COMPARATIVE RESPONSE ANALYSIS OF BUILDINGS WITH AND WITHOUT BRACING UNDER WIND LOAD EFFECT

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Submitted by:

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CANDIDATE'S DECLARATION

I, VIKRANT VIPLAV, Roll No. 2K17/STE/21, student of M. Tech. (Structural Engineering), hereby declare that the project Dissertation titled "**COMPARATIVE RESPONSE ANALYSIS OF BUILDINGS WITH AND WITHOUT BRACING UNDER WIND LOAD EFFECT"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled "**COMPARATIVE RESPONSE ANALYSIS OF BUILDINGS WITH AND WITHOUT BRACING UNDER WIND LOAD EFFECT**" which is submitted by **VIKRANT VIPLAV**, 2K17/STE/21, Civil Engineering, 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 not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **DR. RITU RAJ**

Date: SUPERVISOR

ABSTRACT

In the present era, the trend in construction industries is more inclined towards tall building i.e. vertical expansion of the building, due to the scarcity of land available and increasing population. The cost of the building increases as the height of the building increases due to the increase in the weight of the building and forces. As the height of the building increases, lateral movement of the building also increases (sway).To reduce the sway one of the techniques used is ‘bracing’. There are many types of bracings normally used in the practice such as x-bracing, v-bracing, inverted v-bracing, eccentric bracing, k-bracing etc. Also these bracing can be provided at different positions in the buildings. In the present study, 20 storey steel structure of height 60m (3 m each storey) was considered. The structure was designed as per IS 800:2007 code with dead load, live load and wind load combinations. Static analysis was performed using E-tabs software assuming, importance factor as 1.15, Terrain category IV and Topography to be flat. The analysis was performed according to IS 875:2015. The analysis was performed for buildings of two plan shapes, square and plus shape, with x-bracing, v-bracing, inverted v-bracing, diagonal bracing, k-bracing and without bracing. The results were compared and studied. It was found that the lateral response of the structure was more in the structure without bracing than other models. It was also observed that lateral loads were more in the case of X-bracing. Finally, it can be concluded that Inverted V-bracing is better for wind loading.

ACKNOWLEDGEMENT

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Place: **VIKRANT VIPLAV**

Date: **2K17/STE/21**

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MRF – Moment Resisting Frame

DBF – Diagonal Braced Frame

VBF – V Braced Frame

I.VBF – Inverted V Braced Frame

XBF – X Braced Frame

KBF – K Braced Frame

M_Y – Moment about Y-axis

M_X – Moment about X-axis

Δ_X – Lateral Displacement along X-axis

F_X – Shear force along X-axis

0º WIND ANGLE – Wind flow along the direction of X-axis

30º WIND ANGLE – Wind flow at 30º anticlockwise direction of X-axis

60º WIND ANGLE – Wind flow at 60º anticlockwise direction of X-axis

Chapter -1
INTRODUCTION

1.1.GENERAL

The advancement in construction in the present era has made many engineers and researchers enthusiastic and excited about skyscrapers. Lightweight and high strength materials along with different construction techniques and systems have led to the construction of many marvellously tall buildings like Burj Khalifa in Dubai, Taipei 101 in Taiwan, and Shanghai Tower in China, etc. in the past couple of decades. However, the construction of tall buildings has its own set of problems. Major concerns of the skyscrapers are first, lateral instability and second, the discomfort of occupants caused by dynamic behaviour due to lateral loads, like wind and earthquake. The lateral instability of tall buildings depends more on lateral stiffness than the strength of the building and to increase the lateral stiffness, many researchers have come up with various ideas of construction systems like Diagrid system, Outrigger system, Tube system, tube in tube system, Bracing system, Bracing with tube system, and etc.

This paper focuses on studying the behaviour and importance of bracings in tall buildings as they are highly efficient and economical for resisting lateral forces caused due to wind and earthquake.

1.2. BRACING SYSTEM

Bracings are diagonal members which work primarily in axial stress, resulting in minimum member size. Braced frames are generally placed in the cavity of the walls and lift core area for aesthetic purposes but nowadays they are exposed to the public in many buildings. In the structural system, bracings are classified into two categories majorly as,

a) Concentric Bracing System
The structural system in which all members (columns, beams, and bracings) meet at a common endpoint is called as concentric bracing. They provide lateral resistance mainly through axial force, so they are easy to design and assemble during construction. Concentric bracings have various shapes such as K-bracing, V-bracing, I.V-bracing, Z-bracing, Diagonal bracing, X-bracing, etc. depending on the orientation in which bracings are placed as shown in figure 1.1

