.66	1.141	1507.160	0.432	0.274	0.225	0.938	0.375	40.71	5104931.19	23.09
16	48	150.09	1.160	1636.846	0.441	0.276	0.227	0.941	0.400	41.50	5808277.27	24.63
17	51	151.44	1.181	1770.336	0.449	0.279	0.229	0.945	0.425	42.28	6557000.51	26.17
18	54	152.72	1.203	1907.740	0.458	0.282	0.231	0.948	0.450	43.06	7351100.92	27.71
19	57	153.93	1.226	2049.171	0.468	0.285	0.234	0.952	0.475	43.84	8190578.49	29.24
20	60	155.09	1.250	2194.742	0.477	0.288	0.236	0.955	0.500	44.62	9075433.23	30.78
21	63	156.19	1.276	2344.562	0.487	0.291	0.238	0.959	0.525	45.40	10005665.14	32.32
22	66	157.25	1.303	2498.743	0.497	0.294	0.241	0.963	0.550	46.18	10981274.21	33.86
23	69	158.26	1.331	2657.390	0.507	0.297	0.243	0.967	0.575	46.97	12002260.45	35.40
24	72	159.24	1.360	2820.608	0.518	0.300	0.246	0.971	0.600	47.75	13068623.85	36.94
25	75	160.17	1.391	2988.500	0.529	0.303	0.249	0.975	0.625	48.53	14180364.42	38.48
26	78	161.08	1.423	3161.164	0.540	0.306	0.252	0.980	0.650	49.32	15337482.16	40.02
27	81	161.95	1.456	3338.695	0.552	0.309	0.255	0.984	0.675	50.10	16539977.06	41.56
28	84	162.79	1.490	3521.186	0.563	0.313	0.258	0.988	0.700	50.88	17787849.13	43.10

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_Ri
	m	kN		kN-m						kN	kg-m	kN
29	87	163.60	1.526	3708.728	0.574	0.316	0.261	0.993	0.725	51.65	19081098.37	44.64
30	90	164.39	1.563	3901.404	0.586	0.319	0.264	0.997	0.750	52.41	20419724.77	46.18
31	93	165.15	1.601	4099.300	0.597	0.322	0.267	1.002	0.775	53.16	21803728.34	47.71
32	96	165.89	1.640	4302.493	0.608	0.325	0.270	1.006	0.800	53.89	23233109.07	49.25
33	99	166.61	1.681	4511.061	0.618	0.328	0.273	1.010	0.825	54.58	24707866.97	50.79
34	102	167.31	1.723	4725.078	0.628	0.330	0.277	1.014	0.850	55.24	26228002.04	52.33
35	105	168.00	1.766	4944.613	0.637	0.332	0.280	1.018	0.875	55.86	27793514.27	53.87
36	108	168.66	1.810	5169.735	0.645	0.335	0.284	1.022	0.900	56.42	29404403.67	55.41
37	111	169.31	1.856	5400.509	0.651	0.336	0.287	1.026	0.925	56.91	31060670.23	56.95
38	114	169.94	1.903	5636.997	0.656	0.337	0.291	1.029	0.950	57.33	32762313.97	58.49
39	117	170.55	1.951	5879.258	0.659	0.338	0.295	1.032	0.975	57.66	34509334.86	60.03
40	120	171.15	2.000	6127.351	0.660	0.338	0.298	1.035	1.000	57.91	36301732.93	61.57

Table A.29: Calculation of Single Lateral Force for Design Input in X- Direction-40 Storey

Storey	**Height**	**Pmean**	**Pbi**	**Pri**	**Vxmean**	**Mxmean**	**Vxb**	**Mxb**	**Vxr**	**Mxr**	**Vx**	**Pdesign**
40	120	171.15	57.91	61.57	171.15	0.00	57.91	0.00	61.57	0.00	255.67	255.67
39	117	170.55	57.66	60.03	341.70	513.45	115.57	173.73	121.60	184.70	509.46	253.79
38	114	169.94	57.33	58.49	511.64	1538.56	172.90	520.44	180.09	549.49	761.29	251.83
37	111	169.31	56.91	56.95	680.94	3073.48	229.81	1039.15	237.04	1089.75	1011.09	249.80
36	108	168.66	56.42	55.41	849.60	5116.31	286.23	1728.58	292.45	1800.85	1258.81	247.72
35	105	168.00	55.86	53.87	1017.60	7665.12	342.09	2587.26	346.32	2678.19	1504.38	245.57
34	102	167.31	55.24	52.33	1184.91	10717.91	397.33	3613.52	398.65	3717.15	1747.76	243.37
33	99	166.61	54.58	50.79	1351.53	14272.65	451.91	4805.51	449.44	4913.10	1988.88	241.13
32	96	165.89	53.89	49.25	1517.42	18327.23	505.80	6161.24	498.70	6261.43	2227.72	238.84
31	93	165.15	53.16	47.71	1682.57	22879.50	558.96	7678.63	546.41	7757.53	2464.24	236.51
30	90	164.39	52.41	46.18	1846.96	27927.22	611.37	9355.50	592.59	9396.77	2698.39	234.16
29	87	163.60	51.65	44.64	2010.56	33468.11	663.02	11189.60	637.23	11174.53	2930.16	231.76
28	84	162.79	50.88	43.10	2173.35	39499.81	713.90	13178.67	680.32	13086.21	3159.50	229.34
27	81	161.95	50.10	41.56	2335.30	46019.87	764.00	15320.37	721.88	15127.18	3386.40	226.90
26	78	161.08	49.32	40.02	2496.37	53025.76	813.32	17612.37	761.90	17292.82	3610.82	224.42
25	75	160.17	48.53	38.48	2656.55	60514.89	861.85	20052.33	800.38	19578.52	3832.73	221.91

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
24	72	159.24	47.75	36.94	2815.79	68484.53	909.60	22637.88	837.32	21979.66	4052.10	219.38
23	69	158.26	46.97	35.40	2974.05	76931.89	956.57	25366.69	872.72	24491.62	4268.91	216.81
22	66	157.25	46.18	33.86	3131.30	85854.04	1002.75	28236.40	906.58	27109.79	4483.12	214.21
21	63	156.19	45.40	32.32	3287.49	95247.94	1048.16	31244.65	938.91	29829.54	4694.68	211.57
20	60	155.09	44.62	30.78	3442.58	105110.42	1092.78	34389.12	969.69	32646.26	4903.57	208.88
19	57	153.93	43.84	29.24	3596.52	115438.18	1136.62	37667.46	998.94	35555.33	5109.72	206.15
18	54	152.72	43.06	27.71	3749.23	126227.73	1179.69	41077.34	1026.64	38552.14	5313.09	203.37
17	51	151.44	42.28	26.17	3900.67	137475.42	1221.97	44616.40	1052.81	41632.06	5513.62	200.53
16	48	150.09	41.50	24.63	4050.76	149177.44	1263.47	48282.32	1077.43	44790.48	5711.24	197.62
15	45	148.66	40.71	23.09	4199.41	161329.71	1304.17	52072.72	1100.52	48022.79	5905.88	194.63
14	42	147.13	39.91	21.55	4346.54	173927.94	1344.08	55985.25	1122.07	51324.35	6097.43	191.55
13	39	145.51	39.09	20.01	4492.05	186967.58	1383.17	60017.49	1142.08	54690.57	6285.79	188.37
12	36	143.76	38.27	18.47	4635.81	200443.73	1421.44	64167.01	1160.55	58116.81	6470.85	185.06
11	33	141.87	37.42	16.93	4777.68	214351.15	1458.86	68431.34	1177.48	61598.46	6652.45	181.60
10	30	139.82	36.55	15.39	4917.50	228684.19	1495.41	72807.94	1192.87	65130.90	6830.40	177.96
9	27	137.57	35.64	13.85	5055.06	243436.68	1531.05	77294.17	1206.73	68709.52	7004.50	174.10
8	24	135.07	34.69	12.31	5190.13	258601.87	1565.74	81887.33	1219.04	72329.70	7174.47	169.97
7	21	132.27	33.68	10.77	5322.40	274172.27	1599.42	86584.55	1229.81	75986.82	7339.97	165.50
6	18	129.07	32.58	9.24	5451.47	290139.48	1632.00	91382.80	1239.05	79676.27	7500.54	160.57
5	15	125.34	31.38	7.70	5576.81	306493.90	1663.37	96278.80	1246.75	83393.41	7655.56	155.02
4	12	120.85	30.00	6.16	5697.66	323224.33	1693.37	101268.93	1252.90	87133.65	7804.14	148.58
3	9	115.17	28.36	4.62	5812.83	340317.30	1721.73	106349.05	1257.52	90892.36	7944.90	140.76
2	6	107.41	26.24	3.08	5920.24	357755.79	1747.97	111514.25	1260.60	94664.92	8075.35	130.45
1	3	94.77	22.96	1.54	6015.01	375516.51	1770.94	116758.17	1262.14	98446.71	8189.68	114.33
0	0	47.38	11.39	0.00	6062.40	393561.54	1782.33	122070.98	1262.14	102233.12	**8246.36**	56.67

Table A.30: Wind Forces in Y-Direction by MGLF Method-40Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	mϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
1	3	53.57	1.001	35.335	0.338	0.354	0.220	0.808	0.025	18.96	22688.58	1.37
2	6	57.64	1.003	76.117	0.344	0.357	0.220	0.811	0.050	20.56	90754.33	2.74
3	9	61.70	1.006	122.407	0.349	0.360	0.220	0.813	0.075	22.19	204197.25	4.10
4	12	65.73	1.010	174.256	0.355	0.363	0.221	0.816	0.100	23.84	363017.33	5.47
5	15	69.73	1.016	231.709	0.361	0.366	0.222	0.819	0.125	25.50	567214.58	6.84
6	18	73.68	1.023	294.803	0.367	0.369	0.222	0.822	0.150	27.17	816788.99	8.21
7	21	77.58	1.031	363.573	0.374	0.372	0.223	0.825	0.175	28.85	1111740.57	9.58
8	24	81.42	1.040	438.051	0.380	0.375	0.224	0.829	0.200	30.54	1452069.32	10.94
9	27	85.20	1.051	518.268	0.387	0.378	0.225	0.832	0.225	32.24	1837775.23	12.31
10	30	88.90	1.063	604.255	0.394	0.382	0.227	0.836	0.250	33.94	2268858.31	13.68
11	33	92.52	1.076	696.042	0.401	0.385	0.228	0.839	0.275	35.65	2745318.55	15.05
12	36	96.07	1.090	793.660	0.408	0.389	0.229	0.843	0.300	37.35	3267155.96	16.41
13	39	99.53	1.106	897.139	0.416	0.392	0.231	0.847	0.325	39.06	3834370.54	17.78
14	42	102.90	1.123	1006.511	0.424	0.396	0.233	0.851	0.350	40.77	4446962.28	19.15
15	45	106.19	1.141	1121.807	0.432	0.400	0.235	0.855	0.375	42.47	5104931.19	20.52
16	48	109.39	1.160	1243.060	0.441	0.404	0.237	0.860	0.400	44.18	5808277.27	21.89
17	51	112.50	1.181	1370.300	0.449	0.408	0.239	0.864	0.425	45.88	6557000.51	23.25
18	54	115.51	1.203	1503.558	0.458	0.412	0.241	0.869	0.450	47.58	7351100.92	24.62
19	57	118.44	1.226	1642.867	0.468	0.416	0.243	0.874	0.475	49.27	8190578.49	25.99
20	60	121.27	1.250	1788.257	0.477	0.420	0.246	0.878	0.500	50.97	9075433.23	27.36
21	63	124.02	1.276	1939.758	0.487	0.425	0.248	0.883	0.525	52.66	10005665.14	28.73
22	66	126.68	1.303	2097.399	0.497	0.429	0.251	0.888	0.550	54.34	10981274.21	30.09
23	69	129.24	1.331	2261.211	0.507	0.433	0.254	0.894	0.575	56.02	12002260.45	31.46
24	72	131.73	1.360	2431.223	0.518	0.438	0.256	0.899	0.600	57.69	13068623.85	32.83
25	75	134.12	1.391	2607.463	0.529	0.443	0.259	0.904	0.625	59.36	14180364.42	34.20
26	78	136.43	1.423	2789.961	0.540	0.447	0.262	0.910	0.650	61.02	15337482.16	35.57
27	81	138.67	1.456	2978.746	0.552	0.452	0.265	0.915	0.675	62.66	16539977.06	36.93
28	84	140.82	1.490	3173.849	0.563	0.457	0.268	0.921	0.700	64.29	17787849.13	38.30
29	87	142.89	1.526	3375.302	0.574	0.461	0.272	0.927	0.725	65.90	19081098.37	39.67

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	mϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
30	90	144.90	1.563	3583.136	0.586	0.466	0.275	0.932	0.750	67.48	20419724.77	41.04
31	93	146.83	1.601	3797.386	0.597	0.470	0.278	0.938	0.775	69.03	21803728.34	42.40
32	96	148.69	1.640	4018.090	0.608	0.474	0.281	0.943	0.800	70.54	23233109.07	43.77
33	99	150.48	1.681	4245.288	0.618	0.479	0.285	0.948	0.825	72.01	24707866.97	45.14
34	102	152.21	1.723	4479.022	0.628	0.482	0.288	0.954	0.850	73.41	26228002.04	46.51
35	105	153.88	1.766	4719.340	0.637	0.486	0.292	0.958	0.875	74.73	27793514.27	47.88
36	108	155.50	1.810	4966.294	0.645	0.489	0.296	0.963	0.900	75.97	29404403.67	49.24
37	111	157.05	1.856	5219.939	0.651	0.491	0.299	0.967	0.925	77.11	31060670.23	50.61
38	114	158.56	1.903	5480.338	0.656	0.493	0.303	0.970	0.950	78.13	32762313.97	51.98
39	117	160.01	1.951	5747.560	0.659	0.494	0.307	0.973	0.975	79.02	34509334.86	53.35
40	120	161.42	2.000	6021.677	0.660	0.494	0.311	0.975	1.000	79.78	36301732.93	54.72

