Response Of Tall Building With Different Side Ratio Under Wind Load

A REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE AWARD OF THE DEGREE
OF

**MASTER OF
TECHNOLOGY IN**

CIVIL ENGINEERING

Submitted By

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UNDER THE SUPERVISION OF

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JULY, 2021

CANDIDATE DECLARATION

I, "**PAYAL DEVI"** student of M. Tech Structural Engineering, DTU hereby declare that the project dissertation titled "**Response of Tall Building with different Side Ratio under Wind Load**" is submitted to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has never before been used to give a degree, diploma, associateship, fellowship, or other equivalent title or recognition.

Place: Delhi

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CERTIFICATE

I hereby certify that the Project Dissertation title "Response of Tall Building with different Side Ratios under Wind Load" which is submitted by Payal Devi (2K19/STE/19) to Civil Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has never been submitted in part or in whole for a degree or diploma at this university or anywhere else.

Place: Delhi

Dr. RITU RAJ

Supervisor

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Date:30.07.2021

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1 Introduction

1.1 Overview

High Rise Buildings are cantilever structures that are susceptible to both static and dynamic loadings. Such structures are subjected to significant lateral loads and must account for deflections and accelerations caused by horizontal loading, which is most commonly caused due to unanticipated deflections, wind, or earthquakes. When a building is much higher than neighboring buildings or its proportions are narrow enough to give the appearance of a tall building, it is classified as high-rise buildings. Occupant comfort along with serviceability is the dominant criteria along with safety of structure in design of such structures.

In Aerodynamics Optimization, shape of buildings is extensively known concept that greatly determines the response of the high structures under wind loading. Optimizing the geometry of supertall structures for aerodynamics during the design stage is an excellent technique to reduce wind response. Tall building shapes geometry can optimize a fluid-based aerodynamic response. Studies have shown that softening corners, setbacks, changing cross-sectional form, adding spoilers and porosity, and apertures in the building elevation of tall buildings all reduce across-wind reactions.

Wind is complicated phenomenon and is a random time-dependent load composed of a mean plus a fluctuating component. Due to this fluctuating component, all structures experiences dynamic oscillations. Motion of wind is so unpredictable that one need to be compute the statistical distribution of velocity rather than just simple averages. The mean component of wind speed produces a static force on a structure. The time-varying component that is the fluctuating component too, which is created by the gusty nature of the wind, is overlaid on the static component and has many frequencies distributed across a large band. Turbulence intensity, which is the ratio of the standard deviation to the mean wind speed and is given in percentages, is a common way to quantify variable velocity.

When a wind load acts on a structure, it creates a positive pressure on the windward side and a suction (negative) pressure on the leeward side. The net wind force is computed as the summation of windward pressure and leeward suction but each of these two have their own local impact. Due to the roughness of earth surface, there acts a drag force on wind flow near the ground. This effect gradually decreases as the height increases and at a certain gradient level (around 400m), this drag-force becomes negligible. The degree of surface roughness and drag caused by surrounding projections that oppose wind flow determines the vertical profile of wind speed. Gradient height is the height at which the drag effects become zero, while gradient velocity is the corresponding velocity that do not show variation above this height. The atmospheric boundary layer is the height up to which terrain and topography influences the wind speed.

In low rise buildings, only static effects are sufficient to be considered whereas in tall buildings, the aerodynamic and dynamic effects are to be analyzed along with the static effects. High Rise structures are subjected to along with as well as across wind effects. The along wind effect are caused primarily due to buffeting phenomenon caused due to gust effects whereas across wind induced effects are due to vortex shedding.

Other dynamic wind induced phenomenon need to be evaluated that are due to increase in amplitude of oscillation with increase in wind speed. Galloping phenomenon are more susceptible to structural elements that are not circular, which is due to transverse oscillations of structures due to wind response that are in phase with motion due to the development of aerodynamic forces. Flutter is another unsteady oscillatory motion induced by the interaction of aerodynamic force and structural elastic deformation.

The lateral stability and gravity system for the superstructure, as well as the foundation design, are the most important design concerns for tall buildings. The basic goal of tall building design is to offer enough stiffness to resist lateral or gravity loads.

To determine the design pressure coefficients and force coefficients for such structures subjected to wind generated loads, the designers consult applicable wind load standards such as (AS/NZS: 1170.2-2002, ASCE: 7-02-2002, BS: 63699-1995, IS: 875 (Part-3) 2005). These standards, on the other hand, give information for simple cross-sectional shapes with a small number of wind incidence angles. These codes do not include information on wind loadings for buildings with unconventional shapes or for varying angles of wind attack. To determine these wind response coefficients, wind tunnel testing and CFD techniques are commonly used on models of such buildings.

1.2 Loads Acting on a Structure

Loads such as self-weight, imposed loads, snow loads, and horizontal loads from both wind and seismic loads must all be considered while designing a building. Wind load, however are considered to be constantly acting force compared to seismic that is instantaneous in nature. A structure is required to be analysed for safety against all the different load combinations acting on it. Loads are classified as:

a) Static load
b) Dynamic load

Static loads are permanent part of structure and don't change with time and space within a structure whereas dynamic load on the other hand, are temporary in nature and are a function of space within a structure.

Loads acting on a structure may also be classified under following sub categories:

a) Geophysical Forces
b) Human made Forces

Geophysical forces are the forces that are due to continuous changes in nature, may be subdivided as gravitational, meteorological and seismological forces. Human made forces are a result of movement of people and equipment, variations of shocks generated due to machines, tools, blasts and impact. However, geophysical and human made forces are often mutually dependent.

1.3 Structural System

Following are the essential components or subsystems of high rise building structural systems:

a. Vertical load resisting system

b. Lateral load resisting system

c. Floor System and Connections

d. Damping System for energy dissipation

1.4 Need of study

In the present study, different side ratio having same height and plan area models have been used to study the wind response analysis of those models. Wind response coefficients are obtained by CFD analysis which are directly used for computation of forces acting on the prototype. In this study, effect of side ratio will be determined by comparing various parameters like force, moments and displacements.

1.5 Objective and Scope

- To investigate the effect of side ratio under the action of wind loadings for following models having same plan area and height:
    1. Rectangular Plan building (30m*30m) with side ratio 1
    2. Rectangular Plan building (36m*25m) with side ratio 1.44
    3. Rectangular Plan building (45m*20m) with side ratio 2.25
    4. Rectangular Plan building (60m*15m) with side ratio 4

- To compare various parameters such as Axial Force (F_x), and Deflections of storey in X and Z for all the models under the action of wind load.

- Effect of different models in resisting wind loads incident at different angle of attack 0°, 30°, 60° and 90° on models having same plan area.

1.6 Method of Evaluation

The following factors influences wind loads:

1) Wind attack angle

2) The structure's aspect ratio and shape

3) Density and velocity of air as a function of height above ground level

4) The topography of the building's surroundings.

DESIGN WIND PRESSURE

According to IS-875 (Code for Practice for Design Loads for Building and Structures) (Part 3 Wind Load), Design wind velocity is given as:

$$(V_Z) = V_b * K_1 * K_2 * K_3 * K_4$$

Where, V_Z = Design wind velocity

V_b=Basic Wind velocity

K_1= Probability Factor/Risk Coefficient

K_2=Terrain and Height Factor

K_3=Topography Factor

K_4=Importance factor for the cyclonic region

The wind pressure at height z is calculated as follows:

$$\mathbf{P_z=0.6\ [V_z]^2}$$

DESIGN WIND LOAD

The difference in external and interior pressures is used to determines the wind load. As a result, the computation of wind loads is as follows:

$$F= (C_e - C_i) *A*P_d$$

where, C_e = external pressure coefficient

C_i= internal pressure coefficient

A = surface area of the structural unit

P_d = design wind pressure

Risk Coefficient K_1

In IS 875 part 3, based upon statistical concepts that take into account the degree of reliability. Peak wind speed is based upon probability of occurrence of maximum storm over a 50 years return period. The wind speeds for terrain category 2 are indicated in the table of the code for a height of 10 metres above ground level. The risk coefficients for several classes of structures, as well as their typical return period, are listed in the table of IS-Code.

Terrain and Height Factor K_2

Terrains are divided into numerous categories based on the obstacles that the building faces, as well as the ground surface roughness.

The Category-I of Terrain consists of Open landscape with only a few barriers that do not surpass 1.5m in height. Open seacoasts and flat, treeless plains fall under this category.

Terrain Category 2 – In this category the height of surrounding obstructions does not exceed 1.5 to 10m having well-scattered landscape

Terrain Category 3 – In this terrain type, the height of obstructive structures is about 10m, and they are tightly spaced. It could feature a few isolated tall buildings or none at all.

Terrain Category 4 – A very closely situated high rise building in the environment of the building consideration, which involves huge cities, falls into this category

The wind profile varies depending on the ground roughness, and as a result, each terrain group has a different wind profile. The terrain and height multipliers for various heights and terrain categories are listed in Table 2 of IS code 875 part 3, which are then multiplied by the basic wind velocity to generate the design wind velocity.

Topography Factor (K_3)

The basic wind velocity V_b accounts for influence on the building's notional height above sea level. It ignores topographical characteristics such as mountains, valleys, ridges, and escarpments, among others. Wind is accelerated and decelerated by landforms such as mountains and valleys. The factor K_3 takes into account these nuances. This factor measures the enhancement caused due to hills, cliffs etc. in the wind speed.