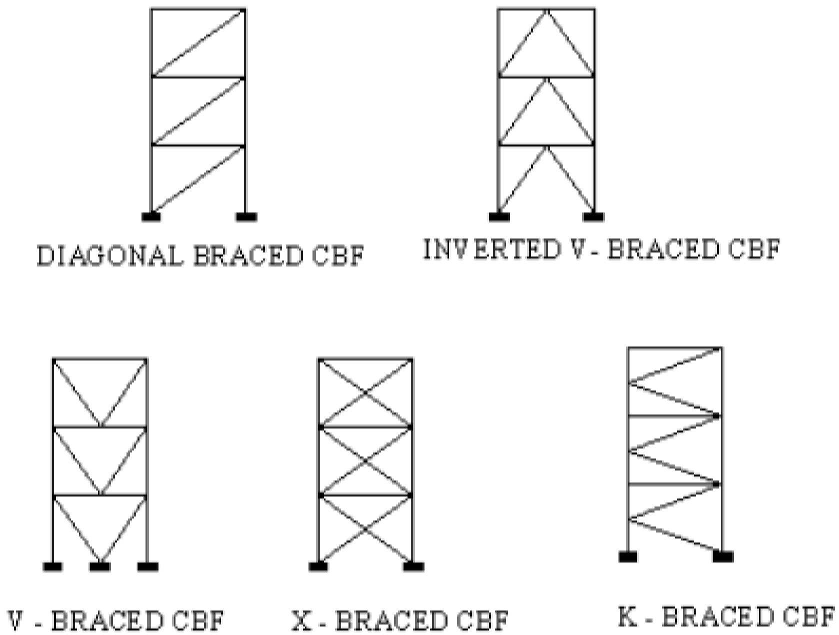

Fig.1.1. Concentric bracing frame with different shapes

b) Eccentric Bracing System.

Eccentric bracing is different from concentric bracing, as the braces are offset from the columns or do not intersect at the floor beams. These type of bracings are eccentrically connected and lateral resistance is provided through axial force and bending moment. They are designed such that they do not buckle under extreme loading conditions and the axial forces induce is transmitted to either column or another brace through shear and bending in a link. Some of the examples of eccentric bracing are shown in figure 1.2.

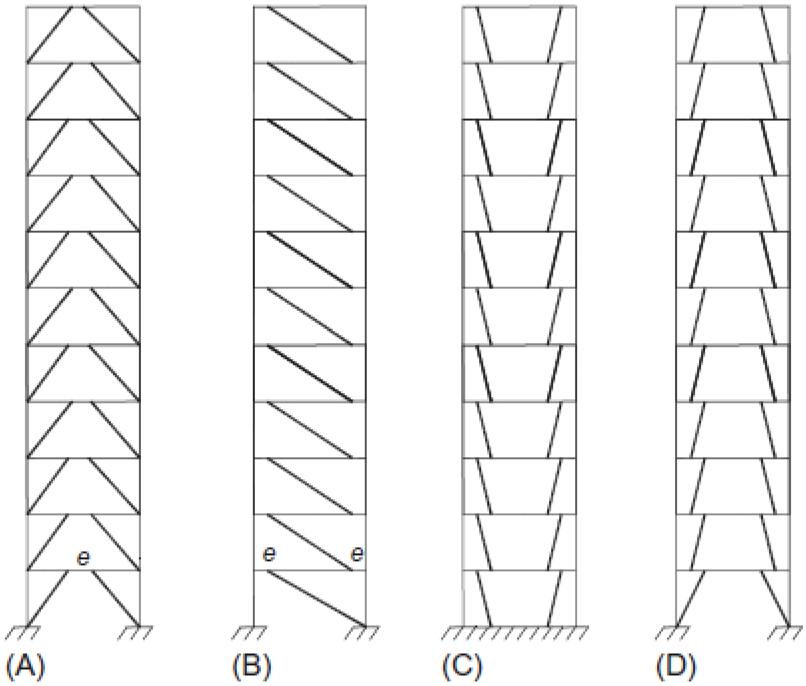

Fig.1.2. Eccentric bracing frames with different shapes

1.3. Nature and effect of wind

The wind is a complicated random varying occurrence. The velocity with which wind blows is the sum of two components, mean and fluctuating, and both vary with height, terrain profile and topography. The fluctuating velocity is the cause of gusting. Small and medium height buildings act as rigid structures, so it is adequate to consider equivalent static wind load for lateral wind forces. However, tall buildings which act as flexible structures, it becomes important to consider wind energy spectrum, integral length scale, averaging time and frequency of the structure. These buildings vibrate due to inherent turbulence in the wind and the turbulence generated by the structure itself due to the separation of flow.