Table A.31: Calculation of Single Lateral Force for Design Input in Y- Direction-40 Storey

Storey	**Height**	**Pmean**	**Pbi**	**Pri**	**Vmean**	**Mean**	**Vxb**	**Mxb**	**Vxr**	**Mxr**	**Vx**	**Pdesign**
40	120	161.42	79.78	54.72	161.42	0.00	79.78	0.00	54.72	0.00	258.16	258.16
39	117	160.01	79.02	53.35	321.44	484.27	158.80	239.33	108.06	164.15	513.52	255.36
38	114	158.56	78.13	51.98	480.00	1448.59	236.93	715.73	160.04	488.34	765.91	252.39
37	111	157.05	77.11	50.61	637.05	2888.57	314.04	1426.51	210.65	968.46	1015.19	249.28
36	108	155.50	75.97	49.24	792.54	4799.72	390.01	2368.62	259.90	1600.43	1261.22	246.02
35	105	153.88	74.73	47.88	946.43	7177.35	464.74	3538.65	307.77	2380.12	1503.84	242.62
34	102	152.21	73.41	46.51	1098.64	10016.63	538.15	4932.88	354.28	3303.44	1742.94	239.10
33	99	150.48	72.01	45.14	1249.12	13312.54	610.16	6547.34	399.42	4366.29	1978.39	235.45
32	96	148.69	70.54	43.77	1397.81	17059.90	680.70	8377.81	443.19	5564.56	2210.07	231.69
31	93	146.83	69.03	42.40	1544.63	21253.33	749.73	10419.91	485.60	6894.14	2437.89	227.82
30	90	144.90	67.48	41.04	1689.53	25887.23	817.21	12669.10	526.64	8350.94	2661.73	223.84
29	87	142.89	65.90	39.67	1832.43	30955.82	883.11	15120.73	566.30	9930.85	2881.51	219.78
28	84	140.82	64.29	38.30	1973.24	36453.10	947.39	17770.05	604.61	11629.76	3097.12	215.61
27	81	138.67	62.66	36.93	2111.91	42372.83	1010.05	20612.22	641.54	13443.58	3308.48	211.36
26	78	136.43	61.02	35.57	2248.35	48708.56	1071.07	23642.38	677.10	15368.19	3515.49	207.01
25	75	134.12	59.36	34.20	2382.47	55453.60	1130.43	26855.58	711.30	17399.50	3718.06	202.57
24	72	131.73	57.69	32.83	2514.19	62601.00	1188.12	30246.87	744.13	19533.41	3916.11	198.04
23	69	129.24	56.02	31.46	2643.44	70143.58	1244.14	33811.23	775.59	21765.79	4109.53	193.43
22	66	126.68	54.34	30.09	2770.11	78073.89	1298.49	37543.67	805.68	24092.57	4298.25	188.72

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
21	63	124.02	52.66	28.73	2894.13	86384.23	1351.14	41439.13	834.41	26509.62	4482.16	183.91
20	60	121.27	50.97	27.36	3015.41	95066.63	1402.11	45492.56	861.77	29012.85	4661.18	179.02
19	57	118.44	49.27	25.99	3133.85	104112.85	1451.39	49698.90	887.76	31598.16	4835.21	174.03
18	54	115.51	47.58	24.62	3249.36	113514.39	1498.97	54053.06	912.38	34261.43	5004.16	168.95
17	51	112.50	45.88	23.25	3361.86	123262.48	1544.84	58549.96	935.63	36998.57	5167.94	163.78
16	48	109.39	44.18	21.89	3471.24	133348.05	1589.02	63184.49	957.52	39805.47	5326.46	158.52
15	45	106.19	42.47	20.52	3577.43	143761.78	1631.49	67951.55	978.04	42678.03	5479.62	153.16
14	42	102.90	40.77	19.15	3680.34	154494.08	1672.26	72846.02	997.19	45612.14	5627.34	147.72
13	39	99.53	39.06	17.78	3779.86	165535.09	1711.32	77862.79	1014.97	48603.71	5769.53	142.19
12	36	96.07	37.35	16.41	3875.93	176874.68	1748.67	82996.74	1031.39	51648.62	5906.10	136.57
11	33	92.52	35.65	15.05	3968.45	188502.46	1784.31	88242.75	1046.43	54742.78	6036.97	130.87
10	30	88.90	33.94	13.68	4057.34	200407.80	1818.25	93595.69	1060.11	57882.08	6162.07	125.10
9	27	85.20	32.24	12.31	4142.54	212579.83	1850.49	99050.45	1072.42	61062.41	6281.33	119.25
8	24	81.42	30.54	10.94	4223.96	225007.45	1881.04	104601.93	1083.37	64279.68	6394.67	113.34
7	21	77.58	28.85	9.58	4301.54	237679.33	1909.89	110245.04	1092.94	67529.77	6502.04	107.37
6	18	73.68	27.17	8.21	4375.23	250583.97	1937.06	115974.71	1101.15	70808.60	6603.39	101.35
5	15	69.73	25.50	6.84	4444.96	263709.65	1962.55	121785.88	1107.99	74112.04	6698.68	95.29
4	12	65.73	23.84	5.47	4510.70	277044.54	1986.39	127673.55	1113.46	77436.00	6787.87	89.19
3	9	61.70	22.19	4.10	4572.40	290576.62	2008.58	133632.72	1117.56	80776.38	6870.95	83.08
2	6	57.64	20.56	2.74	4630.04	304293.81	2029.15	139658.46	1120.30	84129.07	6947.90	76.95
1	3	53.57	18.96	1.37	4683.60	318183.93	2048.11	145745.90	1121.67	87489.96	7018.74	70.84
0	0	0.00	9.41	0.00	4683.60	332234.74	2057.51	151890.22	1121.67	90854.96	**7027.00**	8.25

CALCULATION OF 50 STOREY BUILDING

Calculation of DGLF Method

Location of building : Mumbai

Plan Dimensions of building w =24 m; d= 24 m

Wind Zone Z= III

Basic Wind Speed Vb =44 m/s

Average storey height h= 3 m

Frame spacing in X-Direction sx= 8 m

Frame spacing in Y-Direction sy= 8 m

Number of storeys n =50 nos.

Total height of the building H= 150 m

Aspect ratio h/d =6.25

Table A.32: Wind Parameters-50 Storey

Risk coefficient factor, k1	k1	1	
Topography factor, k3	k3	1	
Importance factor, k4	k4	1	
Wind directionality factor, Kd	kd	0.9	
Area averaging factor, Ka	ka	1	
Combination Factor, Kc	kc	1	
Design wind speed, Vz = k1 k2 k3 k4 Vb	Vz	44	*k2 m/s
Wind pressure at height ,z pz = $0.6Vz^2$	pz	1161.6	*k2 N/m^2
Design wind pressure , pd = ka kd kc pz	pd	1045.44	*k2 N/m^2

Table A.33: Calculation of Design Pressures in X- and Y- Direction-50 Storey

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
0	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
3	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
6	1.010	0.740	44.422	32.542	1.184	0.635	1.066	0.572
9	1.045	0.765	45.999	33.668	1.270	0.680	1.143	0.612
12	1.071	0.790	47.118	34.751	1.332	0.725	1.199	0.652
15	1.091	0.813	47.986	35.792	1.382	0.769	1.243	0.692
18	1.107	0.836	48.695	36.793	1.423	0.812	1.280	0.731
21	1.120	0.858	49.295	37.754	1.458	0.855	1.312	0.770
24	1.132	0.879	49.814	38.676	1.489	0.898	1.340	0.808

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
27	1.143	0.899	50.272	39.562	1.516	0.939	1.365	0.845
30	1.152	0.918	50.682	40.412	1.541	0.980	1.387	0.882
33	1.160	0.937	51.053	41.228	1.564	1.020	1.407	0.918
36	1.168	0.955	51.391	42.010	1.585	1.059	1.426	0.953
39	1.175	0.972	51.703	42.760	1.604	1.097	1.444	0.987
42	1.182	0.988	51.991	43.479	1.622	1.134	1.460	1.021
45	1.188	1.004	52.259	44.169	1.639	1.171	1.475	1.053
48	1.193	1.019	52.510	44.829	1.654	1.206	1.489	1.085
51	1.199	1.033	52.746	45.461	1.669	1.240	1.502	1.116
54	1.204	1.047	52.968	46.067	1.683	1.273	1.515	1.146
57	1.209	1.060	53.179	46.647	1.697	1.306	1.527	1.175
60	1.213	1.073	53.378	47.202	1.710	1.337	1.539	1.203
63	1.217	1.085	53.568	47.733	1.722	1.367	1.550	1.230
66	1.222	1.096	53.749	48.241	1.733	1.396	1.560	1.257
69	1.225	1.107	53.922	48.728	1.745	1.425	1.570	1.282
72	1.229	1.118	54.087	49.194	1.755	1.452	1.580	1.307
75	1.233	1.128	54.246	49.639	1.766	1.478	1.589	1.331
78	1.236	1.138	54.399	50.065	1.776	1.504	1.598	1.354
81	1.240	1.147	54.545	50.473	1.785	1.529	1.607	1.376
84	1.243	1.156	54.687	50.863	1.794	1.552	1.615	1.397
87	1.246	1.164	54.823	51.237	1.803	1.575	1.623	1.418
90	1.249	1.173	54.955	51.594	1.812	1.597	1.631	1.437
93	1.252	1.180	55.083	51.937	1.820	1.618	1.638	1.457
96	1.255	1.188	55.206	52.265	1.829	1.639	1.646	1.475
99	1.257	1.195	55.326	52.579	1.837	1.659	1.653	1.493
102	1.260	1.202	55.442	52.881	1.844	1.678	1.660	1.510
105	1.263	1.208	55.555	53.170	1.852	1.696	1.667	1.527
108	1.265	1.215	55.664	53.448	1.859	1.714	1.673	1.543
111	1.268	1.221	55.771	53.715	1.866	1.731	1.680	1.558
114	1.270	1.227	55.875	53.972	1.873	1.748	1.686	1.573
117	1.272	1.232	55.976	54.219	1.880	1.764	1.692	1.587
120	1.274	1.238	56.074	54.457	1.887	1.779	1.698	1.601
123	1.277	1.243	56.170	54.688	1.893	1.794	1.704	1.615
126	1.279	1.248	56.264	54.910	1.899	1.809	1.709	1.628
129	1.281	1.253	56.356	55.125	1.906	1.823	1.715	1.641
132	1.283	1.258	56.445	55.334	1.912	1.837	1.720	1.653
135	1.285	1.262	56.532	55.537	1.918	1.851	1.726	1.666
138	1.287	1.267	56.618	55.734	1.923	1.864	1.731	1.677
141	1.289	1.271	56.701	55.926	1.929	1.877	1.736	1.689
144	1.291	1.275	56.783	56.114	1.935	1.889	1.741	1.700
147	1.292	1.280	56.864	56.298	1.940	1.902	1.746	1.712
150	1.294	1.284	56.942	56.479	1.945	1.914	1.751	1.723

Table A.34: Building Parameters in X- and Y- Direction-50 Storey

Total height of structure	h	150.000	m
Average breadth of the structure between heights 0 and h	boh	24.000	m
Depth of structure	d	24.000	m
Measure of integral turbulence length scale at height h = 100(h/10)$\hat{0}$.25	Lh	196.799	m
Time Period of building, T = 0.09h/$\sqrt{d}$	T	2.756	seconds
Fundamental natural frequency of the structure, fo = 1/T	fo	0.363	Hz
Ratio of structural damping to critical damping of the structure, β	β	0.020	

Table A.35: Calculation of Cdyn in X-Direction-50 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	1	
Peak Factor	gR	3.788	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.096	
Size Reduction factor	S	0.087	
Reduced Frequency	N	1.728	
Turbulence Spectrum	E	0.063	

Table A.36: Calculation of Cdyn in Y-Direction-50 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	4	
Peak Factor	gR	3.788	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.210	
Size Reduction factor	S	0.056	
Reduced Frequency	N	2.371	
Turbulence Spectrum	E	0.051	

Table A.37: Wind Forces in X- Direction-50 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.300	1.000	0.914	0.940	43.32	47.38
3	0.304	1.000	0.915	0.940	86.75	94.77
6	0.308	1.002	0.917	1.066	98.45	107.41
9	0.312	1.004	0.918	1.143	105.70	115.17
12	0.317	1.006	0.919	1.199	111.07	120.85
15	0.321	1.010	0.921	1.243	115.38	125.34
18	0.326	1.014	0.922	1.280	119.01	129.07
21	0.330	1.020	0.924	1.312	122.17	132.27
24	0.335	1.026	0.925	1.340	124.99	135.07
27	0.340	1.032	0.927	1.365	127.54	137.57
30	0.346	1.040	0.929	1.387	129.89	139.82
33	0.351	1.048	0.931	1.407	132.07	141.87
36	0.357	1.058	0.933	1.426	134.12	143.76
39	0.362	1.068	0.935	1.444	136.07	145.51
42	0.368	1.078	0.937	1.460	137.91	147.13
45	0.374	1.090	0.940	1.475	139.68	148.66
48	0.380	1.102	0.942	1.489	141.39	150.09
51	0.387	1.116	0.945	1.502	143.04	151.44
54	0.393	1.130	0.947	1.515	144.64	152.72
57	0.400	1.144	0.950	1.527	146.20	153.93
60	0.407	1.160	0.953	1.539	147.73	155.09
63	0.414	1.176	0.955	1.550	149.22	156.19
66	0.422	1.194	0.958	1.560	150.69	157.25