Importance Factor for cyclonic region K_4

Major storms are particularly common on India's east coast. On the west coast, Gujrat is exposed to severe cyclones. During cyclones, the wind speed may exceed the normal speed specified by the code's fundamental speed map. Based on the importance of the cyclones in the table below, different values for K_4 factor, which incorporates the effect of cyclone storms whose impact is felt along 60-65 km breadth, will be given:

Table 1-1 Importance Factor

	K_4
Structures of post-cyclone importance for emergency services (such as cyclone shelters, hospitals, schools, communication towers, etc.)	1.30
Industrial structures	1.15
All other structures	1.00

1.7 Types of Structural systems for Hight Rise Buildings

From the perspective of a structural engineer, the tall building's lateral stability structural system is its most important aspect. The history of the development of structural systems for tall structures can be classified into several stages. Various lateral stability system includes:

A. Moment resisting rigid frame structure
B. Braced frame structural system
C. Shear wall system
D. Tube structures
E. Core-outrigger system
F. Diagrid structures

The moment resisting frame (MRF) system (also known as rigid frame) is a lateral resistance system in which the beams and columns are rigidly attached. Bracing system carries lateral loads and can be provided as vertical as well as horizontal bracing. Shear wall is a structural member that limits the sway of buildings and increases the stability creating a rigid moment resisting frame. Tube structures acts a hollow cylinder cantilevered on ground. Chicago Wills tower is constructed using this technique. Outriggers are one another most widely used systems for relatively regular floor layout. To connect the core and the columns at the periphery, steel trusses, girders, concrete walls, or deep beams are used. The main benefit of using an outrigger is that it prevents the core from rotating and reduces lateral deflection and overturning moment.

2 Literature Review

2.1 General

From the 1960s, many researchers have concluded many convenient information using the traditional approach assuming the wind pressure to act statically. This approach helped to estimate results from wind tunnel testing that is carried out in a uniform steady velocity.

The history of design of tall structures in itself is gigantic. Over the centuries, architects and structural engineers worked together, to evolve tall buildings. Today's skyscrapers are a result of continuous innovation, experimentation and discovery. In the 20th and 21st century, urbanization encouraged the construction of tall building, making it taller and taller with increase in demand. Before the 19th century, world's tallest building was a church. In the nineteenth century, Chicago pioneered a new type of structure that relied on iron or steel to support the weight of the structure. The Home Insurance Building in Chicago, which stands 42 metres tall, was the world's first skyscraper in 1885. Following that, an increasing number of tall buildings were constructed, including the Empire State Building (102 stories) in 1931. After that, with the fast-emerging construction technique and development of computer modelling technique, increasingly tall buildings were built all around the world.

As the building goes taller and taller, keeping in mind the demand of serviceability and functionality, cross sections should be selected very carefully as additional lateral forces are formed from unexpected deflections. In most cases, wind load is the governing load in tall building design for lateral stability system design, as opposed to seismic loading. This is due to the longer natural period of the tall building, which results in a smaller seismic response as compared seismic response for low rise buildings. However, depending on the location and relevance of the structure, a necessary check may be required.

2.2 Codal Provision

2.2.1 British Standard (BS: 63699-Part 2:1997)

This code of practice for wind load explains how to determine natural wind actions for structural design of buildings and civil engineering projects for each of the load situations that are taken into account. This code of practice is applicable to building and structures with heights up to 200 m and bridge having no span greater than 200 m. This code also intends to predict characteristic wind actions on land-based structures and their elements. There is no information about the wind pressure distribution for uneven cross-sectional shapes. Information about different skew angle wind is also not included in this code of practice.

2.2.2 American Standard (ASCE4, 2002)

ASCE-7-10 has given a detailed information about wind loads on low-rise buildings by incorporating a number of adjustment parameters that account for the complicated 3D dynamic character of wind flow. The information on low-rise buildings with different aspect ratio are also available in this standard. However, there is lack of information about wind loads on high rise buildings with different cross-sectional shapes. Similarly, no information is available in case of skew wind.

2.2.3 Australia and New Zealand Standard (AS/NZS-1170-2, 2011)

This code of practice covers the structures which falls within the criteria such as (i) building less than or equal to 200 m height and (ii) structures with roof span less than 100m. This code also includes the wind load for structures other than offshore structures bridges and transmission towers. The information about the cross-sectional shape other than square and rectangular shape is not included in this code of practice. Very little information about the pressure distribution is available when building is attacked by the skew wind angle.

2.2.4 Indian Standard (18475, part-3, 1987)

According to IS: 875 (Part-3), 1987, the external pressure coefficients (C_{pe}) for rectangular clad buildings are given only for uniform cross section along the height. These values are available for different height to width ratios and wind incidence angles namely 0° and 90° only. Typical values are shown in Table 2.1. Similarly, force coefficients (Cf) are given in the existing code (Clause 6.3.2.1, Fig. 4) for buildings with rectangular cross- section.

2.3 Reference Research paper and their Summaries

A. (Effects of Side Ratio on Wind-Induced Pressure Distribution on Rectangular Buildings) **by J. A. Amin and A. K. Ahuja**

The findings of wind tunnel testing on 1:300 scaled-down models of rectangular buildings with the same plan area and height but side ratios ranging from 0.25 to 4 are presented in this paper. Because wind pressures vary, pressure coefficient mean, maximum, lowest, and r.m.s. values are obtained at pressure sites on all models' surfaces. The usefulness of side ratios of models in changing the surface pressure distribution is investigated at a wind incidence angle of 0 to 90 at a 15-degree interval. They discovered that model side ratio has a large impact on the amount and distribution of wind pressure on leeward and sidewalls, but only a little impact on windward walls when the wind incidence angle is zero. Changes in side ratio have little effect on the general magnitude of peak pressures and peak suctions in building models with constant cross section, but they do influence the wind angle at which they occur.

B. (Experimental Study of Wind Pressures on Irregular Plan Shape Buildings), 2008) **by J. A. Amin and A. K. Ahuja.**

The findings of wind tunnel tests on a 1:5000 scaled-down model with the same plan area and height but different plan shapes ("L" and "T") are provided in this study. Wind pressure fluctuates at pressure sites on all surfaces, and the mean, maximum, minimum, and r.m.s. values of pressure coefficients are calculated.
They came to the conclusion that there is a significant difference in pressure along the height as well as the breadth of different faces of the models, and that changing the plan dimensions has a significant impact on the wind pressure distributions on different faces of the building models.

C. (Wind tunnel study of wind effects on a high-rise building at a scale of 1:300) **by R. Sheng and L. Perret**

The goal of this research is to use wind-tunnel testing on a high-rise building with a well-defined atmospheric boundary layer at a 1:300 scale to investigate the unstable features of global and local wind loads, as well as their relationships with the atmospheric boundary layer. For global and local wind loads, complete information on wind is analyzed, including mean velocity profile, turbulence strength, and power spectrum of the fluctuation. The findings of this study reveal that, depending on the location, upstream flow or shear layers that form at the building's upstream corners, or both, influence wall-pressure pressures on the tower.

D. (Experimental study of wind-induced pressures on tall buildings of different shapes) **by Suresh K Nagar and Ritu Raj**

In this paper, mean wind pressure coefficients of a square and H-plan shaped tall buildings are investigated using wind tunnel testing. The experiment was conducted for various wind direction angles from 0º, 30º, 60º and 90º and for various identical building interference conditions. In order to investigate the interference effects, interfering factor were calculated. Different interference conditions taken under consideration were Full blockage, Half blockage, No blockage.

Non-dimensional interference factors (IF) represent the aerodynamic pressures on a plan-shaped major building with interference from nearby plan-shaped buildings and are used to depict interference effects. They proposed that the value of mean wind pressure coefficient decreases with an increase in the wind incidence angle up-to an angle of 60º. Suction starts after further increase in wind incidence angle. The interference factor in both the models is less than unity. The interfering building at full blockage produces more suction compared to other two condition. The configuration of the interfering in no blockage condition caused almost no effect on mean pressure coefficient for square shaped building while it’s reduced to almost 50% in case of H shape building.

E. (Shear Wall Analysis and Design Optimization In Case of High Rise Buildings Using Etabs) **by M. Pavani, G. Nagesh Kumar**

In this research work, they constructed a shear wall and optimised it using the software ETabs. Shear walls are positioned in such a way that they can sustain lateral stresses in zone III throughout the structure, according to Indian standards. The following are the optimization approaches employed in this project: The size of the shear wall is uniform throughout the building, and then the result is analysed, and the failed shear wall dimensions are increased to resist the entire structure; in this way, the optimization was repeated a number of times until the entire structure became stable to resist the forces; in this way, the optimization was repeated a number of times until the entire structure became stable to resist the forces and Finally, the optimization was done until the entire structure was stable enough to withstand the forces.

F. (Effects of Aerodynamic Modifications of Building Shapes on Wind Induced Response of Tall Buildings) **by Kwok and Bailey**

Wind tunnel tests were undertaken by Kwok and Bailey (1987), Kwok et al (1988), and Kwok (1988) to assess the effects of aerodynamic devices, building edge configuration, and through building opening on wind induced vibrations in tall structures. The dynamic along wind and crosswind responses of the rectangular cross-section CAARC Standard Tall Building were found to be significantly different reduced when horizontal slots, slotted corners, and chamfered corners were used.