The horizontal dynamic forces due to wind act in the direction of flow as well as across the flow. The fluctuating component of wind velocity along the direction of flow leads to vibration of the structure and if this vibration matches up with the natural frequency of vibration the building will cause resonance, so the major portion of the dynamic effect of wind is due to this resonance. This resonance leads to structural failure and discomfort to the occupants, so dampers are used to reduce them.

The across wind response caused due to the separation of flow from the cross-section of structure results in vortex shedding at the given frequency. The pattern of across wind phenomena is comparatively regular for symmetrical and rounded structures like chimney and towers. Buildings which are tall and slender, the across wind is important behaviour to consider. The fig.1.3 shows the how wind flows around an isolated building causing separation of flow and vortex shedding.

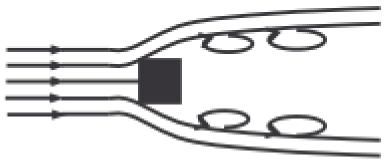

Fig.1.3. Flow of wind around a building.

Chapter-2
LITERATURE REVIEW

2.1 GENERAL

This study aims to understand the effect of the different bracing system employed in tall buildings with (i) wind loads at different angle of incidence and (ii) wind pressure distribution over the height of the building. The study includes two plan shapes: Square plane shape and plus plane shape buildings with three angle of incidence of wind.

During the last couple of decades, many researchers have analysed, numerically and analytically various models with different types of lateral load resisting systems such as Diagrid system, bracing system, bracing with tube structure, outrigger system, etc. Others have conducted wind tunnel test on models to study the effect of wind on various parameters related to the stability of tall buildings.

This chapter has included many such research papers and contributions which have direct or indirect relevance in understanding the behaviour of wind load on the structure.

2.2 RESEARCH REVIEW

Alberto Carpinteri, Giuseppe Lacidogna, Sandro Cammarano (2013), In their paper, studied the structural behaviour of tall buildings sustained by any kind of bracings and shear walls with closed or open section. They compared the results, lateral displacement and storey rotation, obtained by analytical and numerical methods, were similar.

Xiaoye Yu, Tianjian Ji, Tianxin Zheng (2015), they studied bracing arrangements of a four-bay four-storey frame. Used both numerical and analytical methods to examine the relationships between lateral stiffness and internal forces, between internal forces and bracing patterns and between bracing patterns and lateral stiffness (displacement) of the frame. They concluded that the mega X-brace or the double inversed V-brace leads to the stiffest four-bay and four-storey frame, depending on the panel aspect ratio and the member size ratio of columns to beams.

Kyoung Sun Moon (2014), this study investigated comparative structural efficiency between three structural systems for tall buildings, based on lateral stiffness. Tall buildings of 40, 60, 80 and 100 storeys were optimally designed with braced tubes, diagrids and outrigger structures to meet the lateral stiffness requirements. It was found that both the braced tubes and diagrids are very efficient structural systems for tall buildings. For very tall buildings with greater height to width aspect ratios, braced tubes tend to be more efficient than diagrids.

Kim et al. (2008) compared the structural efficiency of the diagrids, braced tube and outrigger system for a 51-storey building in Asan, Korea, the height-to-width aspect ratio of which is about 5.5. Based on the comparative study, they found that the diagrid system was the most efficient among the three for the building.

A.Tallin & B. Ellingwood (1985) investigated the lateral-torsional response of buildings to wind forces used realistic wind force spectra and random vibration theory. They concluded that the across-wind force is the major factor in determining the total response of the building. The torsional motion, in some cases, maybe the largest contributor to the total response, particularly near the perimeter of the building, when the centre-of-rigidity is displaced from the building centre and the stiffness is an important factor in determining the motion sensitivity of a tall building.

D.E. Nassani et al. (2017) assessed the seismic behaviour of steel frames of four different height levels (4, 8, 12, and 16 storeys) by using unbracing and bracing systems. They showed improvement in the seismic resistance of frames with the incorporation of bracing and revealed that the bracing elements were very effective in diminishing drifts since the reduction of inter-storey drifts in comparison to unbraced frames were on the average 58%. Also steel braces considerably reduced the global damage index. IVF, VBF and ZBF systems were recommended because they showed lower storey displacement and inter-storey drift ratio indicating that these systems have strength and stiffness.