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
69	0.430	1.212	0.961	1.570	152.14	158.26
72	0.438	1.230	0.964	1.580	153.57	159.24
75	0.446	1.250	0.968	1.589	154.98	160.17
78	0.454	1.270	0.971	1.598	156.38	161.08
81	0.463	1.292	0.974	1.607	157.77	161.95
84	0.472	1.314	0.978	1.615	159.14	162.79
87	0.481	1.336	0.981	1.623	160.51	163.60
90	0.491	1.360	0.985	1.631	161.88	164.39
93	0.501	1.384	0.988	1.638	163.24	165.15
96	0.511	1.410	0.992	1.646	164.59	165.89
99	0.521	1.436	0.996	1.653	165.94	166.61
102	0.532	1.462	1.000	1.660	167.29	167.31
105	0.543	1.490	1.004	1.667	168.63	168.00
108	0.554	1.518	1.008	1.673	169.97	168.66
111	0.565	1.548	1.012	1.680	171.30	169.31
114	0.577	1.578	1.016	1.686	172.63	169.94
117	0.588	1.608	1.020	1.692	173.95	170.55
120	0.599	1.640	1.024	1.698	175.26	171.15
123	0.610	1.672	1.028	1.704	176.56	171.74
126	0.621	1.706	1.032	1.709	177.84	172.31
129	0.632	1.740	1.036	1.715	179.10	172.87
132	0.641	1.774	1.040	1.720	180.33	173.42
135	0.650	1.810	1.043	1.726	181.52	173.96
138	0.657	1.846	1.047	1.731	182.68	174.49
141	0.664	1.884	1.050	1.736	183.79	175.00
144	0.668	1.922	1.053	1.741	184.84	175.51
147	0.671	1.960	1.056	1.746	185.84	176.00
150	0.672	2.000	1.058	1.751	186.78	176.49
					7655.47	

Table A.38: Wind Forces in Y- Direction-50 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.300	1.000	0.812	0.531	21.75	26.78
3	0.304	1.000	0.814	0.531	43.60	53.57
6	0.308	1.002	0.816	0.572	47.03	57.64
9	0.312	1.004	0.818	0.612	50.46	61.70
12	0.317	1.006	0.820	0.652	53.90	65.73
15	0.321	1.010	0.822	0.692	57.33	69.73
18	0.326	1.014	0.824	0.731	60.74	73.68
21	0.330	1.020	0.827	0.770	64.14	77.58
24	0.335	1.026	0.829	0.808	67.52	81.42
27	0.340	1.032	0.832	0.845	70.87	85.20
30	0.346	1.040	0.835	0.882	74.18	88.90
33	0.351	1.048	0.837	0.918	77.47	92.52
36	0.357	1.058	0.840	0.953	80.71	96.07
39	0.362	1.068	0.843	0.987	83.92	99.53
42	0.368	1.078	0.846	1.021	87.08	102.90

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
45	0.374	1.090	0.849	1.053	90.20	106.19
48	0.380	1.102	0.853	1.085	93.28	109.39
51	0.387	1.116	0.856	1.116	96.31	112.50
54	0.393	1.130	0.860	1.146	99.30	115.51
57	0.400	1.144	0.863	1.175	102.25	118.44
60	0.407	1.160	0.867	1.203	105.14	121.27
63	0.414	1.176	0.871	1.230	108.00	124.02
66	0.422	1.194	0.875	1.257	110.81	126.68
69	0.430	1.212	0.879	1.282	113.58	129.24
72	0.438	1.230	0.883	1.307	116.31	131.73
75	0.446	1.250	0.887	1.331	118.99	134.12
78	0.454	1.270	0.892	1.354	121.64	136.43
81	0.463	1.292	0.896	1.376	124.25	138.67
84	0.472	1.314	0.901	1.397	126.82	140.82
87	0.481	1.336	0.905	1.418	129.36	142.89
90	0.491	1.360	0.910	1.437	131.86	144.90
93	0.501	1.384	0.915	1.457	134.34	146.83
96	0.511	1.410	0.920	1.475	136.78	148.69
99	0.521	1.436	0.925	1.493	139.19	150.48
102	0.532	1.462	0.930	1.510	141.58	152.21
105	0.543	1.490	0.935	1.527	143.93	153.88
108	0.554	1.518	0.941	1.543	146.26	155.50
111	0.565	1.548	0.946	1.558	148.56	157.05
114	0.577	1.578	0.951	1.573	150.83	158.56
117	0.588	1.608	0.957	1.587	153.07	160.01
120	0.599	1.640	0.962	1.601	155.28	161.42
123	0.610	1.672	0.967	1.615	157.45	162.79
126	0.621	1.706	0.972	1.628	159.57	164.12
129	0.632	1.740	0.977	1.641	161.65	165.41
132	0.641	1.774	0.982	1.653	163.68	166.66
135	0.650	1.810	0.987	1.666	165.63	167.89
138	0.657	1.846	0.991	1.677	167.52	169.08
141	0.664	1.884	0.995	1.689	169.32	170.25
144	0.668	1.922	0.998	1.700	171.02	171.40
147	0.671	1.960	1.001	1.712	172.63	172.52
150	0.672	2.000	1.003	1.723	174.13	173.63
					5303.88	

CALCULATION OF MGLF FORCES

Table A.39: Calculation of MGLF Forces in X- and Y Direction- 50 Storey

CALCULATION OF MGLF FORCES-X			
Terrain Category		I	
No. of Storeys	N	50	nos.
Peak Factor	gR	3.788	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.096	
Size Reduction factor	S	0.087	
Reduced Frequency	N	1.728	
Turbulence Spectrum	E	0.063	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	1006931.702	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	150.000	m
Storey Height	h	3.000	m
Mean BBM		176459.698	
Res. extreme BBM component	M_R	40083.340	kN-m
miϕiZi	miϕiZi	864450866.463	
CALCULATION OF MGLF FORCES-Y			
Terrain Category		IV	
No. of Storeys	N	50	nos.
Peak Factor	gR	3.788	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.210	
Size Reduction factor	S	0.056	
Reduced Frequency	N	2.371	
Turbulence Spectrum	E	0.051	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	1006931.702	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	150.000	m
Storey Height	h	3.000	m
Mean BBM		170792.134	
Res. extreme BBM component	M_R	41761.788	kN-m
miϕiZi	miϕiZi	864450866.463	

Table A.40: Wind Forces in X-Direction by MGLF Method-50Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
0	0	47.38	1.000	0.000	0.300	0.220	0.227	0.914	0.000	10.42	0.00	0.00
1	3	94.77	1.000	64.594	0.304	0.221	0.227	0.915	0.020	20.99	20138.63	1.37
2	6	107.41	1.002	146.510	0.308	0.223	0.227	0.917	0.040	23.95	80554.54	2.74
3	9	115.17	1.004	235.882	0.312	0.225	0.228	0.918	0.060	25.86	181247.71	4.11
4	12	120.85	1.006	330.457	0.317	0.226	0.228	0.919	0.080	27.32	322218.14	5.48
5	15	125.34	1.010	429.195	0.321	0.228	0.228	0.921	0.100	28.54	503465.85	6.85
6	18	129.07	1.014	531.523	0.326	0.229	0.229	0.922	0.120	29.60	724990.83	8.22
7	21	132.27	1.020	637.102	0.330	0.231	0.229	0.924	0.140	30.56	986793.07	9.59
8	24	135.07	1.026	745.725	0.335	0.233	0.230	0.925	0.160	31.44	1288872.58	10.96
9	27	137.57	1.032	857.270	0.340	0.235	0.231	0.927	0.180	32.26	1631229.36	12.33
10	30	139.82	1.040	971.672	0.346	0.236	0.232	0.929	0.200	33.04	2013863.40	13.70
11	33	141.87	1.048	1088.904	0.351	0.238	0.233	0.931	0.220	33.78	2436774.72	15.07
12	36	143.76	1.058	1208.967	0.357	0.240	0.234	0.933	0.240	34.50	2899963.30	16.44
13	39	145.51	1.068	1331.883	0.362	0.242	0.235	0.935	0.260	35.19	3403429.15	17.81
14	42	147.13	1.078	1457.691	0.368	0.244	0.236	0.937	0.280	35.87	3947172.27	19.18
15	45	148.66	1.090	1586.441	0.374	0.246	0.237	0.940	0.300	36.54	4531192.66	20.55
16	48	150.09	1.102	1718.190	0.380	0.248	0.238	0.942	0.320	37.20	5155490.32	21.92
17	51	151.44	1.116	1853.005	0.387	0.250	0.240	0.945	0.340	37.85	5820065.24	23.30
18	54	152.72	1.130	1990.956	0.393	0.252	0.241	0.947	0.360	38.49	6524917.43	24.67
19	57	153.93	1.144	2132.117	0.400	0.254	0.243	0.950	0.380	39.13	7270046.89	26.04
20	60	155.09	1.160	2276.565	0.407	0.256	0.245	0.953	0.400	39.77	8055453.62	27.41
21	63	156.19	1.176	2424.379	0.414	0.259	0.246	0.955	0.420	40.41	8881137.61	28.78
22	66	157.25	1.194	2575.638	0.422	0.261	0.248	0.958	0.440	41.05	9747098.88	30.15
23	69	158.26	1.212	2730.422	0.430	0.263	0.250	0.961	0.460	41.69	10653337.41	31.52
24	72	159.24	1.230	2888.812	0.438	0.266	0.252	0.964	0.480	42.34	11599853.21	32.89
25	75	160.17	1.250	3050.886	0.446	0.268	0.254	0.968	0.500	42.98	12586646.28	34.26
26	78	161.08	1.270	3216.724	0.454	0.271	0.256	0.971	0.520	43.64	13613716.62	35.63
27	81	161.95	1.292	3386.404	0.463	0.274	0.258	0.974	0.540	44.29	14681064.22	37.00
28	84	162.79	1.314	3560.002	0.472	0.276	0.260	0.978	0.560	44.96	15788689.09	38.37
29	87	163.60	1.336	3737.593	0.481	0.279	0.263	0.981	0.580	45.62	16936591.23	39.74
30	90	164.39	1.360	3919.252	0.491	0.282	0.265	0.985	0.600	46.30	18124770.64	41.11
31	93	165.15	1.384	4105.050	0.501	0.284	0.267	0.988	0.620	46.98	19353227.32	42.48
32	96	165.89	1.410	4295.057	0.511	0.287	0.270	0.992	0.640	47.66	20621961.26	43.85
33	99	166.61	1.436	4489.343	0.521	0.290	0.272	0.996	0.660	48.36	21930972.48	45.22
34	102	167.31	1.462	4687.974	0.532	0.293	0.275	1.000	0.680	49.05	23280260.96	46.59
35	105	168.00	1.490	4891.015	0.543	0.296	0.277	1.004	0.700	49.75	24669826.71	47.96

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
36	108	168.66	1.518	5098.529	0.554	0.299	0.280	1.008	0.720	50.46	26099669.72	49.33
37	111	169.31	1.548	5310.577	0.565	0.302	0.283	1.012	0.740	51.16	27569790.01	50.70
38	114	169.94	1.578	5527.219	0.577	0.305	0.285	1.016	0.760	51.86	29080187.56	52.07
39	117	170.55	1.608	5748.512	0.588	0.308	0.288	1.020	0.780	52.56	30630862.39	53.44
40	120	171.15	1.640	5974.512	0.599	0.311	0.291	1.024	0.800	53.25	32221814.48	54.81
41	123	171.74	1.672	6205.273	0.610	0.314	0.294	1.028	0.820	53.93	33853043.83	56.18
42	126	172.31	1.706	6440.848	0.621	0.317	0.297	1.032	0.840	54.58	35524550.46	57.55
43	129	172.87	1.740	6681.286	0.632	0.319	0.300	1.036	0.860	55.21	37236334.35	58.92
44	132	173.42	1.774	6926.638	0.641	0.322	0.303	1.040	0.880	55.81	38988395.51	60.29
45	135	173.96	1.810	7176.950	0.650	0.324	0.306	1.043	0.900	56.36	40780733.94	61.66
46	138	174.49	1.846	7432.267	0.657	0.326	0.309	1.047	0.920	56.86	42613349.64	63.03
47	141	175.00	1.884	7692.636	0.664	0.327	0.312	1.050	0.940	57.30	44486242.61	64.40
48	144	175.51	1.922	7958.097	0.668	0.329	0.315	1.053	0.960	57.67	46399412.84	65.77
49	147	176.00	1.960	8228.693	0.671	0.329	0.318	1.056	0.980	57.95	48352860.35	67.14
50	150	176.49	2.000	8504.463	0.672	0.330	0.321	1.058	1.000	58.15	50346585.12	68.51