G. (Wind Load on High Rise Buildings with Different Configurations: A Critical Review)) **by A.K. Roy**

This paper described the wind effects for structural frame with altered plan shapes and outcomes. The wind load is evaluated based on elementary wind speed and other aspects as kind of topography, terrain, and the usage of building and its risk aspect for that specific region are associated with respect to allowable drifts of distinct buildings.

They come to the conclusion that the Wind Pressure Coefficient is highest in square plan shapes and lowest in circular plan shapes of tall buildings, and that the octagonal plan shape of tall building with sharp windward edge is more effective than the hexagonal plan shape of tall building with sharp windward edges in reducing wind pressure coefficient. For maximum mean overturning moment coefficients, tapered models, such as 4-Tapered and Setback Models, provide superior aerodynamic behaviour in the along-wind direction, whereas corner modification models provide better aerodynamic behaviour in the across-wind direction.

H. (Wind pressure and velocity pattern around 'N' plan shape tall building) **by A. Mukherjee and A. K. Bairagi**

Mukherjee et al. (2017) studied the wind pressure and velocity pattern around 'N' shaped tall buildings. The paper is centred around determining the wind pressure coefficient and wind velocity analysis of the building using k-ε methods.

I. (Modelling of Wind Pressure Coefficients on C-Shaped Building Models) b**y M. Mallick, A. Mohanta, A. Kumar, and V. Raj**

Monalisa Mallick et al. (2018) studied the simulation of the wind pressure coefficient on C-shaped building models by means of numerical analysis using ANSYS Fluent and concluded that the pressure on the building was remarkably influenced by the structure geometry, orientation, aspect ratios, and wind angle of attack.

J. (Field measurements of wind pressures on a 600 m high skyscraper during a landfall typhoon and comparison with wind tunnel test) by J.W. Zhang, Q.S.Li

In this paper Structural health monitory and wind tunnel test were conducted simultaneous on a 600m high skyscrapers to examined and compared the measurement of wind induced pressure on windward, leeward and side faces of tall structures. The major goal of this research is to learn more about typhoon-generated wind forces on super-tall structures. Pressure coefficient, probability distribution, peak factor, power spectral density, and cladding pressure correlation were among the many characteristics presented and analysed.

CHAPTER – 3

DETAIL OF PROTOTYPE BUILDING

3.1 GENERAL

To accomplish the objective of carrying out the wind response analysis, a square shape and a rectangular shape model with different side ratio of 1, 1.44, 2.25 and 4 of height 90 m having the same plan area is made using STAAD.Prov8i. For all the shapes, Column A is analysed and all the models are analysed for wind incidence angles 0°, 30°, 60° and 90°. Axial force, and deflection is observed, tabulated and compared for column A for change in side ratio whereas only deflections are observed for Column B. Columns under consideration are also shown below.

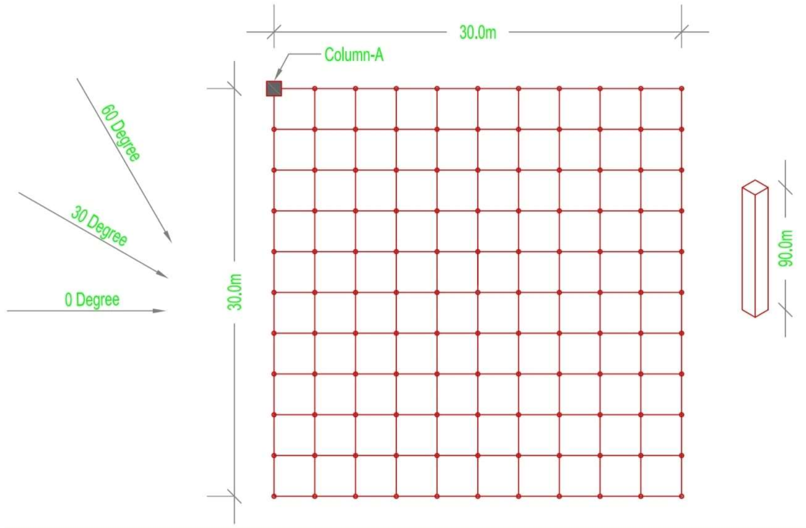

Figure 0-1 Position of column A in square model

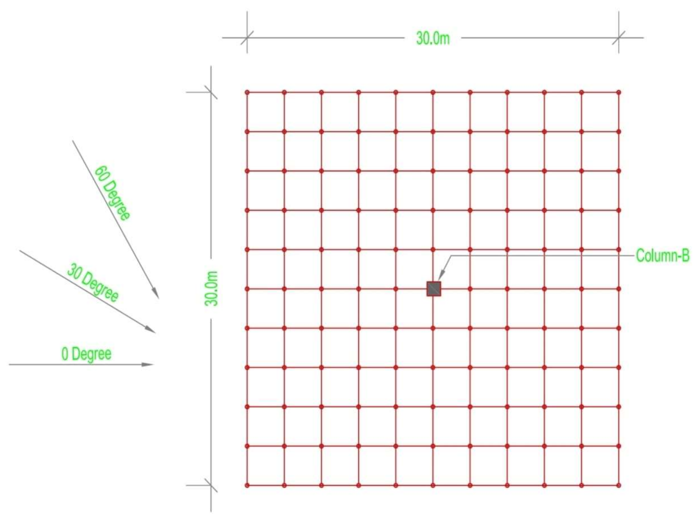

Figure 0-2 Position of Column B in square model

3.2 MODELLING AND ANALYSIS

In all buildings, all cross-section is considered for wind response analysis. The height and floor area of prototype building are kept 90 m and 900 m^2 respectively.

The prototype building comprises 30 stories, with the lowest storey being 3 metres tall and the other levels being 3 metres tall. R.C.C. beams, slabs, and columns are used to construct building frames.

The dimensions of the building and elements are listed in Table 3.1. M-25 and Fe-415 are the concrete and steel reinforcing grades used in prototype buildings, respectively.

Table 0-1 Dimension of Model

<table>
<tr><th>Modal shape</th><th>Prototype Dimension(m)</th><th>Side Ratio</th><th>Height of Model (m)</th><th>Aspect Ratio</th></tr>
<tr><td>Square</td><td>30*30</td><td>1</td><td rowspan="4">90</td><td rowspan="4">3</td></tr>
<tr><td>Rectangle-1</td><td>36*25</td><td>1.44</td></tr>
<tr><td>Rectangle-2</td><td>45*20</td><td>2.25</td></tr>
<tr><td>Rectangle-3</td><td>60*15</td><td>4</td></tr>
</table>

Table 0-2 Description of the building elements

S. No.	Particulars	Details/ Values
1.	Storey height	3 m
3.	Size of beams	450 mm x 500 mm
4.	Size of columns (from first storey to thirty storey)	600 mm x 600 mm

5.	Thickness of floor slab	150 mm

Load and Load Combination

The following load combinations are considered as per IS 875 (Part 3):

1. Load Case 1 = 1.5 [D.L + L.L]
2. Load Case 2 = 1.2 [D.L + L.L + W.L]
3. Load Case 3 = 1.5 [D.L + L.L - W.L]
4. Load Case 4 = 1.5 [D.L + W.L]
5. Load Case 5 = 1.5 [D.L - W.L]

Solidity Ratio: The effective area (projected area of all individual elements) of a frame normal to the wind direction divided by the area contained by the frame's normal to the wind direction boundary is known as the solidity ratio. In the present model, this solidity ratio factor is taken as .99 as shown below:

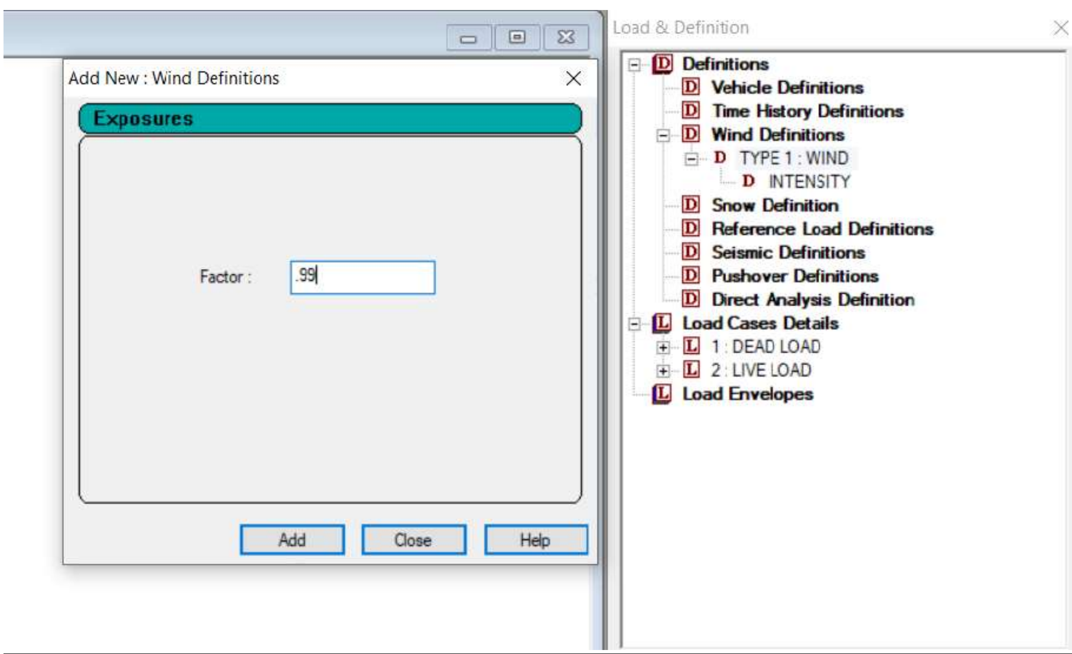

Figure 0-3 Solidarity Ratio

Calculation of Wind load

In the present study, we have considered basic wind speed of 47 ms^{-1}

Wind Load parameters:

Risk Coefficient(k_1) = 1 (All general structure and building)

Terrain category coefficient(k_2) = used linear interpolation to calculate factor as per height of building.