Dhara Panchal and Sharad Purohit (2013) carried experimental study to control the dynamic response of building model using bracings for controlled as well as uncontrolled building models. It was found that response quantities like displacement and acceleration obtained for controlled systems with bracings showed a considerable reduction. Inverted V-type concentric bracing was found to have a maximum increase in the damping as compared to other types of the bracing system.

Dhanaraj M. Patil, Keshav K. Sangle (2015) performed a pushover analysis of 2-D steel tall buildings of different heights with different bracings to study the performance on these buildings under earthquake load. They compared the results obtained and showed that CBF and VBF significantly lower lateral displacement and inter-storey drift ratio indicating large strength and stiffness of these systems.
The result also showed that CBF and VBF have a nearly similar and least seismic response for base shear for all storeys and high for MRF and XBF.
They concluded that Seismic performance of buildings with ZBF was higher than buildings with other bracings.

Ramtin Avini et al. (2019) compared the results obtained through design code and CWT for wind loading on 80 m tall buildings with minimal surrounding at two different location, namely New York and London. The horizontal acceleration at top of the building due to wind was calculated and discussed in terms of comfortability criteria. They found that analytical method provides conservative results to CWT. CWT being a relatively cheap and accurate tool in comparison to wind tunnel test provides a preliminary understanding of aerodynamic effect of wind on tall building model with different surrounding.

Ahsan Kareem (1982) devised a method to evaluate the fluctuating wind forces and its distribution on the tall building. It was applied to understand and quantify the crosswind loads on a square cross-sectional building. The methodology also provided information on the local Spatio-temporal variation of pressure fluctuations which could provide useful input to the cladding design.

Hideyuki Tanaka et al. (2012) conducted aerodynamic force measurements and wind pressure measurements for tall building models with various building shapes and configurations with same height and volume and compared the aerodynamic characteristics of tall buildings.

H. Hayashida & Y. Iwasa (1990) studied the effects of aerodynamic displacement and forces on high rise buildings with different plan shapes. Eight types of the plan were considered of equal floor area. Each building was of 600 m and the wind tunnel test was conducted. The buildings were subjected to vortex-induced vibration and two wind direction. The results obtained were compared with the analytical method. They concluded that the change in the shape of the structure and direction of the wind has a significant change in aerodynamic behaviour of the structure under wind load.

2.3. Indian standard code

I.S. code 875 (part-3) provides the general formula for the determination of wind forces on a building. The wind load calculation depends upon the different factors:

i) Topography of surroundings
ii) Aspect ratio and shape of the building
iii) The angle of wind direction
iv) Speed and density of air along the height

Computation of wind load

Design of wind speed (V_Z):

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

V_b = basic wind speed in m/s;

Where,

K_1 is Probability factor (risk coefficient)
K_2 is terrain category
K_3 is topography factor
K_4 is The Importance factor

The basic wind speed (V_b) for any site shall be obtained from the figure given in I.S. code page no. 6 and shall be modified to include the following effects to get design wind velocity at any height (V_z) for the chosen structure.

a) Risk level;
b) Terrain roughness height and size of the structure; and
c) Local topography
d) The Importance factor

Note: design wind speed up to 10m height from mean ground level shall be considered constant.

Wind Pressure and force on a building:

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

$$P_Z = 0.6\,(V_Z)^2$$

Where,

P_Z = wind pressure in N/m^2 at height z, and
V_Z = design wind velocity in m/s at height z

The design wind pressure,

$$P_d = K_d * K_a * K_c * P_Z$$

where,

K_d = Wind directionality factor
K_a = Area averaging factor
K_c = Combination factor

The calculation of wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, takes account of the pressure difference between opposite faces of such elements or units. For clad structures, it is necessary to know the internal pressure as well as the external pressure. The wind load, F, acting in a direction normal to the individual structural element or cladding unit is:

$$F = (C_{pe} - C_{pi}) * A * P_d$$

Where,

C_{pe} = external pressure coefficient,

C_{pi} = internal pressure coefficient

A = surface area of a structural element or cladding unit, and

P_d = design wind pressure

Chapter-3
STRUCTURE MODELLING

3.1. GENERAL

The 3-dimensional models of structures are created and wind load analysis is done using E-Tabs software. The lateral wind load to be applied on the buildings are based on the Indian standard IS-875:2015(Part 3) and the live loads and dead loads are based on IS 875:1987(Part 1) and (Part 2). The buildings consist of steel columns and beams along with concrete slab is of 20 storeys which are analysed for different types of bracings placed at the corner bays on the face of the structure. The objective of this thesis is achieved by considering two plan shape (square and plus as shown below in this chapter) tall building models with and without bracings.