Table A.41: Wind Forces in Y-Direction by MGLF Method-50Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
1	3	53.57	1.000	39.302	0.304	0.328	0.245	0.814	0.020	17.57	20138.63	1.33
2	6	57.64	1.002	84.634	0.308	0.330	0.245	0.816	0.040	19.03	80554.54	2.65
3	9	61.70	1.004	136.027	0.312	0.332	0.245	0.818	0.060	20.51	181247.71	3.98
4	12	65.73	1.006	193.496	0.317	0.335	0.245	0.820	0.080	22.01	322218.14	5.31
5	15	69.73	1.010	257.037	0.321	0.337	0.246	0.822	0.100	23.51	503465.85	6.63
6	18	73.68	1.014	326.636	0.326	0.340	0.246	0.824	0.120	25.03	724990.83	7.96
7	21	77.58	1.020	402.267	0.330	0.342	0.247	0.827	0.140	26.54	986793.07	9.28
8	24	81.42	1.026	483.900	0.335	0.345	0.248	0.829	0.160	28.06	1288872.58	10.61
9	27	85.20	1.032	571.496	0.340	0.347	0.248	0.832	0.180	29.58	1631229.36	11.94
10	30	88.90	1.040	665.014	0.346	0.350	0.249	0.835	0.200	31.10	2013863.40	13.26
11	33	92.52	1.048	764.411	0.351	0.353	0.250	0.837	0.220	32.62	2436774.72	14.59
12	36	96.07	1.058	869.641	0.357	0.355	0.251	0.840	0.240	34.14	2899963.30	15.92
13	39	99.53	1.068	980.660	0.362	0.358	0.253	0.843	0.260	35.65	3403429.15	17.24
14	42	102.90	1.078	1097.422	0.368	0.361	0.254	0.846	0.280	37.15	3947172.27	18.57
15	45	106.19	1.090	1219.884	0.374	0.364	0.255	0.849	0.300	38.65	4531192.66	19.89
16	48	109.39	1.102	1348.003	0.380	0.367	0.257	0.853	0.320	40.15	5155490.32	21.22
17	51	112.50	1.116	1481.741	0.387	0.370	0.258	0.856	0.340	41.63	5820065.24	22.55
18	54	115.51	1.130	1621.058	0.393	0.373	0.260	0.860	0.360	43.11	6524917.43	23.87

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
19	57	118.44	1.144	1765.920	0.400	0.376	0.262	0.863	0.380	44.59	7270046.89	25.20
20	60	121.27	1.160	1916.295	0.407	0.380	0.263	0.867	0.400	46.05	8055453.62	26.53
21	63	124.02	1.176	2072.153	0.414	0.383	0.265	0.871	0.420	47.51	8881137.61	27.85
22	66	126.68	1.194	2233.470	0.422	0.387	0.267	0.875	0.440	48.97	9747098.88	29.18
23	69	129.24	1.212	2400.222	0.430	0.390	0.269	0.879	0.460	50.42	10653337.41	30.50
24	72	131.73	1.230	2572.390	0.438	0.394	0.271	0.883	0.480	51.86	11599853.21	31.83
25	75	134.12	1.250	2749.961	0.446	0.397	0.273	0.887	0.500	53.30	12586646.28	33.16
26	78	136.43	1.270	2932.923	0.454	0.401	0.276	0.892	0.520	54.73	13613716.62	34.48
27	81	138.67	1.292	3121.269	0.463	0.405	0.278	0.896	0.540	56.16	14681064.22	35.81
28	84	140.82	1.314	3314.997	0.472	0.409	0.280	0.901	0.560	57.58	15788689.09	37.14
29	87	142.89	1.336	3514.110	0.481	0.413	0.283	0.905	0.580	59.01	16936591.23	38.46
30	90	144.90	1.360	3718.614	0.491	0.417	0.285	0.910	0.600	60.43	18124770.64	39.79
31	93	146.83	1.384	3928.522	0.501	0.421	0.288	0.915	0.620	61.84	19353227.32	41.11
32	96	148.69	1.410	4143.851	0.511	0.425	0.290	0.920	0.640	63.26	20621961.26	42.44
33	99	150.48	1.436	4364.625	0.521	0.430	0.293	0.925	0.660	64.67	21930972.48	43.77
34	102	152.21	1.462	4590.871	0.532	0.434	0.296	0.930	0.680	66.08	23280260.96	45.09
35	105	153.88	1.490	4822.626	0.543	0.439	0.298	0.935	0.700	67.48	24669826.71	46.42
36	108	155.50	1.518	5059.932	0.554	0.443	0.301	0.941	0.720	68.88	26099669.72	47.75
37	111	157.05	1.548	5302.835	0.565	0.447	0.304	0.946	0.740	70.27	27569790.01	49.07
38	114	158.56	1.578	5551.392	0.577	0.452	0.307	0.951	0.760	71.66	29080187.56	50.40
39	117	160.01	1.608	5805.666	0.588	0.456	0.310	0.957	0.780	73.02	30630862.39	51.73
40	120	161.42	1.640	6065.726	0.599	0.461	0.313	0.962	0.800	74.37	32221814.48	53.05
41	123	162.79	1.672	6331.652	0.610	0.465	0.316	0.967	0.820	75.69	33853043.83	54.38
42	126	164.12	1.706	6603.530	0.621	0.469	0.319	0.972	0.840	76.98	35524550.46	55.70
43	129	165.41	1.740	6881.456	0.632	0.473	0.323	0.977	0.860	78.23	37236334.35	57.03
44	132	166.66	1.774	7165.534	0.641	0.477	0.326	0.982	0.880	79.42	38988395.51	58.36
45	135	167.89	1.810	7455.878	0.650	0.480	0.329	0.987	0.900	80.55	40780733.94	59.68
46	138	169.08	1.846	7752.612	0.657	0.483	0.332	0.991	0.920	81.59	42613349.64	61.01
47	141	170.25	1.884	8055.869	0.664	0.485	0.336	0.995	0.940	82.54	44486242.61	62.34
48	144	171.40	1.922	8365.793	0.668	0.487	0.339	0.998	0.960	83.39	46399412.84	63.66
49	147	172.52	1.960	8682.538	0.671	0.488	0.342	1.001	0.980	84.12	48352860.35	64.99
50	150	173.63	2.000	9006.271	0.672	0.488	0.346	1.003	1.000	84.72	50346585.12	66.31

Table A.42: Calculation of Single Lateral Force for Design Input in X- Direction-50 Storey

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
50	150	176.49	58.15	68.51	176.49	0.00	58.15	0.00	68.51	0.00	266.36	266.36
49	147	176.00	57.95	67.14	352.49	529.47	116.11	174.46	135.66	205.54	531.06	264.70
48	144	175.51	57.67	65.77	528.00	1586.96	173.77	522.78	201.43	612.52	794.03	262.98
47	141	175.00	57.30	64.40	703.01	3170.97	231.07	1044.10	265.84	1216.82	1055.23	261.20
46	138	174.49	56.86	63.03	877.49	5279.98	287.94	1737.32	328.87	2014.33	1314.60	259.37
45	135	173.96	56.36	61.66	1051.45	7912.46	344.30	2601.13	390.53	3000.95	1572.08	257.49
44	132	173.42	55.81	60.29	1224.87	11066.81	400.11	3634.03	450.83	4172.55	1827.64	255.56
43	129	172.87	55.21	58.92	1397.75	14741.43	455.33	4834.36	509.75	5525.03	2081.24	253.60
42	126	172.31	54.58	57.55	1570.06	18934.67	509.91	6200.34	567.30	7054.28	2332.84	251.60
41	123	171.74	53.93	56.18	1741.80	23644.84	563.84	7730.07	623.48	8756.18	2582.42	249.58
40	120	171.15	53.25	54.81	1912.95	28870.23	617.09	9421.58	678.30	10626.64	2829.95	247.53
39	117	170.55	52.56	53.44	2083.50	34609.07	669.65	11272.85	731.74	12661.52	3075.40	245.46
38	114	169.94	51.86	52.07	2253.43	40859.57	721.51	13281.80	783.81	14856.73	3318.77	243.37
37	111	169.31	51.16	50.70	2422.74	47619.87	772.67	15446.34	834.51	17208.16	3560.03	241.26
36	108	168.66	50.46	49.33	2591.40	54888.09	823.13	17764.37	883.84	19711.69	3799.17	239.14
35	105	168.00	49.75	47.96	2759.39	62662.29	872.88	20233.76	931.80	22363.21	4036.18	237.01
34	102	167.31	49.05	46.59	2926.71	70940.48	921.94	22852.41	978.39	25158.61	4271.04	234.86
33	99	166.61	48.36	45.22	3093.32	79720.61	970.29	25618.22	1023.61	28093.78	4503.73	232.69
32	96	165.89	47.66	43.85	3259.22	89000.58	1017.95	28529.09	1067.46	31164.61	4734.24	230.52
31	93	165.15	46.98	42.48	3424.37	98778.23	1064.93	31582.96	1109.94	34366.99	4962.57	228.32
30	90	164.39	46.30	41.11	3588.76	109051.34	1111.23	34777.75	1151.05	37696.81	5188.68	226.11
29	87	163.60	45.62	39.74	3752.36	119817.62	1156.85	38111.44	1190.79	41149.95	5412.57	223.89
28	84	162.79	44.96	38.37	3915.15	131074.71	1201.81	41581.99	1229.15	44722.31	5634.21	221.64
27	81	161.95	44.29	37.00	4077.10	142820.15	1246.10	45187.42	1266.15	48409.77	5853.58	219.38
26	78	161.08	43.64	35.63	4238.17	155051.44	1289.74	48925.71	1301.78	52208.23	6070.67	217.09

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
25	75	160.17	42.98	34.26	4398.34	167765.95	1332.72	52794.92	1336.04	56113.57	6285.44	214.77
24	72	159.24	42.34	32.89	4557.58	180960.99	1375.06	56793.08	1368.92	60121.68	6497.87	212.43
23	69	158.26	41.69	31.52	4715.85	194633.73	1416.75	60918.25	1400.44	64228.45	6707.93	210.06
22	66	157.25	41.05	30.15	4873.10	208781.27	1457.80	65168.50	1430.59	68429.78	6915.59	207.65
21	63	156.19	40.41	28.78	5029.29	223400.56	1498.21	69541.90	1459.36	72721.54	7120.79	205.21
20	60	155.09	39.77	27.41	5184.38	238488.44	1537.99	74036.54	1486.77	77099.63	7323.51	202.72
19	57	153.93	39.13	26.04	5338.31	254041.58	1577.12	78650.50	1512.81	81559.94	7523.69	200.18
18	54	152.72	38.49	24.67	5491.03	270056.52	1615.61	83381.85	1537.47	86098.36	7721.28	197.59
17	51	151.44	37.85	23.30	5642.47	286529.60	1653.46	88228.69	1560.77	90710.77	7916.21	194.93
16	48	150.09	37.20	21.92	5792.55	303457.01	1690.66	93189.08	1582.69	95393.06	8108.42	192.21
15	45	148.66	36.54	20.55	5941.21	320834.67	1727.20	98261.06	1603.24	100141.14	8297.82	189.40
14	42	147.13	35.87	19.18	6088.34	338658.29	1763.08	103442.67	1622.43	104950.87	8484.32	186.50
13	39	145.51	35.19	17.81	6233.85	356923.32	1798.27	108731.90	1640.24	109818.16	8667.81	183.49
12	36	143.76	34.50	16.44	6377.60	375624.85	1832.77	114126.71	1656.69	114738.88	8848.16	180.35
11	33	141.87	33.78	15.07	6519.48	394757.67	1866.55	119625.02	1671.76	119708.94	9025.23	177.07
10	30	139.82	33.04	13.70	6659.29	414316.09	1899.59	125224.68	1685.46	124724.22	9198.83	173.60
9	27	137.57	32.26	12.33	6796.86	434293.98	1931.85	130923.44	1697.80	129780.61	9368.74	169.91
8	24	135.07	31.44	10.96	6931.93	454684.56	1963.29	136718.99	1708.76	134873.99	9534.69	165.95
7	21	132.27	30.56	9.59	7064.20	475480.35	1993.85	142608.85	1718.35	140000.27	9696.34	161.65
6	18	129.07	29.60	8.22	7193.27	496672.94	2023.45	148590.39	1726.57	145155.32	9853.23	156.90
5	15	125.34	28.54	6.85	7318.61	518252.75	2051.99	154660.75	1733.42	150335.03	10004.76	151.53
4	12	120.85	27.32	5.48	7439.45	540208.57	2079.32	160816.73	1738.90	155535.30	10150.05	145.29
3	9	115.17	25.86	4.11	7554.63	562526.93	2105.18	167054.68	1743.01	160752.01	10287.73	137.68
2	6	107.41	23.95	2.74	7662.04	585190.81	2129.13	173370.22	1745.76	165981.05	10415.37	127.64
1	3	94.77	20.99	1.37	7756.81	608176.92	2150.12	179757.61	1747.13	171218.32	10527.27	111.90
0	0	47.38	10.42	0.00	7804.19	631447.34	2160.54	186207.96	1747.13	176459.70	**10582.75**	55.48

Table A.43: Calculation of Single Lateral Force for Design Input in Y- Direction-50 Storey