Topography coefficient(k_3) = 1

Importance factor(k_4) = 1

Wind directionality factor = .90

Area averaging factor = .90

Combination factor = .90

Using above data, Design wind Pressure calculated with height is a below:

Table 0-3 Wind Pressure intensity with height

Height of building(m)	Value of K_1	Value of K_2	Value of K3	Value of K_4	$V_z=V_b*k_1*k_2*k_3*k_4$ (m/s)	Pz=.6Vz^2 [KN/m]
10	1	1.05	1	1	49.35	1.461
15	1	1.09	1	1	51.23	1.574
20	1	1.12	1	1	52.64	1.66
30	1	1.15	1	1	54.05	1.75
50	1	1.2	1	1	56.4	1.90
100	1	1.26	1	1	59.22	2.10

Table 0-4 Design Wind Pressure

Pz=.6Vz^2 [KN/m]	K_d	K_a	K_c	$P_d = K_d * K_a * K_c * P_z$
1.461	.90	.90	.90	1.3149
1.574	.90	.90	.90	1.417236966
1.66	.90	.90	.90	1.496323584
1.75	.90	.90	.90	1.57755735
1.90	.90	.90	.90	1.7177184
2.10	.90	.90	.90	1.89

Therefore, Intensity of pressure with storey height is given as below:

Storey height (m)	Design pressure intensity (KN/m^2)
3	1.19286
6	1.19286
9	1.19286
12	1.31512815
15	1.355513618
18	1.417236966
21	1.464431279
24	1.504350339
27	1.528559433
30	1.55296177
33	1.57755735
36	1.598201283
39	1.618979414
42	1.63989174
45	1.660938264
48	1.682118984
51	1.703433902

54	1.721155555
57	1.731487631
60	1.741850626
63	1.75224454
66	1.762669373
69	1.773125125
72	1.783611796
75	1.794129385
78	1.804677894
81	1.815257322
84	1.825867668
87	1.836508934
90	1.847181118

Calculation of C_{pe} and C_{pi}

Internal Pressure Coefficient is taken as +0.2 and other with an internal pressure coefficient of –0.2 (considering no large openings). This internal pressure coefficient is algebraically added to the external pressure coefficient and the analysis which indicates greater distress of the member, is adopted.

External pressure Coefficient for various angle of incidence is taken from ANSYS data where C_{pe} is calculated for different faces using CFD technique. The external pressure coefficient for different faces with different angle of attack of wind is tabulated as below:

Table 0-5 External Pressure Coefficient data (taken from ANSYS CFD model)

Building model	Angle of attack	Face A	Face B	Face C	Face D
Square	0°	+0.75	-0.49	-0.69	-0.69
	30°	+0.69	-0.53	-0.12	-0.66
	60°	-0.31	-0.58	+0.51	-0.55
	90°	-0.68	-0.65	+0.68	-0.45
Rectangle-1	0°	+0.74	-0.44	-0.66	-0.67
	30°	+0.69	-0.50	+0.14	-0.64
	60°	-0.30	-0.56	+.52	-0.53
	90°	-0.66	-0.62	+0.67	-0.43
Rectangle-2	0°	+0.74	-0.35	-0.62	-0.62
	30°	+0.68	-0.47	+0.15	-0.55
	60°	-0.30	-0.53	+.42	-0.49
	90°	-0.65	-0.61	+0.71	-0.36
Rectangle-3	0°	+0.73	-0.24	-0.59	-0.59
	30°	+0.67	-0.44	+0.17	-0.52
	60°	-0.29	-0.51	+0.57	-0.41
	90°	-0.61	-0.58	+0.74	-0.21

3 RESULTS AND DISCUSSION

3.1 MODEL 1

Model 1 is a square shaped building with side ratio 1 having a plan area of 900m^2 and height 90m. The plan view and Staad modelling are shown as below:

- **Column A**

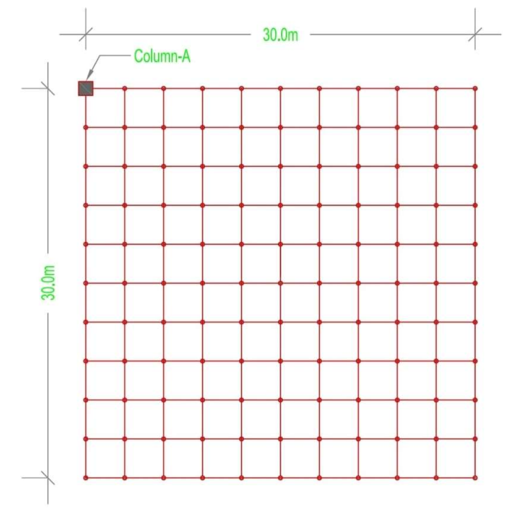

Figure 3-1 Plan view of Model 1 showing Column A

Nodes and Beam element of Column A in Staad modelling:

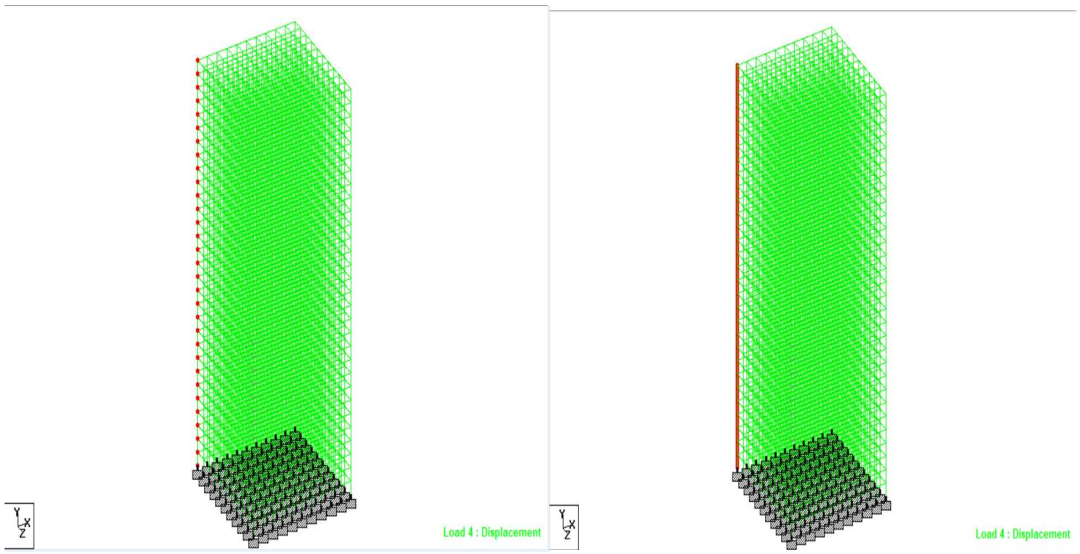

Figure 3-2 Staad Model showing column A position

Graphs for Column A

Deflections of Column

Horizontal deflection at column A at every floor level in ‘X’ direction and ‘Z’ direction and in different wind incidence angle are obtained during the analysis. The results are plotted as line graphs as shown in Fig. 4.4 and 4.5. Maximum deflection in Column A is around 87.8mm at top of the building at 0^0 wind incidence angle in X direction and maximum deflection in Z direction is around 86.05mm at top of building at 90^0.

For X translational deflection, as the angle of incidence changes from 0^0 to 30^0, the maximum horizontal deflection decreases a little, however on further increase of angle of attack it goes on decreasing as shown in the plot.

For Z direction, with increase in angle of attack, horizontal deflection also increases.