3.2. DETAILS OF MODELS

3.2.1. Square shape plan models

The plan area of the model is 625 m^2 with 200 mm thick slab as floor. The beam and columns are of steel I-section with bracings of angle section. Models are of height 60m. The specifications of the material and size of the individual elements are given table 3.1.

The fig.3.1 shows the 3-D view of building with square shape plan.

Fig 3.2 to 3.7 show the front view or elevation of structure with the different bracing system.

Sl. No.	**Parameters**	**Values**
1.	Beam size	ISLB300
2.	Column size	ISWB300
3.	Bracing size	ISA 100X100X8
4.	Grade of Steel	Fe345
5.	Grade of concrete	M30
6.	Floor Dimension	25mX25m
7.	No. of bays	5
8.	Height of each Storey	3m
9.	No. of storeys	20

Table 3.1. Material properties and Size of elements

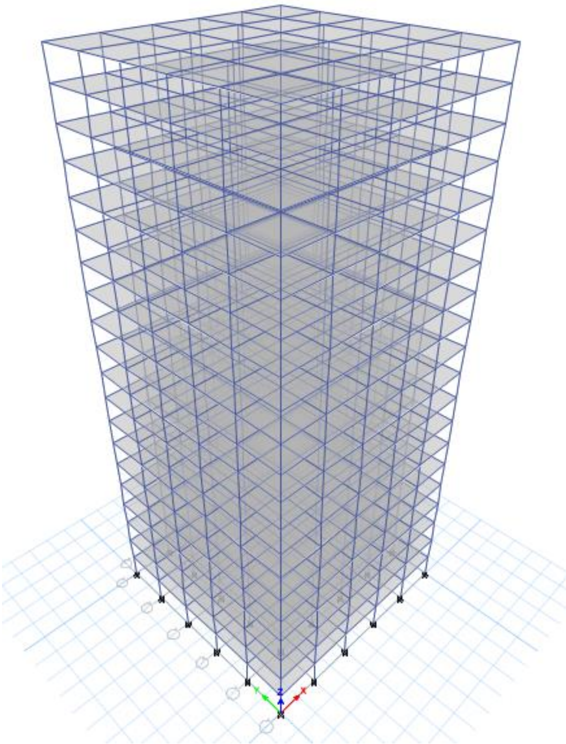

Fig.3.1. 3-D model of square shape plan building