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
50	150	173.63	84.72	66.31	173.63	0.00	84.72	0.00	66.31	0.00	281.22	281.22
49	147	172.52	84.12	64.99	346.15	520.89	168.83	254.15	131.30	198.94	560.03	278.82
48	144	171.40	83.39	63.66	517.55	1559.35	252.22	760.66	194.96	592.85	836.34	276.31
47	141	170.25	82.54	62.34	687.80	3112.00	334.77	1517.33	257.30	1177.74	1110.02	273.68
46	138	169.08	81.59	61.01	856.88	5175.41	416.36	2521.63	318.31	1949.64	1380.98	270.95
45	135	167.89	80.55	59.68	1024.77	7746.05	496.91	3770.72	377.99	2904.56	1649.10	268.13
44	132	166.66	79.42	58.36	1191.43	10820.35	576.33	5261.45	436.35	4038.53	1914.31	265.21
43	129	165.41	78.23	57.03	1356.84	14394.64	654.56	6990.44	493.38	5347.57	2176.51	262.20
42	126	164.12	76.98	55.70	1520.95	18465.15	731.54	8954.12	549.08	6827.71	2435.64	259.12
41	123	162.79	75.69	54.38	1683.75	23028.02	807.24	11148.75	603.46	8474.95	2691.61	255.97
40	120	161.42	74.37	53.05	1845.17	28079.26	881.61	13570.47	656.51	10285.33	2944.37	252.76
39	117	160.01	73.02	51.73	2005.18	33614.77	954.63	16215.29	708.24	12254.86	3193.85	249.48
38	114	158.56	71.66	50.40	2163.74	39630.32	1026.29	19079.19	758.63	14379.56	3439.98	246.14
37	111	157.05	70.27	49.07	2320.79	46121.54	1096.56	22158.05	807.71	16655.47	3682.72	242.74
36	108	155.50	68.88	47.75	2476.29	53083.93	1165.45	25447.74	855.45	19078.59	3921.99	239.27
35	105	153.88	67.48	46.42	2630.17	60512.80	1232.93	28944.08	901.87	21644.94	4157.75	235.75
34	102	152.21	66.08	45.09	2782.38	68403.31	1299.01	32642.86	946.97	24350.56	4389.92	232.17
33	99	150.48	64.67	43.77	2932.87	76750.47	1363.68	36539.89	990.73	27191.46	4618.44	228.52
32	96	148.69	63.26	42.44	3081.55	85549.06	1426.93	40630.92	1033.17	30163.66	4843.26	224.81
31	93	146.83	61.84	41.11	3228.38	94793.73	1488.78	44911.72	1074.29	33263.19	5064.29	221.03
30	90	144.90	60.43	39.79	3373.28	104478.87	1549.20	49378.06	1114.08	36486.05	5281.47	217.18
29	87	142.89	59.01	38.46	3516.17	114598.70	1608.21	54025.67	1152.54	39828.29	5494.73	213.26
28	84	140.82	57.58	37.14	3656.99	125147.21	1665.80	58850.30	1189.68	43285.91	5703.99	209.26
27	81	138.67	56.16	35.81	3795.66	136118.18	1721.96	63847.69	1225.49	46854.94	5909.17	205.18
26	78	136.43	54.73	34.48	3932.09	147505.15	1776.69	69013.56	1259.97	50531.39	6110.19	201.02

Storey	Height	Pmean	Pbi	Pri	Vmean	Mean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
25	75	134.12	53.30	33.16	4066.21	159301.43	1829.98	74343.61	1293.13	54311.30	6306.97	196.78
24	72	131.73	51.86	31.83	4197.94	171500.06	1881.84	79833.56	1324.96	58190.68	6499.42	192.45
23	69	129.24	50.42	30.50	4327.18	184093.88	1932.26	85479.08	1355.46	62165.55	6687.46	188.03
22	66	126.68	48.97	29.18	4453.86	197075.43	1981.23	91275.86	1384.64	66231.94	6870.98	183.53
21	63	124.02	47.51	27.85	4577.88	210437.01	2028.74	97219.54	1412.49	70385.86	7049.91	178.92
20	60	121.27	46.05	26.53	4699.15	224170.65	2074.80	103305.77	1439.02	74623.33	7224.14	174.23
19	57	118.44	44.59	25.20	4817.59	238268.11	2119.38	109530.15	1464.22	78940.38	7393.58	169.44
18	54	115.51	43.11	23.87	4933.11	252720.89	2162.50	115888.30	1488.09	83333.03	7558.14	164.56
17	51	112.50	41.63	22.55	5045.60	267520.21	2204.13	122375.79	1510.64	87797.30	7717.72	159.58
16	48	109.39	40.15	21.22	5154.99	282657.02	2244.28	128988.18	1531.86	92329.21	7872.22	154.50
15	45	106.19	38.65	19.89	5261.18	298121.99	2282.93	135721.01	1551.75	96924.78	8021.56	149.33
14	42	102.90	37.15	18.57	5364.08	313905.53	2320.08	142569.79	1570.32	101580.04	8165.63	144.07
13	39	99.53	35.65	17.24	5463.61	329997.78	2355.73	149530.03	1587.56	106291.00	8304.35	138.72
12	36	96.07	34.14	15.92	5559.67	346388.60	2389.86	156597.22	1603.48	111053.68	8437.62	133.27
11	33	92.52	32.62	14.59	5652.19	363067.62	2422.49	163766.81	1618.07	115864.11	8565.37	127.74
10	30	88.90	31.10	13.26	5741.09	380024.20	2453.59	171034.27	1631.33	120718.31	8687.50	122.13
9	27	85.20	29.58	11.94	5826.28	397247.47	2483.17	178395.05	1643.27	125612.29	8803.95	116.45
8	24	81.42	28.06	10.61	5907.71	414726.33	2511.24	185844.57	1653.88	130542.09	8914.64	110.69
7	21	77.58	26.54	9.28	5985.29	432449.45	2537.78	193378.28	1663.16	135503.71	9019.50	104.86
6	18	73.68	25.03	7.96	6058.98	450405.32	2562.81	200991.62	1671.12	140493.19	9118.49	98.99
5	15	69.73	23.51	6.63	6128.71	468582.25	2586.32	208680.04	1677.75	145506.54	9211.55	93.06
4	12	65.73	22.01	5.31	6194.44	486968.37	2608.33	216439.00	1683.05	150539.79	9298.64	87.10
3	9	61.70	20.51	3.98	6256.14	505551.69	2628.84	224263.98	1687.03	155588.95	9379.75	81.11
2	6	57.64	19.03	2.65	6313.78	524320.12	2647.88	232150.52	1689.68	160650.05	9454.85	75.10
1	3	53.57	17.57	1.33	6367.35	543261.47	2665.44	240094.15	1691.01	165719.10	9523.95	69.10
0	0	26.78	8.72	0.00	6394.13	562363.52	2674.17	248090.48	1691.01	170792.13	**9558.10**	34.15

CALCULATION OF 60 STOREY BUILDING

Calculation of DGLF Method

CALCULATION OF WIND LOAD: Location of building : Mumbai

Plan Dimensions of building w =24 m

d =24 m

Wind Zone Z =III

Basic Wind Speed Vb =44 m/s

Average storey height h =3 m

Frame spacing in X-Direction sx= 8 m

Frame spacing in Y-Direction sy =8 m

Number of storeys n =60 nos.

Total height of the building H =180 m

Aspect ratio h/d= 7.5

Table A.44: Wind Parameters - 40 Storey

Risk coefficient factor, k1	k1	1	
Topography factor, k3	k3	1	
Importance factor, k4	k4	1	
Wind directionality factor, Kd	kd	0.9	
Area averaging factor, Ka	ka	1	
Combination Factor, Kc	kc	1	
Design wind speed, Vz = k1 k2 k3 k4 Vb	Vz	44	*k2 m/s
Wind pressure at height ,z pz = 0.6*vz$\hat{2}$	pz	1161.6	*k2 N/m2
Design wind pressure , pd = ka kd kc pz	pd	1045.44	*k2 N/m2

Table A.45: Calculation of Design Pressures in X- and Y- Direction-40 Storey

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
0	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
3	0.948	0.713	41.726	31.370	1.045	0.590	0.940	0.531
6	1.010	0.740	44.422	32.542	1.184	0.635	1.066	0.572
9	1.045	0.765	45.999	33.668	1.270	0.680	1.143	0.612
12	1.071	0.790	47.118	34.751	1.332	0.725	1.199	0.652
15	1.091	0.813	47.986	35.792	1.382	0.769	1.243	0.692
18	1.107	0.836	48.695	36.793	1.423	0.812	1.280	0.731

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
21	1.120	0.858	49.295	37.754	1.458	0.855	1.312	0.770
24	1.132	0.879	49.814	38.676	1.489	0.898	1.340	0.808
27	1.143	0.899	50.272	39.562	1.516	0.939	1.365	0.845
30	1.152	0.918	50.682	40.412	1.541	0.980	1.387	0.882
33	1.160	0.937	51.053	41.228	1.564	1.020	1.407	0.918
36	1.168	0.955	51.391	42.010	1.585	1.059	1.426	0.953
39	1.175	0.972	51.703	42.760	1.604	1.097	1.444	0.987
42	1.182	0.988	51.991	43.479	1.622	1.134	1.460	1.021
45	1.188	1.004	52.259	44.169	1.639	1.171	1.475	1.053
48	1.193	1.019	52.510	44.829	1.654	1.206	1.489	1.085
51	1.199	1.033	52.746	45.461	1.669	1.240	1.502	1.116
54	1.204	1.047	52.968	46.067	1.683	1.273	1.515	1.146
57	1.209	1.060	53.179	46.647	1.697	1.306	1.527	1.175
60	1.213	1.073	53.378	47.202	1.710	1.337	1.539	1.203
63	1.217	1.085	53.568	47.733	1.722	1.367	1.550	1.230
66	1.222	1.096	53.749	48.241	1.733	1.396	1.560	1.257
69	1.225	1.107	53.922	48.728	1.745	1.425	1.570	1.282
72	1.229	1.118	54.087	49.194	1.755	1.452	1.580	1.307
75	1.233	1.128	54.246	49.639	1.766	1.478	1.589	1.331
78	1.236	1.138	54.399	50.065	1.776	1.504	1.598	1.354
81	1.240	1.147	54.545	50.473	1.785	1.529	1.607	1.376
84	1.243	1.156	54.687	50.863	1.794	1.552	1.615	1.397
87	1.246	1.164	54.823	51.237	1.803	1.575	1.623	1.418
90	1.249	1.173	54.955	51.594	1.812	1.597	1.631	1.437
93	1.252	1.180	55.083	51.937	1.820	1.618	1.638	1.457
96	1.255	1.188	55.206	52.265	1.829	1.639	1.646	1.475
99	1.257	1.195	55.326	52.579	1.837	1.659	1.653	1.493
102	1.260	1.202	55.442	52.881	1.844	1.678	1.660	1.510
105	1.263	1.208	55.555	53.170	1.852	1.696	1.667	1.527
108	1.265	1.215	55.664	53.448	1.859	1.714	1.673	1.543
111	1.268	1.221	55.771	53.715	1.866	1.731	1.680	1.558
114	1.270	1.227	55.875	53.972	1.873	1.748	1.686	1.573
117	1.272	1.232	55.976	54.219	1.880	1.764	1.692	1.587
120	1.274	1.238	56.074	54.457	1.887	1.779	1.698	1.601
123	1.277	1.243	56.170	54.688	1.893	1.794	1.704	1.615
126	1.279	1.248	56.264	54.910	1.899	1.809	1.709	1.628
129	1.281	1.253	56.356	55.125	1.906	1.823	1.715	1.641
132	1.283	1.258	56.445	55.334	1.912	1.837	1.720	1.653
135	1.285	1.262	56.532	55.537	1.918	1.851	1.726	1.666
138	1.287	1.267	56.618	55.734	1.923	1.864	1.731	1.677
141	1.289	1.271	56.701	55.926	1.929	1.877	1.736	1.689
144	1.291	1.275	56.783	56.114	1.935	1.889	1.741	1.700
147	1.292	1.280	56.864	56.298	1.940	1.902	1.746	1.712
150	1.294	1.284	56.942	56.479	1.945	1.914	1.751	1.723
153	1.296	1.288	57.019	56.657	1.951	1.926	1.756	1.733

Height	k2		Vz(m/s)		pz(kN/m^2)		pd(kN/m^2)	
Category	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4	sea face 1	other face 4
156	1.298	1.292	57.095	56.832	1.956	1.938	1.760	1.744
159	1.299	1.296	57.169	57.005	1.961	1.950	1.765	1.755
162	1.301	1.299	57.242	57.176	1.966	1.961	1.769	1.765
165	1.303	1.303	57.313	57.346	1.971	1.973	1.774	1.776
168	1.304	1.307	57.383	57.516	1.976	1.985	1.778	1.786
171	1.306	1.311	57.452	57.685	1.980	1.997	1.782	1.797
174	1.307	1.315	57.519	57.854	1.985	2.008	1.787	1.807
177	1.309	1.319	57.586	58.023	1.990	2.020	1.791	1.818
180	1.310	1.323	57.651	58.193	1.994	2.032	1.795	1.829

Table A.46: Building Parameters in X- and Y- Direction-60 Storey

Total height of structure	h	180.000	m
Average breadth of the structure between heights 0 and h	boh	24.000	m
Depth of structure	d	24.000	m
Measure of integral turbulence length scale at height h = 100(h/10)$\hat{0}$.25	Lh	205.977	m
Time Period of building, T = 0.09h/sqrt(d)	T	3.307	seconds
Fundamental natural frequency of the structure, fo = 1/T	fo	0.302	Hz
Ratio of structural damping to critical damping of the structure,		0.020	

Table A.47: Calculation of Cdyn in X-Direction-60 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	1	
Peak Factor	gR	3.740	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.091	
Size Reduction factor	S	0.095	
Reduced Frequency	N	1.488	
Turbulence Spectrum	E	0.070	

Table A.48: Calculation of Cdyn in Y-Direction-60 Storey

Average breadth of structure between height s and h	bsh	24	m
Terrain Category	Category	4	
Peak Factor	gR	3.740	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.199	
Size Reduction factor	S	0.064	
Reduced Frequency	N	2.022	
Turbulence Spectrum	E	0.057	