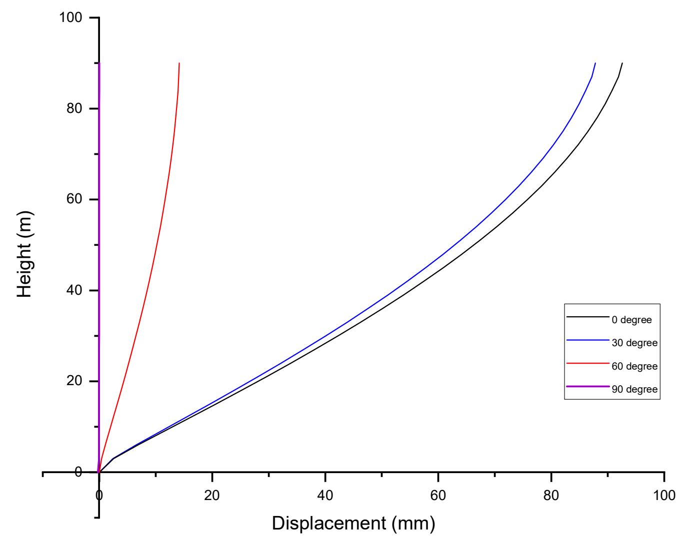

Figure 3-3 X translational Curve with different AOA

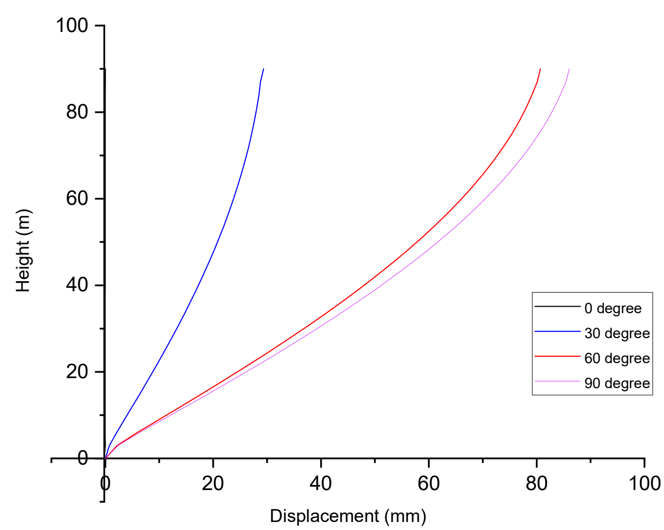

Figure 3-4 Z translational curve with different AOA

Forces on Column A

The Axial force on windward side corner column i.e., Column A increase nearly from top to bottom and small variation is noticed with the change in wind incidence angle. The axial force is maximum (14922kN) at 30^0 wind incidence angles.

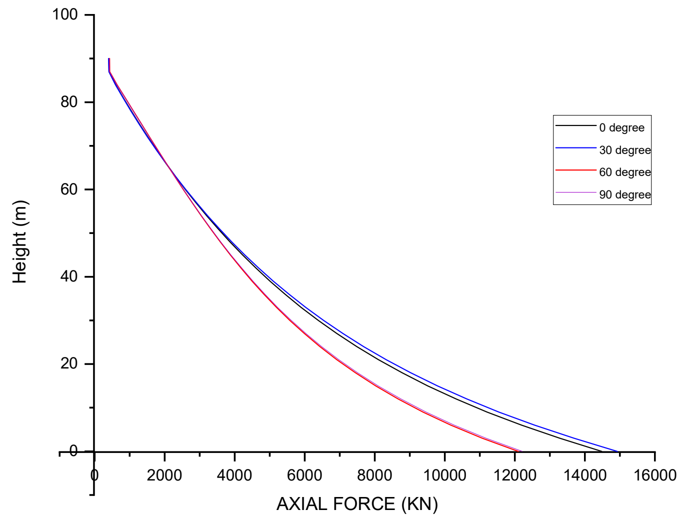

Figure 3-5 Effect of Angle of incidence on Axial force

Column B

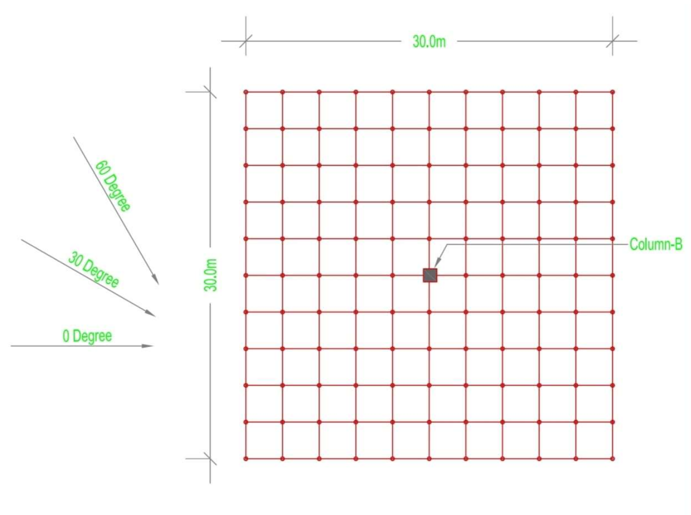

Figure 3-6 Plan View of model showing Column B

- Figures 4-11 and 4-12 show horizontal deflection in the X and Z directions for Column B at various angles of attack.
- At a 0° angle of incidence, the maximum X direction deflection is roughly 92.38mm, while at a 90° angle of incidence, the maximum Z direction deflection is around 86.4mm.

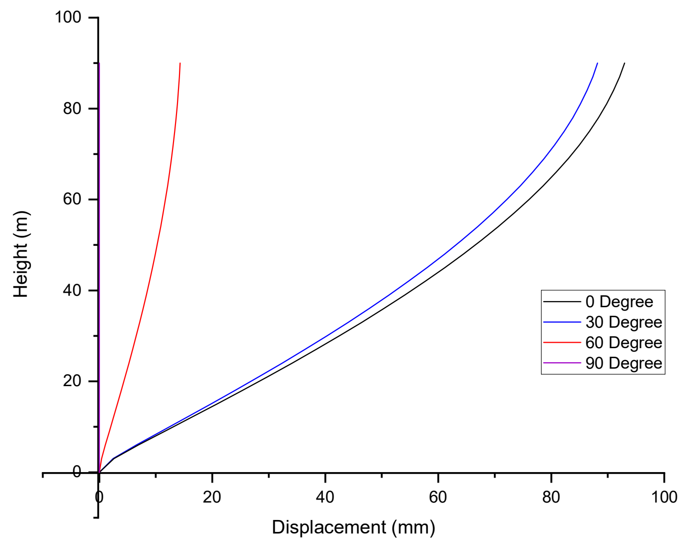

Figure 3-7 X translational deflection for column B

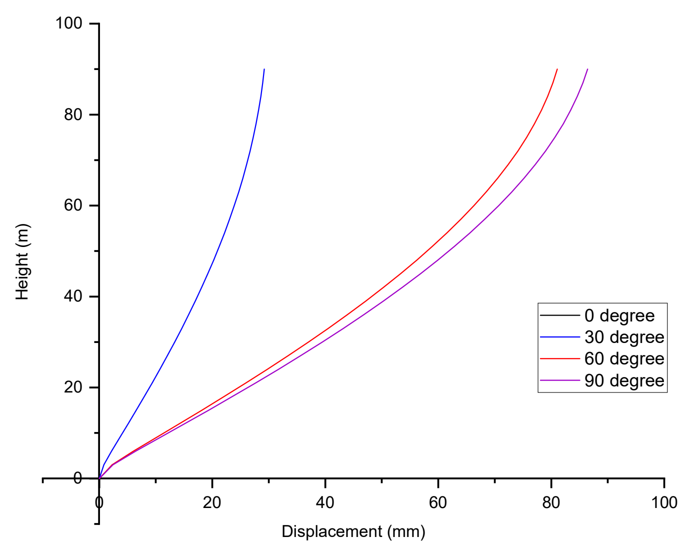

Figure 3-8 Z deflection with angle of incidence

3.2 MODEL 2

Model 2 is a rectangular shaped building with side ratio 1.44 having a plan area of 900m^2 and height 90m.

Column A

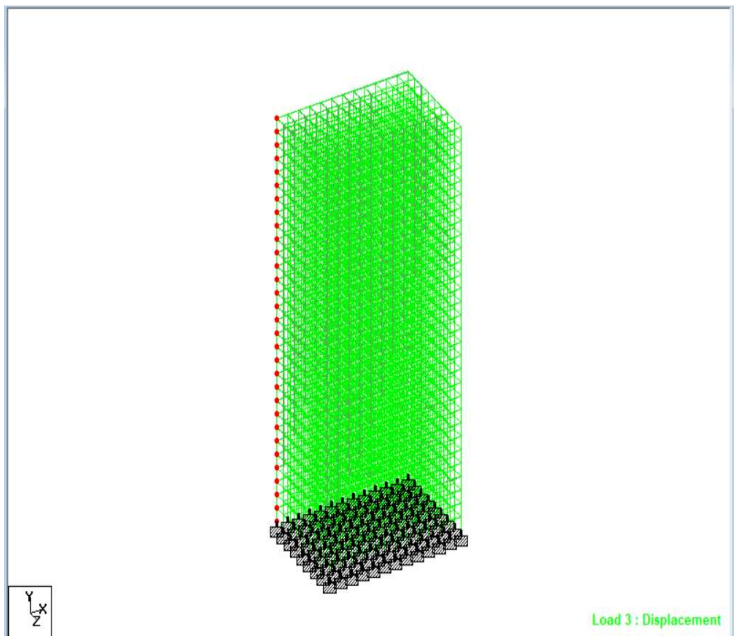

Figure 3-9 Staad model showing Column A

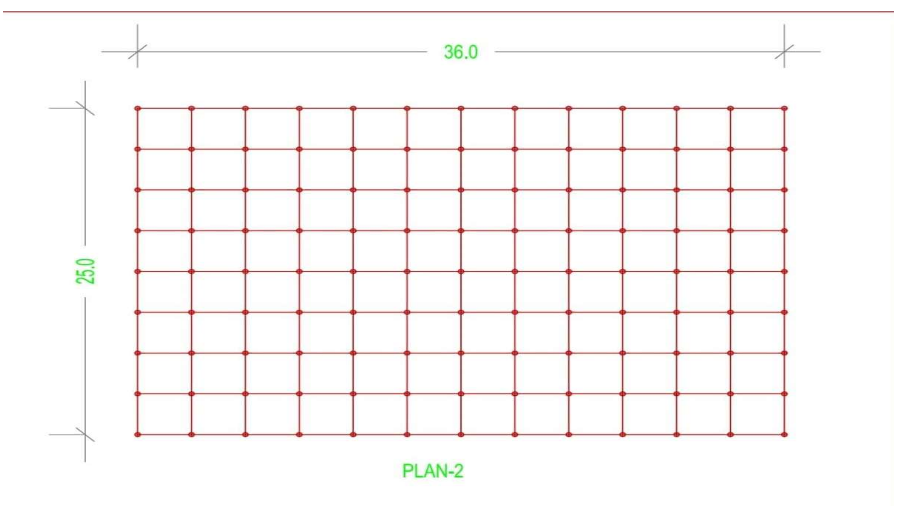

Figure 3-10 Plan view for Model 2

Horizontal Deflection

- Graphs showing variation of deflection for column A nodes in X and Z directions for different angle of incidence are plotted as line graphs as shown in Fig. 4.13 and 4.14.
- Maximum deflection in Column A is around 62.12mm at top of the building at 0^0 wind incidence angle in X direction and maximum deflection in Z direction is around 97.495mm at top of building at 90^0.
- For X translational deflection, as the angle of incidence changes from 0^0 to 30^0, the maximum horizontal deflection decreases a little, however on further increase of angle of attack it goes on decreasing as shown in the plot For Z direction, with increase in angle of attack, horizontal deflection also increases.