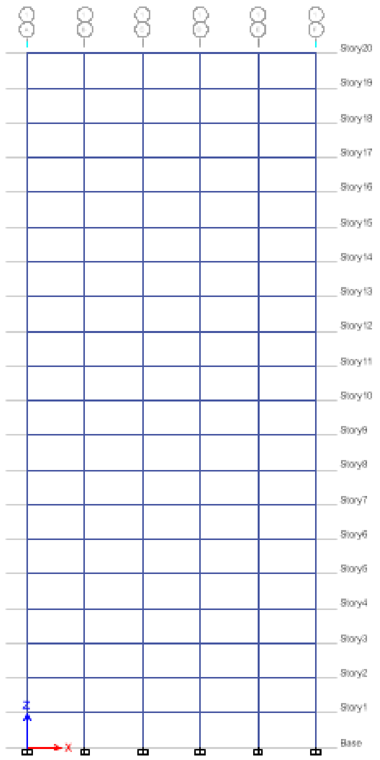

Fig.3.2. MRF model

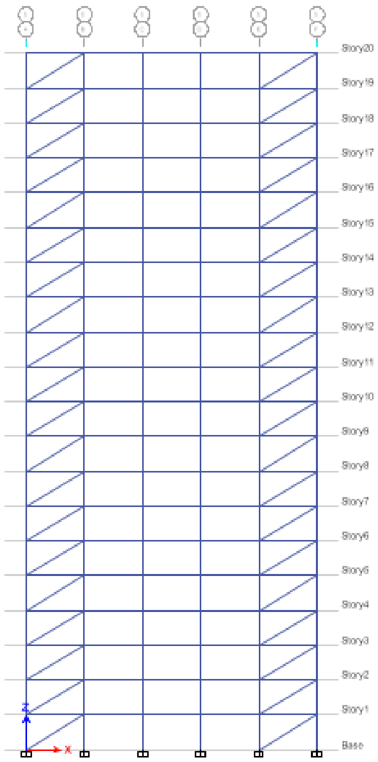

Fig.3.3. Diagonal brace frame

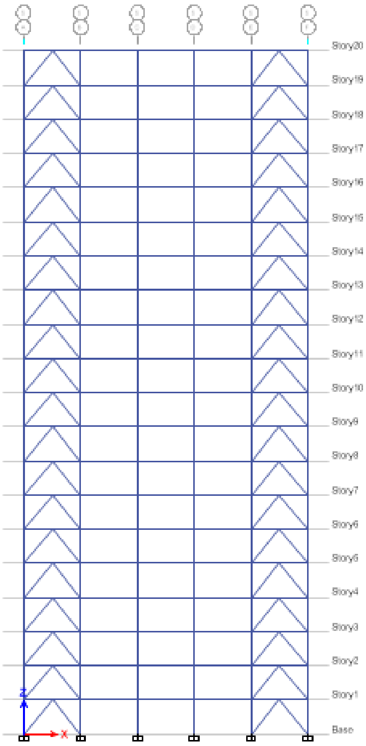

Fig.3.4. I.V-brace frame

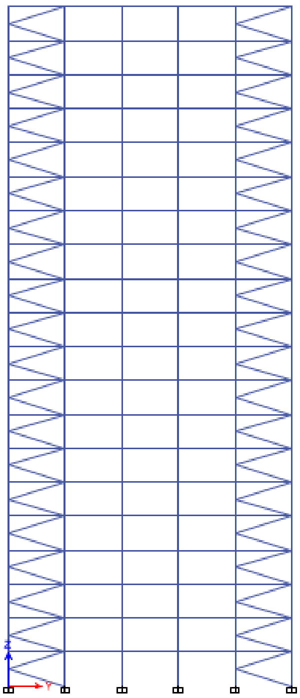

Fig.3.5. K-brace frame

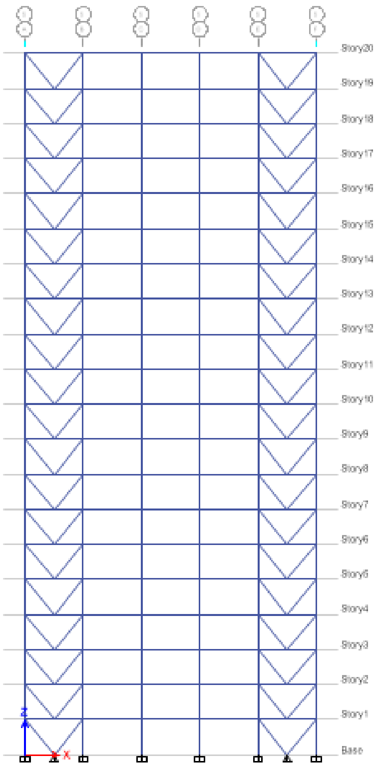

Fig.3.6. V brace frame

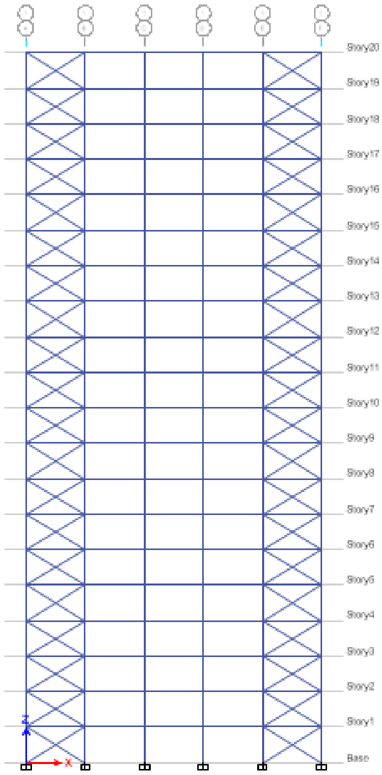

Fig.3.7. X-brace frame

3.2.2. Plus Shape plan models

The models have a plan area of 825 m^2 with 200 mm thick floor slab. Height of structure is 60 m. The length of each bay is 5m. The size of beams, columns and bracings are ISLB300, ISWB300 and ISA100X100X8 respectively.

Grade of steel and concrete used is Fe 345 and M30 respectively.

The fig.3.8 shows the 3-D view of the building with plus shape plan and fig.3.9 to 3.14, front view or elevation of structure with different bracings.