Table A.49: Wind Forces in X- Direction-60 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.273	1.000	0.925	0.940	50.08	54.15
3	0.276	1.000	0.926	0.940	100.26	108.31
6	0.280	1.001	0.927	1.066	113.74	122.76
9	0.283	1.003	0.927	1.143	122.08	131.63
12	0.286	1.004	0.928	1.199	128.23	138.11
15	0.290	1.007	0.930	1.243	133.15	143.24
18	0.294	1.010	0.931	1.280	137.29	147.51
21	0.297	1.014	0.932	1.312	140.87	151.16
24	0.301	1.018	0.933	1.340	144.05	154.37
27	0.305	1.023	0.935	1.365	146.92	157.22
30	0.309	1.028	0.936	1.387	149.55	159.79
33	0.313	1.034	0.937	1.407	151.99	162.14
36	0.318	1.040	0.939	1.426	154.26	164.30
39	0.322	1.047	0.941	1.444	156.41	166.29
42	0.326	1.054	0.942	1.460	158.44	168.15
45	0.331	1.063	0.944	1.475	160.37	169.89
48	0.336	1.071	0.946	1.489	162.23	171.53
51	0.341	1.080	0.948	1.502	164.01	173.07
54	0.346	1.090	0.950	1.515	165.74	174.53
57	0.351	1.100	0.952	1.527	167.41	175.92
60	0.356	1.111	0.954	1.539	169.04	177.24
63	0.361	1.123	0.956	1.550	170.62	178.51
66	0.367	1.134	0.958	1.560	172.17	179.72
69	0.373	1.147	0.960	1.570	173.70	180.87
72	0.379	1.160	0.963	1.580	175.19	181.99
75	0.385	1.174	0.965	1.589	176.66	183.06
78	0.391	1.188	0.968	1.598	178.11	184.09
81	0.398	1.203	0.970	1.607	179.55	185.08
84	0.404	1.218	0.973	1.615	180.97	186.04
87	0.411	1.234	0.975	1.623	182.37	186.97
90	0.418	1.250	0.978	1.631	183.77	187.87
93	0.426	1.267	0.981	1.638	185.15	188.75
96	0.433	1.284	0.984	1.646	186.53	189.59
99	0.441	1.303	0.987	1.653	187.90	190.42
102	0.449	1.321	0.990	1.660	189.27	191.22
105	0.457	1.340	0.993	1.667	190.63	192.00
108	0.466	1.360	0.996	1.673	191.99	192.75
111	0.474	1.380	0.999	1.680	193.35	193.49
114	0.483	1.401	1.003	1.686	194.71	194.21
117	0.493	1.423	1.006	1.692	196.07	194.92
120	0.502	1.444	1.009	1.698	197.43	195.60

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
123	0.512	1.467	1.013	1.704	198.79	196.27
126	0.522	1.490	1.016	1.709	200.15	196.93
129	0.533	1.514	1.020	1.715	201.51	197.57
132	0.543	1.538	1.024	1.720	202.87	198.20
135	0.554	1.563	1.027	1.726	204.23	198.81
138	0.565	1.588	1.031	1.731	205.59	199.41
141	0.576	1.614	1.035	1.736	206.95	200.00
144	0.588	1.640	1.039	1.741	208.31	200.58
147	0.599	1.667	1.042	1.746	209.66	201.15
150	0.610	1.694	1.046	1.751	211.00	201.70
153	0.621	1.723	1.050	1.756	212.33	202.25
156	0.632	1.751	1.054	1.760	213.64	202.79
159	0.642	1.780	1.057	1.765	214.93	203.31
162	0.652	1.810	1.061	1.769	216.19	203.83
165	0.660	1.840	1.064	1.774	217.42	204.34
168	0.668	1.871	1.067	1.778	218.60	204.84
171	0.674	1.903	1.070	1.782	219.74	205.33
174	0.678	1.934	1.073	1.787	220.82	205.81
177	0.681	1.967	1.075	1.791	221.84	206.29
180	0.682	2.000	1.078	1.795	222.79	206.76
					10889.61	

Table A.50: Wind Forces in Y- Direction-60 Storey

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
0	0.273	1.000	0.821	0.531	25.14	30.61
3	0.276	1.000	0.823	0.531	50.36	61.22
6	0.280	1.001	0.824	0.572	54.28	65.88
9	0.283	1.003	0.826	0.612	58.21	70.52
12	0.286	1.004	0.827	0.652	62.14	75.13
15	0.290	1.007	0.829	0.692	66.05	79.69
18	0.294	1.010	0.831	0.731	69.95	84.21
21	0.297	1.014	0.832	0.770	73.81	88.67
24	0.301	1.018	0.834	0.808	77.64	93.05
27	0.305	1.023	0.836	0.845	81.43	97.37
30	0.309	1.028	0.838	0.882	85.18	101.60
33	0.313	1.034	0.841	0.918	88.88	105.74
36	0.318	1.040	0.843	0.953	92.53	109.79
39	0.322	1.047	0.845	0.987	96.13	113.74
42	0.326	1.054	0.848	1.021	99.67	117.60
45	0.331	1.063	0.850	1.053	103.15	121.36
48	0.336	1.071	0.853	1.085	106.58	125.01
51	0.341	1.080	0.855	1.116	109.94	128.57
54	0.346	1.090	0.858	1.146	113.25	132.01
57	0.351	1.100	0.861	1.175	116.49	135.36

Height	Bgnd. Factor	Height Factor	Gust Factor	Design Pressure	Design Force	Mean Wind
s	Bs	Hs	Cdyn	pd	F	Fmean
m				kN/m^2	kN	kN
60	0.356	1.111	0.863	1.203	119.68	138.60
63	0.361	1.123	0.866	1.230	122.81	141.74
66	0.367	1.134	0.869	1.257	125.88	144.77
69	0.373	1.147	0.873	1.282	128.89	147.71
72	0.379	1.160	0.876	1.307	131.85	150.54
75	0.385	1.174	0.879	1.331	134.75	153.28
78	0.391	1.188	0.882	1.354	137.60	155.93
81	0.398	1.203	0.886	1.376	140.40	158.48
84	0.404	1.218	0.889	1.397	143.15	160.94
87	0.411	1.234	0.893	1.418	145.85	163.31
90	0.418	1.250	0.897	1.437	148.51	165.60
93	0.426	1.267	0.901	1.457	151.13	167.80
96	0.433	1.284	0.905	1.475	153.71	169.93
99	0.441	1.303	0.909	1.493	156.25	171.98
102	0.449	1.321	0.913	1.510	158.75	173.96
105	0.457	1.340	0.917	1.527	161.23	175.87
108	0.466	1.360	0.921	1.543	163.68	177.71
111	0.474	1.380	0.925	1.558	166.10	179.49
114	0.483	1.401	0.930	1.573	168.50	181.21
117	0.493	1.423	0.934	1.587	170.87	182.87
120	0.502	1.444	0.939	1.601	173.23	184.48
123	0.512	1.467	0.944	1.615	175.57	186.05
126	0.522	1.490	0.948	1.628	177.90	187.56
129	0.533	1.514	0.953	1.641	180.21	189.04
132	0.543	1.538	0.958	1.653	182.52	190.47
135	0.554	1.563	0.963	1.666	184.81	191.87
138	0.565	1.588	0.968	1.677	187.10	193.24
141	0.576	1.614	0.973	1.689	189.38	194.57
144	0.588	1.640	0.978	1.700	191.65	195.88
147	0.599	1.667	0.983	1.712	193.91	197.17
150	0.610	1.694	0.989	1.723	196.15	198.44
153	0.621	1.723	0.993	1.733	198.38	199.69
156	0.632	1.751	0.998	1.744	200.59	200.92
159	0.642	1.780	1.003	1.755	202.77	202.15
162	0.652	1.810	1.008	1.765	204.91	203.36
165	0.660	1.840	1.012	1.776	207.00	204.58
168	0.668	1.871	1.016	1.786	209.03	205.79
171	0.674	1.903	1.019	1.797	211.00	207.00
174	0.678	1.934	1.022	1.807	212.89	208.21
177	0.681	1.967	1.025	1.818	214.70	209.43
180	0.682	2.000	1.027	1.829	216.41	210.66
					8051.47	

CALCULATION OF MGLF FORCES:

Table A.51: Calculation of MGLF Forces in X- and Y- Direction-60 Storey

CALCULATION OF MGLF FORCES-X			
Terrain Category		I	
No. of Storeys	N	60	nos.
Peak Factor	gR	3.740	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.091	
Size Reduction factor	S	0.095	
Reduced Frequency	N	1.488	
Turbulence Spectrum	E	0.070	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	1180224.261	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	180.000	m
Storey Height	h	3.000	m
Mean BBM		**312525.671**	
Res. extreme BBM component	M_R	74778.457	
miϕiZi	miϕiZi	1451872545.022	
CALCULATION OF MGLF FORCES Y			
Terrain Category		IV	
No. of Storeys	N	60	nos.
Peak Factor	gR	3.740	
Peak Factor for Upwind velocity	gV	3.500	
Turbulence Intensity	Ih	0.199	
Size Reduction factor	S	0.064	
Reduced Frequency	N	2.022	
Turbulence Spectrum	E	0.057	
Damping Coefficient	ζ	0.020	
Mass at each storey	mo	1180224.261	kg
Mass reduction factor	λ	0.000	
Mode Shape Coefficient	β	1.000	
Total height of the building	H	180.000	m
Storey Height	h	3.000	m
Mean BBM		**323466.080**	
Res. extreme BBM component	M_R	85663.256	
miϕiZi	mϕiZi	1451872545.022	

Table A.52: Wind Forces in X-Direction by MGLF Method-60Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
0	0	54.15	1.000	0.000	0.273	0.203	0.239	0.925	0.000	11.01	0.00	0.00
1	3	108.31	1.000	77.756	0.276	0.205	0.239	0.926	0.017	22.15	19670.40	1.41
2	6	122.76	1.001	176.330	0.280	0.206	0.239	0.927	0.033	25.26	78681.62	2.82
3	9	131.63	1.003	283.806	0.283	0.207	0.240	0.927	0.050	27.25	177033.64	4.23
4	12	138.11	1.004	397.426	0.286	0.208	0.240	0.928	0.067	28.76	314726.47	5.65
5	15	143.24	1.007	515.894	0.290	0.210	0.240	0.930	0.083	30.02	491760.11	7.06
6	18	147.51	1.010	638.473	0.294	0.211	0.240	0.931	0.100	31.11	708134.56	8.47
7	21	151.16	1.014	764.705	0.297	0.212	0.241	0.932	0.117	32.08	963849.81	9.88
8	24	154.37	1.018	894.294	0.301	0.214	0.241	0.933	0.133	32.97	1258905.88	11.29
9	27	157.22	1.023	1027.046	0.305	0.215	0.242	0.935	0.150	33.80	1593302.75	12.70
10	30	159.79	1.028	1162.832	0.309	0.216	0.243	0.936	0.167	34.58	1967040.43	14.11
11	33	162.14	1.034	1301.574	0.313	0.218	0.243	0.937	0.183	35.32	2380118.93	15.53
12	36	164.30	1.040	1443.227	0.318	0.219	0.244	0.939	0.200	36.03	2832538.23	16.94
13	39	166.29	1.047	1587.772	0.322	0.221	0.245	0.941	0.217	36.72	3324298.34	18.35
14	42	168.15	1.054	1735.209	0.326	0.222	0.246	0.942	0.233	37.39	3855399.25	19.76
15	45	169.89	1.063	1885.556	0.331	0.224	0.247	0.944	0.250	38.04	4425840.98	21.17
16	48	171.53	1.071	2038.841	0.336	0.225	0.248	0.946	0.267	38.68	5035623.51	22.58
17	51	173.07	1.080	2195.101	0.341	0.227	0.249	0.948	0.283	39.31	5684746.86	23.99
18	54	174.53	1.090	2354.382	0.346	0.229	0.250	0.950	0.300	39.93	6373211.01	25.41
19	57	175.92	1.100	2516.736	0.351	0.230	0.251	0.952	0.317	40.54	7101015.97	26.82
20	60	177.24	1.111	2682.219	0.356	0.232	0.252	0.954	0.333	41.15	7868161.74	28.23
21	63	178.51	1.123	2850.891	0.361	0.234	0.254	0.956	0.350	41.76	8674648.32	29.64
22	66	179.72	1.134	3022.814	0.367	0.236	0.255	0.958	0.367	42.37	9520475.71	31.05
23	69	180.87	1.147	3198.054	0.373	0.238	0.256	0.960	0.383	42.97	10405643.90	32.46
24	72	181.99	1.160	3376.677	0.379	0.239	0.258	0.963	0.400	43.58	11330152.91	33.87
25	75	183.06	1.174	3558.750	0.385	0.241	0.259	0.965	0.417	44.19	12294002.72	35.28
26	78	184.09	1.188	3744.342	0.391	0.243	0.261	0.968	0.433	44.80	13297193.34	36.70
27	81	185.08	1.203	3933.523	0.398	0.245	0.262	0.970	0.450	45.41	14339724.77	38.11
28	84	186.04	1.218	4126.359	0.404	0.247	0.264	0.973	0.467	46.03	15421597.01	39.52
29	87	186.97	1.234	4322.921	0.411	0.249	0.266	0.975	0.483	46.65	16542810.06	40.93
30	90	187.87	1.250	4523.276	0.418	0.252	0.268	0.978	0.500	47.28	17703363.91	42.34