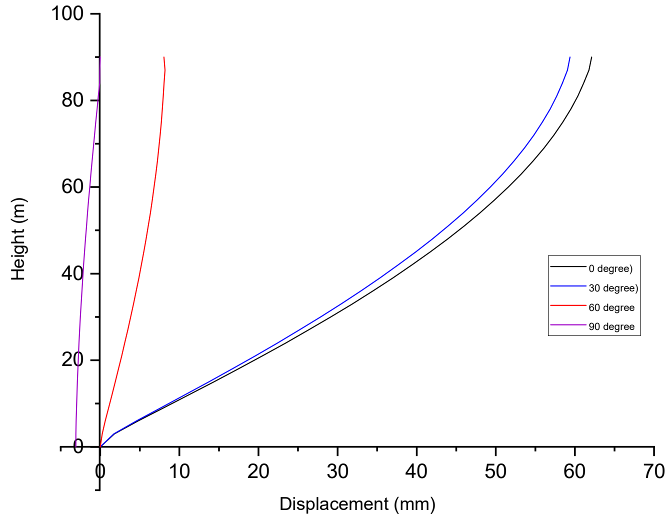

Figure 3-11 X translational defection for column A for different angle of incidence

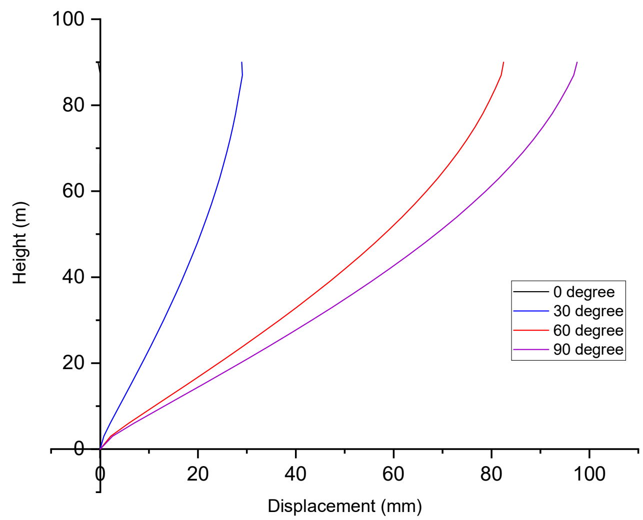

Figure 3-12 Z translational deflection for column A for different angle of incidence

Forces on Column

Axial force is maximum about 13066.622 KN at 0-degree of incidence and is plotted in figure 4-15 as shown:

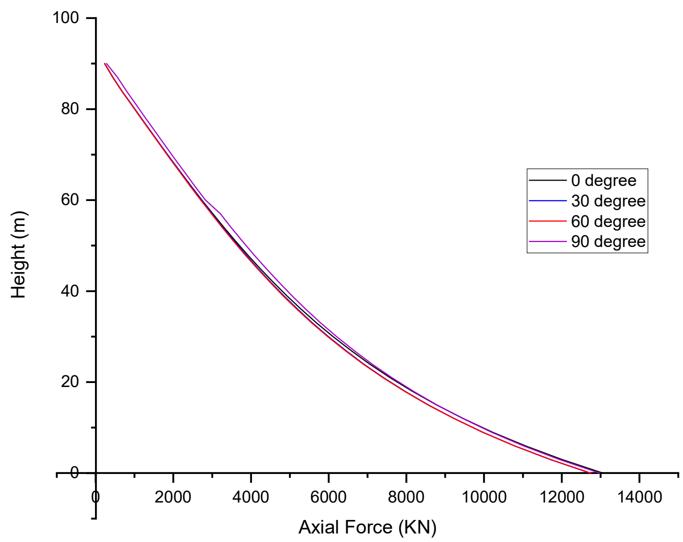

Figure 3-13 Effect of angle of incidence on Axial Force

Column B

Horizontal Deflection:

Figures 4-16 and 4-18 show horizontal deflection in the X and Z directions for Column B at various angles of attack. At an angle of incidence of 0° and 90°, respectively, the maximum horizontal deflection in the X and Z directions is 62mm and 98mm.

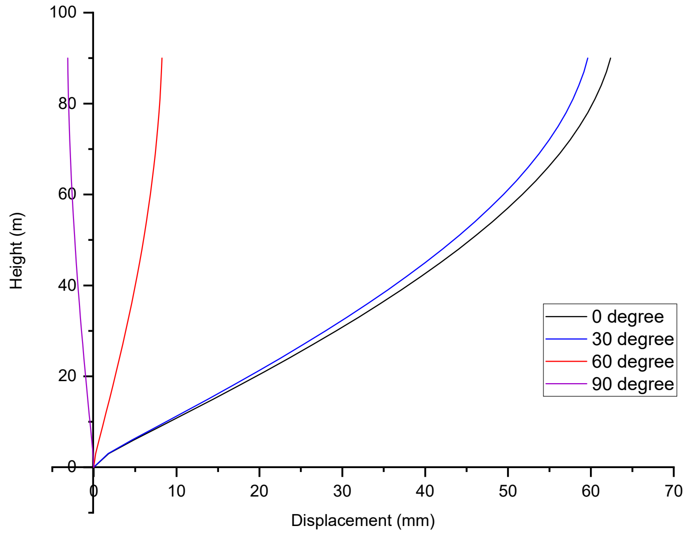

Figure 3-14 Effect of angle of incidence in X translational for Column B

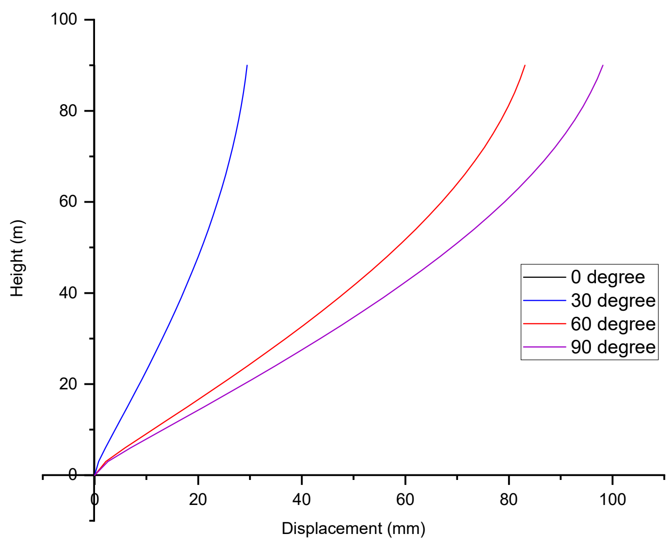

Figure 3-15 Effect of angle of incidence in Z translational for Column B

3.3 Model 3

Model 3 is a rectangular shaped building with side ratio 2.25 having a plan area of 900m^2 and height 90m.

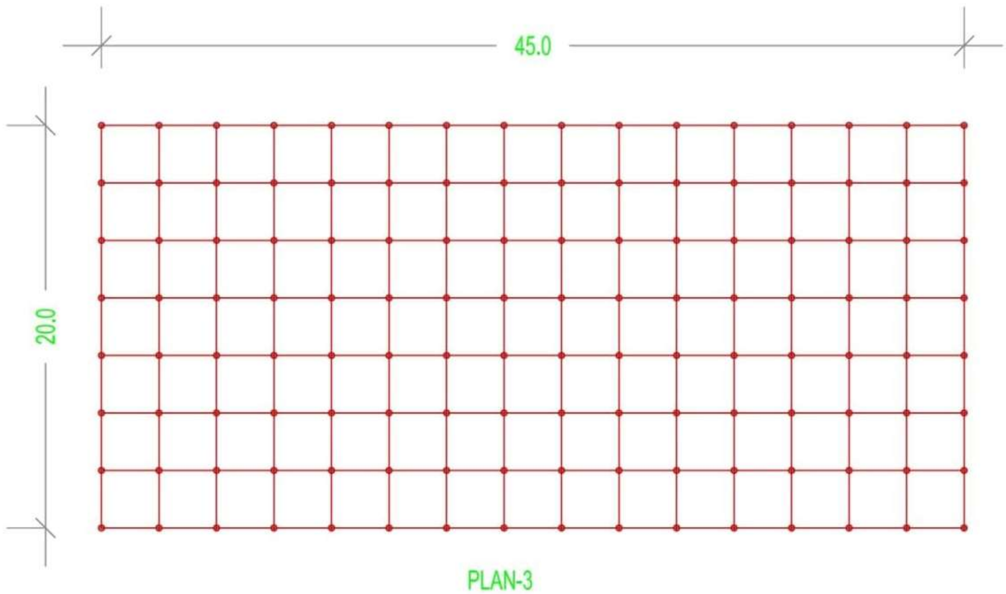

Figure 3-16 Plan View for Model 3

Column A

Horizontal Deflections

At the top of the building, maximum deflection in Column A is around 38.84mm in the X direction at 0° wind incidence angle, and maximum deflection in the Z direction is around 126.42mm at 90° wind incidence angle.