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
31	93	188.75	1.267	4727.492	0.426	0.254	0.269	0.981	0.517	47.91	18903258.58	43.75
32	96	189.59	1.284	4935.635	0.433	0.256	0.271	0.984	0.533	48.55	20142494.05	45.16
33	99	190.42	1.303	5147.772	0.441	0.258	0.273	0.987	0.550	49.20	21421070.34	46.58
34	102	191.22	1.321	5363.968	0.449	0.261	0.275	0.990	0.567	49.85	22738987.43	47.99
35	105	192.00	1.340	5584.286	0.457	0.263	0.277	0.993	0.583	50.51	24096245.33	49.40
36	108	192.75	1.360	5808.789	0.466	0.266	0.279	0.996	0.600	51.18	25492844.04	50.81
37	111	193.49	1.380	6037.539	0.474	0.268	0.281	0.999	0.617	51.86	26928783.55	52.22
38	114	194.21	1.401	6270.597	0.483	0.271	0.283	1.003	0.633	52.55	28404063.88	53.63
39	117	194.92	1.423	6508.021	0.493	0.273	0.285	1.006	0.650	53.24	29918685.02	55.04
40	120	195.60	1.444	6749.869	0.502	0.276	0.288	1.009	0.667	53.95	31472646.96	56.46
41	123	196.27	1.467	6996.197	0.512	0.279	0.290	1.013	0.683	54.66	33065949.71	57.87
42	126	196.93	1.490	7247.062	0.522	0.281	0.292	1.016	0.700	55.39	34698593.27	59.28
43	129	197.57	1.514	7502.516	0.533	0.284	0.294	1.020	0.717	56.12	36370577.64	60.69
44	132	198.20	1.538	7762.612	0.543	0.287	0.297	1.024	0.733	56.85	38081902.82	62.10
45	135	198.81	1.563	8027.402	0.554	0.290	0.299	1.027	0.750	57.60	39832568.81	63.51
46	138	199.41	1.588	8296.935	0.565	0.293	0.301	1.031	0.767	58.34	41622575.60	64.92
47	141	200.00	1.614	8571.259	0.576	0.295	0.304	1.035	0.783	59.09	43451923.21	66.34
48	144	200.58	1.640	8850.423	0.588	0.298	0.306	1.039	0.800	59.84	45320611.62	67.75
49	147	201.15	1.667	9134.472	0.599	0.301	0.309	1.042	0.817	60.58	47228640.84	69.16
50	150	201.70	1.694	9423.450	0.610	0.304	0.311	1.046	0.833	61.31	49176010.87	70.57
51	153	202.25	1.723	9717.403	0.621	0.307	0.314	1.050	0.850	62.03	51162721.71	71.98
52	156	202.79	1.751	10016.371	0.632	0.309	0.317	1.054	0.867	62.73	53188773.36	73.39
53	159	203.31	1.780	10320.396	0.642	0.312	0.319	1.057	0.883	63.39	55254165.82	74.80
54	162	203.83	1.810	10629.518	0.652	0.314	0.322	1.061	0.900	64.02	57358899.08	76.22
55	165	204.34	1.840	10943.777	0.660	0.316	0.325	1.064	0.917	64.61	59502973.16	77.63
56	168	204.84	1.871	11263.210	0.668	0.318	0.327	1.067	0.933	65.13	61686388.04	79.04
57	171	205.33	1.903	11587.853	0.674	0.319	0.330	1.070	0.950	65.59	63909143.73	80.45
58	174	205.81	1.934	11917.744	0.678	0.320	0.333	1.073	0.967	65.96	66171240.23	81.86
59	177	206.29	1.967	12252.916	0.681	0.321	0.336	1.075	0.983	66.25	68472677.54	83.27
60	180	206.76	2.000	12593.404	0.682	0.321	0.338	1.078	1.000	66.45	70813455.66	84.68

Table A.53: Wind Forces in Y-Direction by MGLF Method-60Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
0	0	30.61	1.000	0.000	0.273	0.304	0.265	0.821	0.000	9.31	0.00	0.00
1	3	61.22	1.000	48.645	0.276	0.306	0.265	0.823	0.017	18.73	19670.40	1.46
2	6	65.88	1.001	104.733	0.280	0.308	0.265	0.824	0.033	20.28	78681.62	2.92
3	9	70.52	1.003	168.280	0.283	0.310	0.265	0.826	0.050	21.84	177033.64	4.38
4	12	75.13	1.004	239.274	0.286	0.312	0.265	0.827	0.067	23.41	314726.47	5.84
5	15	79.69	1.007	317.676	0.290	0.313	0.266	0.829	0.083	24.98	491760.11	7.30
6	18	84.21	1.010	403.428	0.294	0.315	0.266	0.831	0.100	26.57	708134.56	8.76
7	21	88.67	1.014	496.457	0.297	0.317	0.267	0.832	0.117	28.15	963849.81	10.23
8	24	93.05	1.018	596.678	0.301	0.320	0.267	0.834	0.133	29.73	1258905.88	11.69
9	27	97.37	1.023	703.992	0.305	0.322	0.268	0.836	0.150	31.31	1593302.75	13.15
10	30	101.60	1.028	818.296	0.309	0.324	0.268	0.838	0.167	32.89	1967040.43	14.61
11	33	105.74	1.034	939.482	0.313	0.326	0.269	0.841	0.183	34.46	2380118.93	16.07
12	36	109.79	1.040	1067.438	0.318	0.328	0.270	0.843	0.200	36.02	2832538.23	17.53
13	39	113.74	1.047	1202.050	0.322	0.330	0.271	0.845	0.217	37.57	3324298.34	18.99
14	42	117.60	1.054	1343.204	0.326	0.333	0.272	0.848	0.233	39.11	3855399.25	20.45
15	45	121.36	1.063	1490.789	0.331	0.335	0.273	0.850	0.250	40.65	4425840.98	21.91
16	48	125.01	1.071	1644.694	0.336	0.337	0.274	0.853	0.267	42.17	5035623.51	23.37
17	51	128.57	1.080	1804.813	0.341	0.340	0.275	0.855	0.283	43.68	5684746.86	24.83
18	54	132.01	1.090	1971.043	0.346	0.342	0.276	0.858	0.300	45.18	6373211.01	26.29
19	57	135.36	1.100	2143.285	0.351	0.345	0.278	0.861	0.317	46.66	7101015.97	27.76
20	60	138.60	1.111	2321.446	0.356	0.347	0.279	0.863	0.333	48.14	7868161.74	29.22
21	63	141.74	1.123	2505.441	0.361	0.350	0.281	0.866	0.350	49.60	8674648.32	30.68
22	66	144.77	1.134	2695.187	0.367	0.353	0.282	0.869	0.367	51.06	9520475.71	32.14
23	69	147.71	1.147	2890.610	0.373	0.355	0.284	0.873	0.383	52.50	10405643.90	33.60
24	72	150.54	1.160	3091.642	0.379	0.358	0.285	0.876	0.400	53.93	11330152.91	35.06
25	75	153.28	1.174	3298.224	0.385	0.361	0.287	0.879	0.417	55.35	12294002.72	36.52
26	78	155.93	1.188	3510.303	0.391	0.364	0.289	0.882	0.433	56.76	13297193.34	37.98
27	81	158.48	1.203	3727.832	0.398	0.367	0.290	0.886	0.450	58.17	14339724.77	39.44
28	84	160.94	1.218	3950.774	0.404	0.370	0.292	0.889	0.467	59.56	15421597.01	40.90
29	87	163.31	1.234	4179.100	0.411	0.373	0.294	0.893	0.483	60.95	16542810.06	42.36
30	90	165.60	1.250	4412.790	0.418	0.376	0.296	0.897	0.500	62.34	17703363.91	43.82

Table A.54: Wind Forces in Y-Direction by MGLF Method-60Storey

Storey	Height	Mean Wind	Height Factor	Mean BBM	Bgnd. Factor	$G_{MB} = G_{YB}$	$G_{MR} = G_{YR}$	G_M	Mode shape	Bgnd. ESWL	miϕiZi	Res. ESWL
	Zi		Hs						ϕi	P_{Bi}		P_{Ri}
	m	kN		kN-m						kN	kg-m	kN
31	93	167.80	1.267	4651.829	0.426	0.380	0.298	0.901	0.517	63.72	18903258.58	45.28
32	96	169.93	1.284	4896.214	0.433	0.383	0.300	0.905	0.533	65.09	20142494.05	46.75
33	99	171.98	1.303	5145.950	0.441	0.386	0.302	0.909	0.550	66.47	21421070.34	48.21
34	102	173.96	1.321	5401.051	0.449	0.390	0.304	0.913	0.567	67.84	22738987.43	49.67
35	105	175.87	1.340	5661.538	0.457	0.394	0.307	0.917	0.583	69.22	24096245.33	51.13
36	108	177.71	1.360	5927.445	0.466	0.397	0.309	0.921	0.600	70.59	25492844.04	52.59
37	111	179.49	1.380	6198.813	0.474	0.401	0.311	0.925	0.617	71.97	26928783.55	54.05
38	114	181.21	1.401	6475.694	0.483	0.405	0.313	0.930	0.633	73.35	28404063.88	55.51
39	117	182.87	1.423	6758.148	0.493	0.409	0.316	0.934	0.650	74.73	29918685.02	56.97
40	120	184.48	1.444	7046.247	0.502	0.413	0.318	0.939	0.667	76.12	31472646.96	58.43
41	123	186.05	1.467	7340.073	0.512	0.417	0.321	0.944	0.683	77.51	33065949.71	59.89
42	126	187.56	1.490	7639.717	0.522	0.421	0.323	0.948	0.700	78.92	34698593.27	61.35
43	129	189.04	1.514	7945.283	0.533	0.425	0.326	0.953	0.717	80.32	36370577.64	62.81
44	132	190.47	1.538	8256.883	0.543	0.429	0.328	0.958	0.733	81.73	38081902.82	64.28
45	135	191.87	1.563	8574.644	0.554	0.433	0.331	0.963	0.750	83.15	39832568.81	65.74
46	138	193.24	1.588	8898.700	0.565	0.438	0.334	0.968	0.767	84.57	41622575.60	67.20
47	141	194.57	1.614	9229.200	0.576	0.442	0.336	0.973	0.783	85.99	43451923.21	68.66
48	144	195.88	1.640	9566.302	0.588	0.446	0.339	0.978	0.800	87.41	45320611.62	70.12
49	147	197.17	1.667	9910.179	0.599	0.451	0.342	0.983	0.817	88.83	47228640.84	71.58
50	150	198.44	1.694	10261.013	0.610	0.455	0.345	0.989	0.833	90.23	49176010.87	73.04
51	153	199.69	1.723	10619.000	0.621	0.459	0.348	0.993	0.850	91.62	51162721.71	74.50
52	156	200.92	1.751	10984.350	0.632	0.463	0.350	0.998	0.867	92.97	53188773.36	75.96
53	159	202.15	1.780	11357.283	0.642	0.466	0.353	1.003	0.883	94.29	55254165.82	77.42
54	162	203.36	1.810	11738.035	0.652	0.470	0.356	1.008	0.900	95.56	57358899.08	78.88
55	165	204.58	1.840	12126.854	0.660	0.473	0.359	1.012	0.917	96.76	59502973.16	80.34
56	168	205.79	1.871	12524.001	0.668	0.476	0.362	1.016	0.933	97.88	61686388.04	81.81
57	171	207.00	1.903	12929.754	0.674	0.478	0.365	1.019	0.950	98.91	63909143.73	83.27
58	174	208.21	1.934	13344.402	0.678	0.479	0.368	1.022	0.967	99.82	66171240.23	84.73
59	177	209.43	1.967	13768.251	0.681	0.480	0.371	1.025	0.983	100.62	68472677.54	86.19
60	180	210.66	2.000	14201.620	0.682	0.481	0.375	1.027	1.000	101.28	70813455.66	87.65

Table A.55: Calculation of Single Lateral Force for Design Input in X- Direction-60 Storey

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
60	180	206.76	66.45	84.68	206.76	0.00	66.45	0.00	84.68	0.00	314.40	314.40
59	177	206.29	66.25	83.27	413.05	620.28	132.70	199.34	167.96	254.05	627.10	312.70
58	174	205.81	65.96	81.86	618.86	1859.43	198.66	597.44	249.82	757.92	938.04	310.94
57	171	205.33	65.59	80.45	824.19	3716.02	264.24	1193.41	330.27	1507.37	1247.16	309.12
56	168	204.84	65.13	79.04	1029.03	6188.60	329.37	1986.15	409.31	2498.17	1554.41	307.25
55	165	204.34	64.61	77.63	1233.37	9275.70	393.98	2974.27	486.93	3726.09	1859.73	305.32
54	162	203.83	64.02	76.22	1437.20	12975.82	458.00	4156.21	563.15	5186.88	2163.08	303.35
53	159	203.31	63.39	74.80	1640.52	17287.43	521.40	5530.22	637.95	6876.33	2464.43	301.35
52	156	202.79	62.73	73.39	1843.30	22208.98	584.12	7094.42	711.34	8790.18	2763.74	299.31
51	153	202.25	62.03	71.98	2045.55	27738.88	646.15	8846.79	783.33	10924.21	3060.99	297.25
50	150	201.70	61.31	70.57	2247.26	33875.53	707.46	10785.24	853.90	13274.19	3356.15	295.16
49	147	201.15	60.58	69.16	2448.40	40617.30	768.04	12907.63	923.05	15835.88	3649.20	293.05
48	144	200.58	59.84	67.75	2648.98	47962.51	827.88	15211.75	990.80	18605.04	3940.13	290.93
47	141	200.00	59.09	66.34	2848.99	55909.46	886.96	17695.38	1057.14	21577.44	4228.93	288.80
46	138	199.41	58.34	64.92	3048.40	64456.41	945.31	20356.27	1122.06	24748.85	4515.58	286.65
45	135	198.81	57.60	63.51	3247.21	73601.61	1002.90	23192.19	1185.57	28115.03	4800.08	284.50
44	132	198.20	56.85	62.10	3445.41	83343.24	1059.75	26200.89	1247.68	31671.75	5082.41	282.33
43	129	197.57	56.12	60.69	3642.98	93679.46	1115.87	29380.15	1308.37	35414.78	5362.56	280.16
42	126	196.93	55.39	59.28	3839.90	104608.38	1171.26	32727.75	1367.64	39339.87	5640.54	277.98
41	123	196.27	54.66	57.87	4036.18	116128.09	1225.92	36241.52	1425.51	43442.80	5916.33	275.79
40	120	195.60	53.95	56.46	4231.78	128236.62	1279.87	39919.28	1481.97	47719.34	6189.91	273.59
39	117	194.92	53.24	55.04	4426.69	140931.95	1333.11	43758.89	1537.01	52165.24	6461.29	271.38
38	114	194.21	52.55	53.63	4620.91	154212.03	1385.66	47758.24	1590.64	56776.27	6730.46	269.16
37	111	193.49	51.86	52.22	4814.40	168074.75	1437.52	51915.23	1642.87	61548.21	6997.40	266.94
36	108	192.75	51.18	50.81	5007.15	182517.94	1488.71	56227.80	1693.68	66476.81	7262.10	264.70
35	105	192.00	50.51	49.40	5199.15	197539.39	1539.22	60693.92	1743.08	71557.84	7524.55	262.45
34	102	191.22	49.85	47.99	5390.36	213136.83	1589.07	65311.58	1791.06	76787.06	7784.74	260.19
33	99	190.42	49.20	46.58	5580.78	229307.91	1638.26	70078.78	1837.64	82160.25	8042.65	257.91
32	96	189.59	48.55	45.16	5770.37	246050.25	1686.81	74993.57	1882.80	87673.17	8298.27	255.62
31	93	188.75	47.91	43.75	5959.12	263361.37	1734.72	80054.01	1926.56	93321.58	8551.59	253.31

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
30	90	187.87	47.28	42.34	6146.99	281238.72	1782.00	85258.18	1968.90	99101.25	8802.57	250.98
29	87	186.97	46.65	40.93	6333.96	299679.69	1828.65	90604.18	2009.83	105007.95	9051.20	248.63
28	84	186.04	46.03	39.52	6520.01	318681.59	1874.68	96090.13	2049.35	111037.44	9297.46	246.26
27	81	185.08	45.41	38.11	6705.09	338241.61	1920.09	101714.16	2087.46	117185.48	9541.32	243.86
26	78	184.09	44.80	36.70	6889.18	358356.87	1964.88	107474.42	2124.15	123447.85	9782.75	241.43
25	75	183.06	44.19	35.28	7072.23	379024.40	2009.07	113369.07	2159.44	129820.31	10021.73	238.98
24	72	181.99	43.58	33.87	7254.22	400241.09	2052.65	119396.28	2193.31	136298.62	10258.21	236.48
23	69	180.87	42.97	32.46	7435.09	422003.74	2095.62	125554.23	2225.77	142878.56	10492.16	233.95
22	66	179.72	42.37	31.05	7614.81	444309.01	2137.99	131841.10	2256.82	149555.88	10723.54	231.38
21	63	178.51	41.76	29.64	7793.31	467153.43	2179.75	138255.07	2286.46	156326.35	10952.30	228.76
20	60	177.24	41.15	28.23	7970.56	490533.37	2220.90	144794.32	2314.69	163185.74	11178.39	226.09
19	57	175.92	40.54	26.82	8146.48	514445.04	2261.45	151457.03	2341.51	170129.81	11401.75	223.36
18	54	174.53	39.93	25.41	8321.01	538884.48	2301.37	158241.36	2366.91	177154.34	11622.31	220.56
17	51	173.07	39.31	23.99	8494.09	563847.52	2340.68	165145.48	2390.91	184255.08	11840.01	217.69
16	48	171.53	38.68	22.58	8665.61	589329.77	2379.35	172167.51	2413.49	191427.80	12054.75	214.74
15	45	169.89	38.04	21.17	8835.50	615326.61	2417.39	179305.57	2434.66	198668.26	12266.44	211.69
14	42	168.15	37.39	19.76	9003.66	641833.12	2454.78	186557.74	2454.42	205972.24	12474.98	208.54
13	39	166.29	36.72	18.35	9169.95	668844.09	2491.49	193922.07	2472.77	213335.50	12680.23	205.25
12	36	164.30	36.03	16.94	9334.24	696353.93	2527.52	201396.55	2489.70	220753.81	12882.06	201.82
11	33	162.14	35.32	15.53	9496.38	724356.66	2562.84	208979.12	2505.23	228222.92	13080.28	198.22
10	30	159.79	34.58	14.11	9656.17	752845.80	2597.42	216667.65	2519.34	235738.61	13274.69	194.41
9	27	157.22	33.80	12.70	9813.39	781814.32	2631.22	224459.90	2532.05	243296.64	13465.04	190.35
8	24	154.37	32.97	11.29	9967.76	811254.49	2664.19	232353.55	2543.34	250892.78	13651.02	185.98
7	21	151.16	32.08	9.88	10118.92	841157.76	2696.26	240346.10	2553.22	258522.79	13832.24	181.22
6	18	147.51	31.11	8.47	10266.43	871514.53	2727.37	248434.90	2561.69	266182.45	14008.19	175.95
5	15	143.24	30.02	7.06	10409.67	902313.82	2757.39	256617.01	2568.74	273867.50	14178.18	169.99
4	12	138.11	28.76	5.65	10547.78	933542.84	2786.15	264889.17	2574.39	281573.73	14341.21	163.03
3	9	131.63	27.25	4.23	10679.41	965186.19	2813.40	273247.63	2578.62	289296.90	14495.76	154.54
2	6	122.76	25.26	2.82	10802.17	997224.41	2838.66	281687.83	2581.45	297032.76	14639.07	143.31
1	3	108.31	22.15	1.41	10910.47	1029630.91	2860.81	290203.80	2582.86	304777.10	14764.74	125.67
0	0	0.00	0.00	0.00	10910.47	1062362.33	2860.81	298786.22	2582.86	312525.67	**14764.74**	0.00

Table A.56: Calculation of Single Lateral Force for Design Input in Y- Direction-60 Storey

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
60	180	210.66	101.28	87.65	210.66	0.00	101.28	0.00	87.65	0.00	344.60	344.60
59	177	209.43	100.62	86.19	420.09	631.98	201.90	303.83	173.84	262.94	686.52	341.92
58	174	208.21	99.82	84.73	628.31	1892.26	301.72	909.52	258.56	784.45	1025.66	339.14
57	171	207.00	98.91	83.27	835.30	3777.18	400.63	1814.68	341.83	1560.14	1361.94	336.29
56	168	205.79	97.88	81.81	1041.09	6283.09	498.51	3016.56	423.63	2585.63	1695.29	333.35
55	165	204.58	96.76	80.34	1245.67	9406.36	595.27	4512.10	503.98	3856.53	2025.63	330.34
54	162	203.36	95.56	78.88	1449.03	13143.37	690.83	6297.91	582.86	5368.46	2352.90	327.27
53	159	202.15	94.29	77.42	1651.18	17490.46	785.12	8370.40	660.28	7117.04	2677.04	324.14
52	156	200.92	92.97	75.96	1852.10	22444.00	878.09	10725.75	736.25	9097.89	2998.01	320.97
51	153	199.69	91.62	74.50	2051.79	28000.30	969.71	13360.02	810.75	11306.63	3315.76	317.76
50	150	198.44	90.23	73.04	2250.22	34155.66	1059.94	16269.14	883.79	13738.87	3630.28	314.51
49	147	197.17	88.83	71.58	2447.39	40906.33	1148.77	19448.95	955.37	16390.23	3941.51	311.23
48	144	195.88	87.41	70.12	2643.27	48248.50	1236.18	22895.25	1025.49	19256.33	4249.44	307.93
47	141	194.57	85.99	68.66	2837.84	56178.32	1322.17	26603.79	1094.14	22332.79	4554.03	304.59
46	138	193.24	84.57	67.20	3031.08	64691.85	1406.75	30570.31	1161.34	25615.22	4855.26	301.23
45	135	191.87	83.15	65.74	3222.95	73785.09	1489.90	34790.55	1227.08	29099.24	5153.11	297.84
44	132	190.47	81.73	64.28	3413.42	83453.94	1571.63	39260.24	1291.35	32780.47	5447.53	294.43
43	129	189.04	80.32	62.81	3602.46	93694.20	1651.95	43975.13	1354.17	36654.52	5738.51	290.98
42	126	187.56	78.92	61.35	3790.02	104501.57	1730.87	48930.99	1415.52	40717.02	6026.00	287.49
41	123	186.05	77.51	59.89	3976.07	115871.64	1808.38	54123.59	1475.41	44963.58	6309.97	283.97
40	120	184.48	76.12	58.43	4160.55	127799.84	1884.50	59548.74	1533.85	49389.82	6590.37	280.41
39	117	182.87	74.73	56.97	4343.43	140281.50	1959.23	65202.25	1590.82	53991.36	6867.17	276.80
38	114	181.21	73.35	55.51	4524.63	153311.78	2032.58	71079.95	1646.33	58763.81	7140.31	273.14
37	111	179.49	71.97	54.05	4704.12	166885.68	2104.55	77177.69	1700.38	63702.79	7409.75	269.43
36	108	177.71	70.59	52.59	4881.83	180998.05	2175.14	83491.33	1752.97	68803.92	7675.42	265.67
35	105	175.87	69.22	51.13	5057.70	195643.54	2244.35	90016.73	1804.09	74062.82	7937.26	261.84
34	102	173.96	67.84	49.67	5231.65	210816.64	2312.19	96749.79	1853.76	79475.10	8195.21	257.95
33	99	171.98	66.47	48.21	5403.63	226511.60	2378.66	103686.37	1901.97	85036.39	8449.21	254.00
32	96	169.93	65.09	46.75	5573.56	242722.50	2443.76	110822.36	1948.71	90742.29	8699.17	249.96
31	93	167.80	63.72	45.28	5741.36	259443.19	2507.47	118153.63	1994.00	96588.44	8945.03	245.86
30	90	165.60	62.34	43.82	5906.96	276667.28	2569.81	125676.06	2037.82	102570.43	9186.69	241.67

Storey	Height	Pmean	Pbi	Pri	Vxmean	Mxmean	Vxb	Mxb	Vxr	Mxr	Vx	Pdesign
29	87	163.31	60.95	42.36	6070.27	294388.16	2630.76	133385.49	2080.19	108683.90	9424.09	237.39
28	84	160.94	59.56	40.90	6231.20	312598.97	2690.33	141277.79	2121.09	114924.46	9657.12	233.03
27	81	158.48	58.17	39.44	6389.68	331292.58	2748.49	149348.77	2160.53	121287.73	9885.69	228.58
26	78	155.93	56.76	37.98	6545.61	350461.62	2805.26	157594.25	2198.51	127769.32	10109.72	224.03
25	75	153.28	55.35	36.52	6698.89	370098.43	2860.61	166010.02	2235.03	134364.86	10329.10	219.38
24	72	150.54	53.93	35.06	6849.43	390195.10	2914.53	174591.84	2270.09	141069.95	10543.73	214.63
23	69	147.71	52.50	33.60	6997.14	410743.39	2967.03	183335.44	2303.69	147880.22	10753.50	209.77
22	66	144.77	51.06	32.14	7141.91	431734.80	3018.09	192236.54	2335.83	154791.29	10958.32	204.81
21	63	141.74	49.60	30.68	7283.65	453160.54	3067.69	201290.81	2366.50	161798.78	11158.06	199.75
20	60	138.60	48.14	29.22	7422.25	475011.49	3115.83	210493.88	2395.72	168898.29	11352.63	194.57
19	57	135.36	46.66	27.76	7557.61	497278.23	3162.50	219841.38	2423.48	176085.45	11541.91	189.28
18	54	132.01	45.18	26.29	7689.62	519951.06	3207.68	229328.87	2449.77	183355.88	11725.78	183.87
17	51	128.57	43.68	24.83	7818.19	543019.92	3251.35	238951.90	2474.60	190705.19	11904.14	178.36
16	48	125.01	42.17	23.37	7943.20	566474.49	3293.52	248705.96	2497.98	198129.00	12076.87	172.73
15	45	121.36	40.65	21.91	8064.56	590304.11	3334.17	258586.53	2519.89	205622.93	12243.86	166.99
14	42	117.60	39.11	20.45	8182.17	614497.80	3373.28	268589.04	2540.34	213182.60	12405.01	161.14
13	39	113.74	37.57	18.99	8295.91	639044.30	3410.85	278708.89	2559.33	220803.62	12560.19	155.19
12	36	109.79	36.02	17.53	8405.70	663932.03	3446.87	288941.46	2576.86	228481.61	12709.32	149.13
11	33	105.74	34.46	16.07	8511.44	689149.12	3481.33	299282.07	2592.93	236212.19	12852.28	142.96
10	30	101.60	32.89	14.61	8613.03	714683.43	3514.21	309726.06	2607.54	243990.98	12988.98	136.70
9	27	97.37	31.31	13.15	8710.40	740522.53	3545.53	320268.70	2620.68	251813.59	13119.34	130.35
8	24	93.05	29.73	11.69	8803.45	766653.72	3575.26	330905.28	2632.37	259675.64	13243.25	123.92
7	21	88.67	28.15	10.23	8892.12	793064.08	3603.41	341631.05	2642.60	267572.75	13360.66	117.40
6	18	84.21	26.57	8.76	8976.33	819740.44	3629.97	352441.27	2651.36	275500.54	13471.48	110.82
5	15	79.69	24.98	7.30	9056.02	846669.43	3654.95	363331.18	2658.67	283454.63	13575.67	104.19
4	12	75.13	23.41	5.84	9131.15	873837.50	3678.36	374296.04	2664.51	291430.62	13673.17	97.50
3	9	70.52	21.84	4.38	9201.66	901230.94	3700.20	385331.13	2668.89	299424.15	13763.95	90.78
2	6	65.88	20.28	2.92	9267.54	928835.93	3720.47	396431.71	2671.81	307430.82	13847.99	84.04
1	3	61.22	18.73	1.46	9328.76	956638.55	3739.20	407593.13	2673.27	315446.26	13925.28	77.30
0	0	0.00	0.00	0.00	9328.76	984624.83	3739.20	418810.74	2673.27	323466.08	**13925.28**	0.00

Appendix B

List of Papers Published

- Jamdar Ruchita R. and Purohit Sharad P.,"Study on Characterization of Wind and its Effect on Structures",International Civil Engineering Symposium(ICES-2014), Department of Civil Engineering, Vellore Institute of Technology(VIT), Vellore, India,14-16 March 2014.