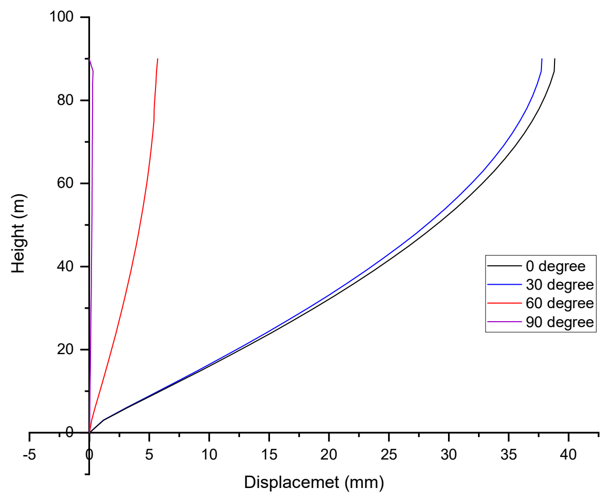

Figure 3-17 Effect on X deflection with angle of incidence

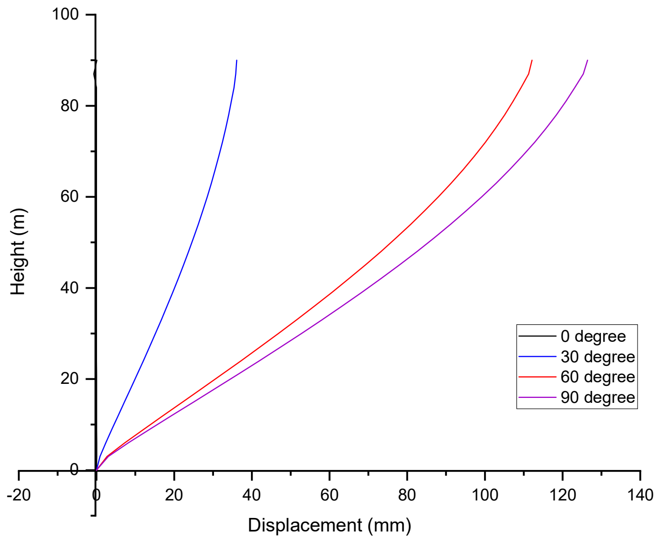

Figure 3-18 Effect on Z deflection with angle of incidence

Forces on column A

Axial force is maximum about 14066.622 KN at 0-degree of incidence and is plotted in figure 4-22 as shown:

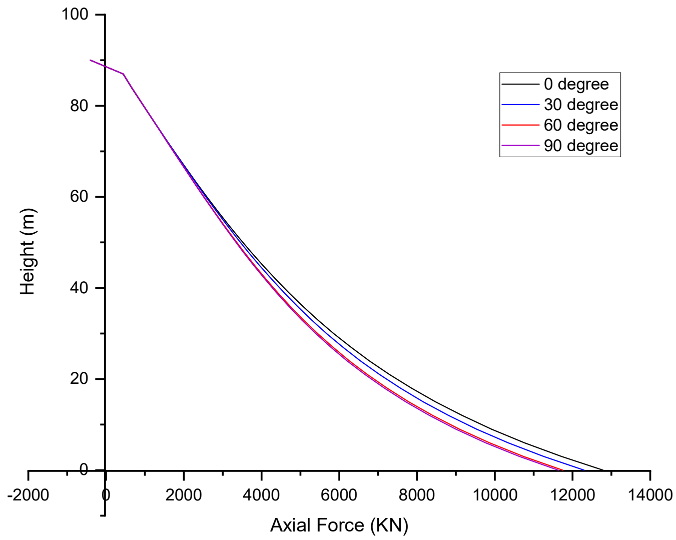

Figure 3-19 Effect on Axial force with angle of incidence

Column B

Horizontal Deflection. At an angle of incidence of 0° and 90°, respectively, the maximum horizontal deflections in the X and Z directions is 39.04mm and 123.62mm.

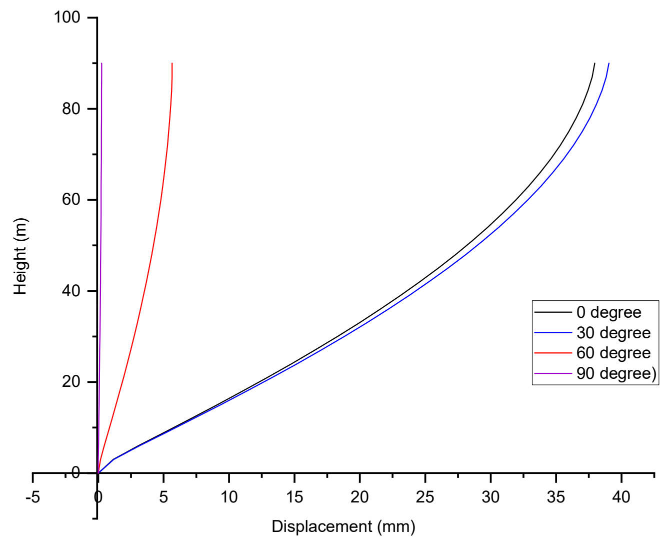

Figure 3-20 Effect on X translation with angle of incidence

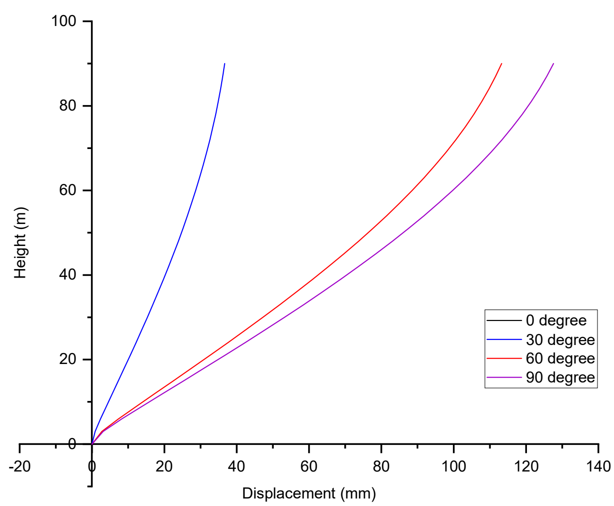

Figure 3-21 Effect on Z translation with angle of incidence

3.4 Model 4

Model 4 is a rectangular shaped model with side ratio 4 having a plan view as shown in the figure 4-25

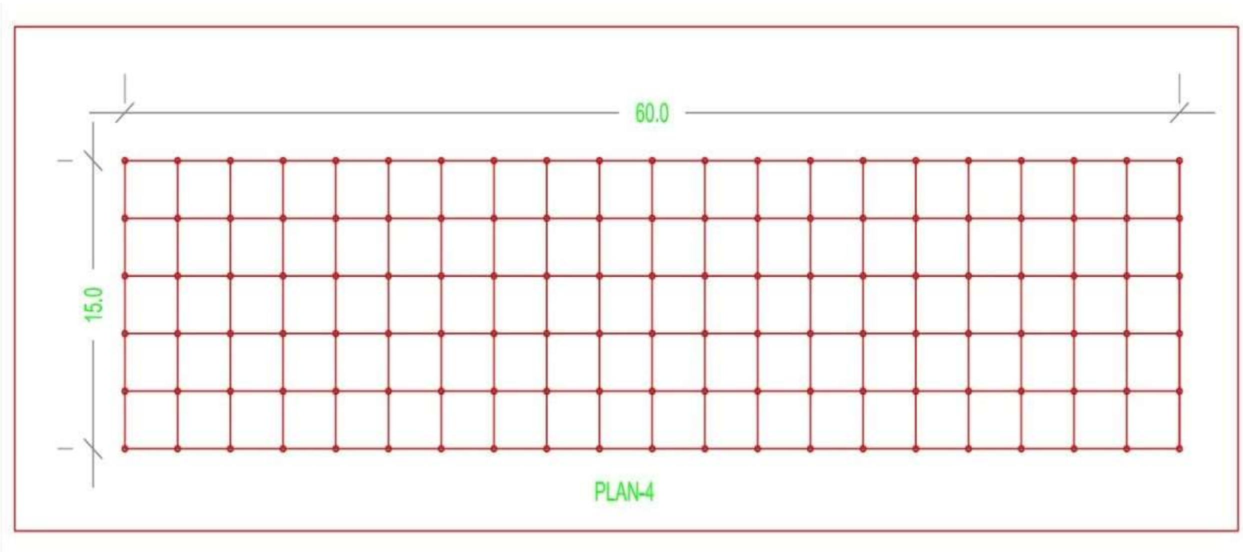

Figure 3-22 Plan View for Model 4

Column A

Horizontal Deflection

In the X direction, maximum deflection in Column A is around 19.10mm at the top of the building at 30°wind incidence angle, and maximum deflection in the Z direction is around 200.8mm at the top of the building at 90°wind incidence angle.

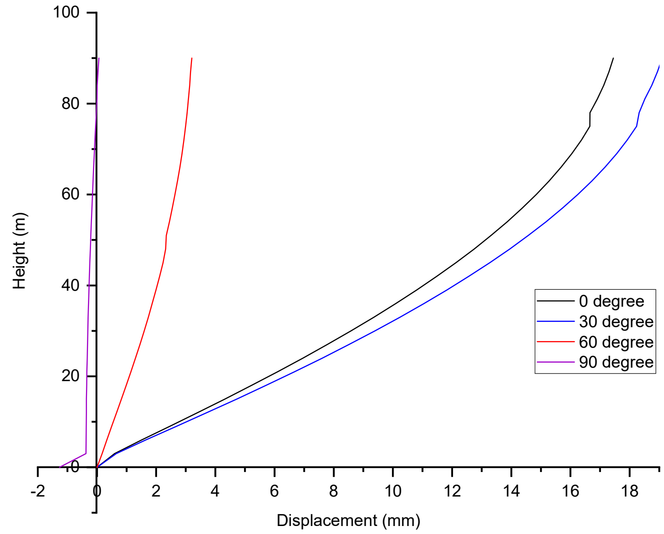

Figure 3-23 Effect on X translation with angle of incidence

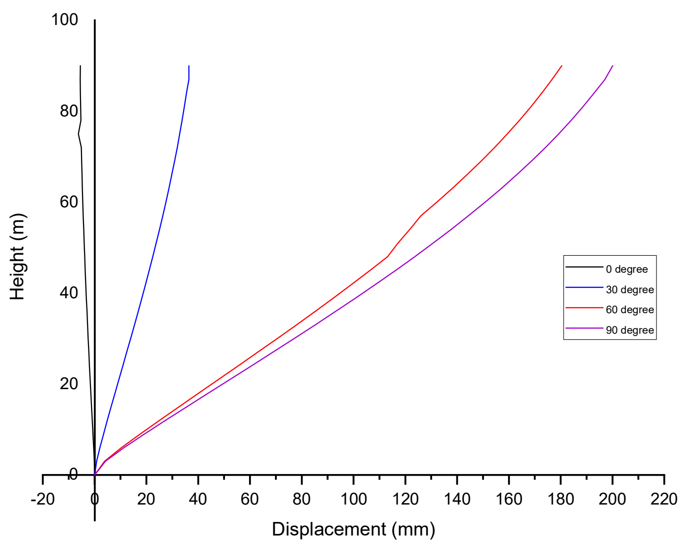

Figure 3-24 Effect on Z translation with angle of incidence

Axial Force on Column A

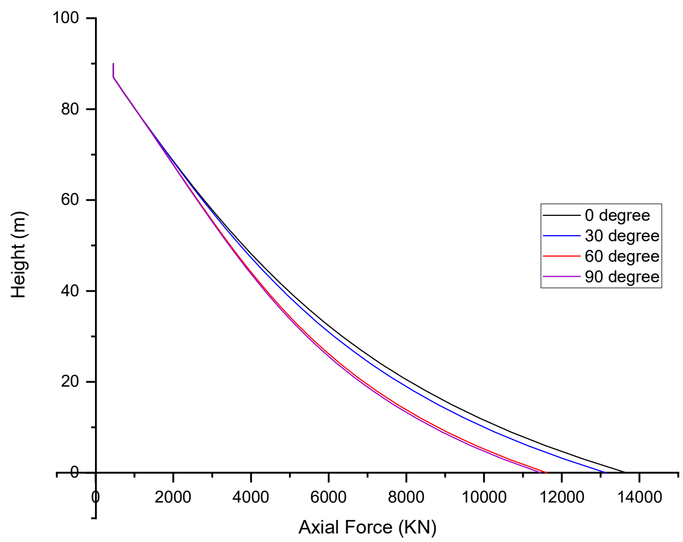

Figure 3-25 Effect on Axial force with angle of incidence

Column B

Horizontal Deflection.

At angles of incidence of 30° and 90°, respectively, the maximum horizontal deflection in the X and Z directions is 17.84mm and 201.8mm.

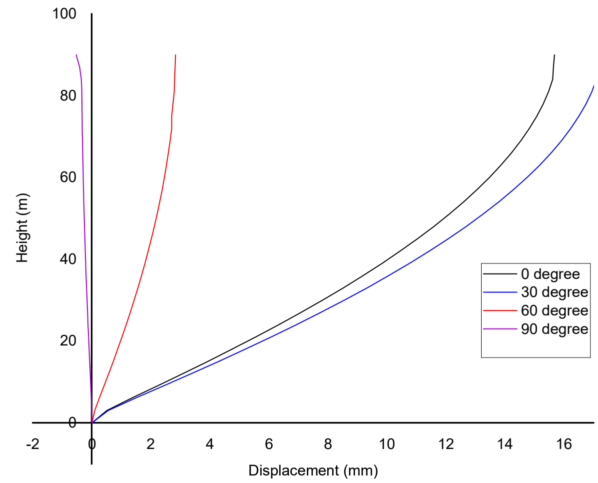

Figure 3-26 Effect on X translation with angle of incidence

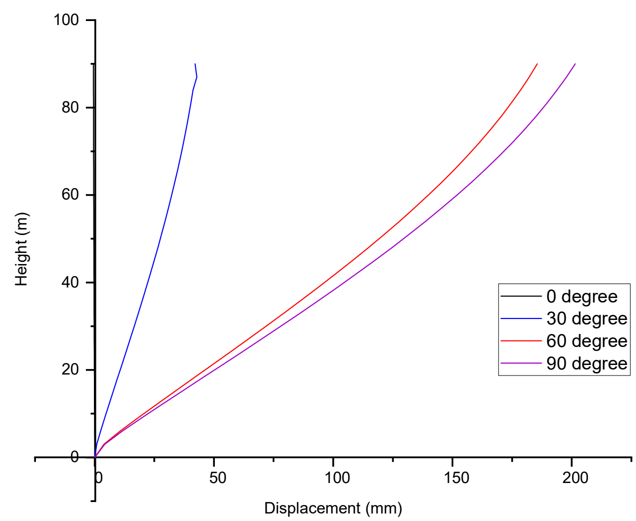

Figure 3-27 Effect on Z translation with angle of incidence

4 CONCLUSION

For Column A, the maximum translational deflections in X and Z directions considering different angle of attack are tabulated as below:

Table 4-1 Maximum translational deflection for column A with different AOA

Building model	Angle of attack	Max X translational (mm)	Max Z translational (mm)
Square (Side ratio 1)	0°	87.812	-0.233
	30°	82.587	29.34
	60°	14.159	80.68
	90°	0.014	86.05
Rectangle-1(Side ratio 1.44)	0°	62.12	-0.40
	30°	59.2	29.96
	60°	8.05	82.483
	90°	-3.093	97.495
Rectangle-2 (Side ratio 2.25)	0°	37.764	.10
	30°	35.84	36.10
	60°	5.68	111.25
	90°	-.021	126.421
Rectangle-3 (Side ratio 4)	0°	17.45	5.45
	30°	19.10	36.47
	60°	3.204	180.1
	90°	0.064	200.8

For Column B,

Table 4-2 Maximum translational deflection for Column B with different AOA

Building model	Angle of attack	Max X translational (mm)	Max Z translational (mm)
Square (Side ratio 1)	0°	88.18	0
	30°	82.98	19.20
	60°	14.305	81.08
	90°	0	87.45
Rectangle-1 (Side ratio 1.44)	0°	62.36	0
	30°	59.62	29.46
	60°	8.235	83.483
	90°	-3.138	98.15
Rectangle-2 (Side ratio 2.25)	0°	37.94	.01
	30°	35.04	36.69
	60°	5.64	111.58
	90°	.0261	123.62
Rectangle-3 (Side ratio 4)	0°	15.68	.545
	30°	17.18	42.47
	60°	2.84	178.1
	90°	0.054	201.8

- From the graphs obtained, it is clearly depicted that Deflection of columns increases with height and as the side ratio changes influence on deflection have been compared for models.
- Horizontal deflection at column A and B at every floor level in ‘X’ and ‘Z’ direction and in different wind incidence angle are obtained during the analysis.
- Deflection in X translational is found to be maximum when the angle of wind is 0-degree and as the angle of attack of wind changes the deflections also get reduced in X translational, However, deflection in Z translational is minimum for 0- degree angle of attack and increases as the angle of attack increases further.
- Max deflection in Z translational is noticed when the angle of attack is 90-degree.
- Maximum deflection in X direction for Column A and B is around 88mm mm at top of the building at 0° wind incidence angle for Model 1 whereas Maximum deflection in Z direction is around 200mm at 90-degree wind incidence for Model 4
- Axial force shows similar nature of curves in all cases being maximum at ground and decreases with increase in height. Axial force on windward side corner column i.e. Column A increase nearly from top to bottom and small variation is observed with the change in wind incidence angle.

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