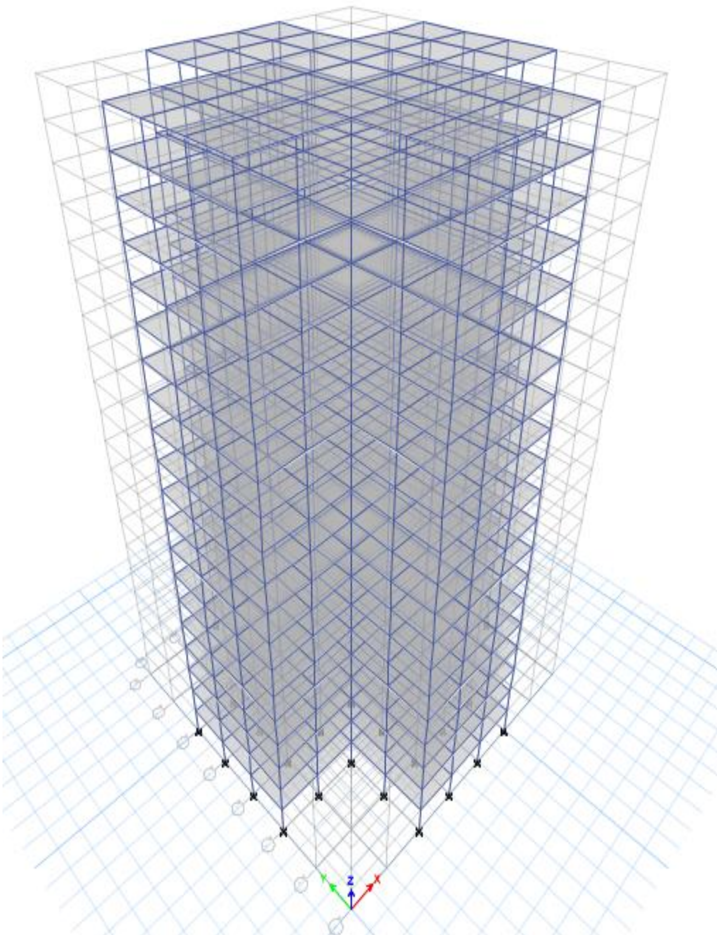

Fig.3.8. 3-D model of plus shape building

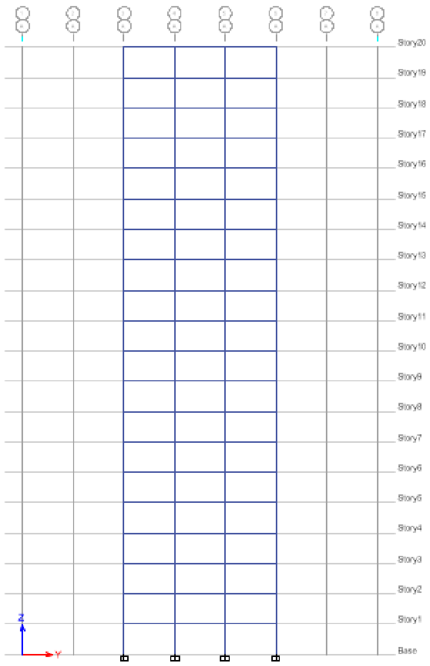

Fig.3.9. MRF model

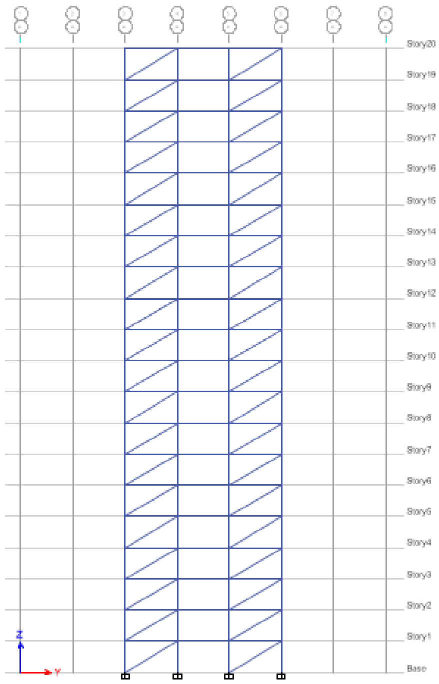

Fig.3.10. Diagonal brace model

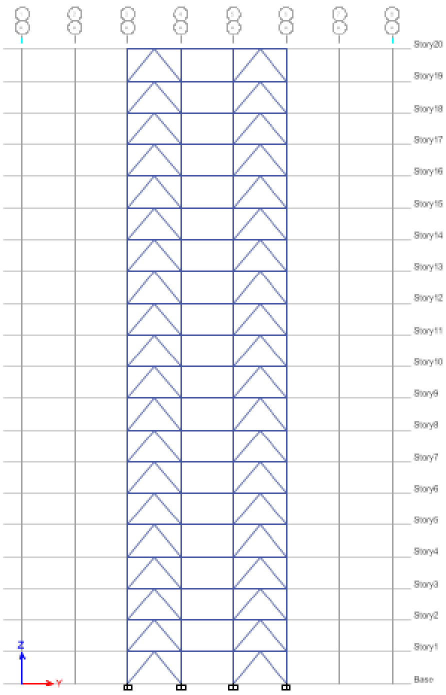

Fig.3.11. I.V-brace frame

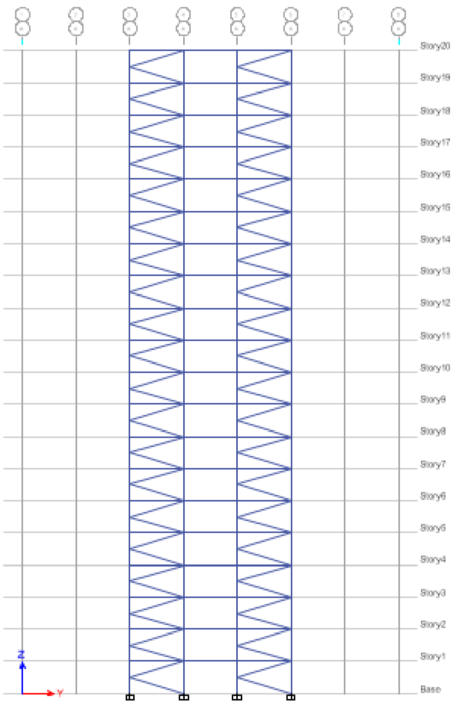

Fig.3.12. K-brace frame

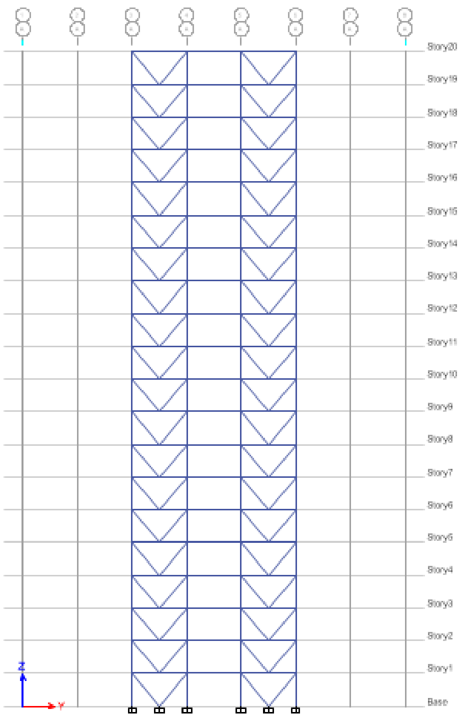

Fig.3.13. V-brace model

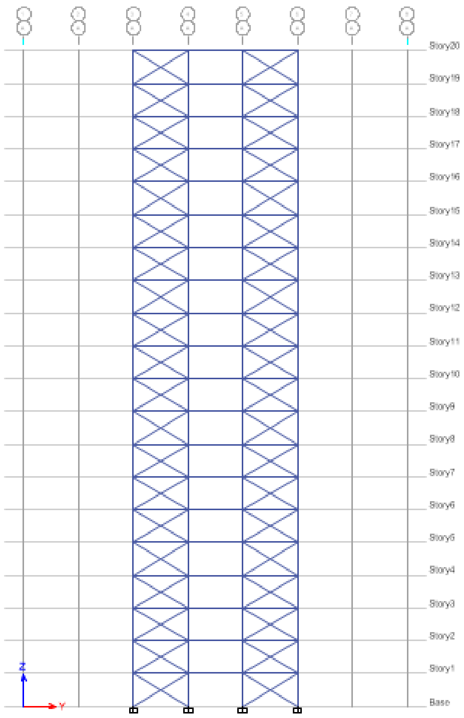

Fig.3.14. X-brace model

3.3. Load consideration

In the analysis, buildings are subjected to self-weight and live load as gravity load. A live load of 2.0 kN/m^2 is considered and self-weight is assigned to the structure and its members. The lateral load is produced by the wind along the height of the building and parameters involved are as given in table 3.1. As per I.S code limit state of collapse, load combination of all three loads is considered as 1.5(D.L +L.L.) or 1.2(D.L+L.L+W.L) or 1.5(D.L+W.L.).

Sl. No.	**Parameters**	**values**
1.	Basic Wind Velocity	55m/s
2.	Terrain Category	IV
3.	Design Period of structure	50 years
4.	Topography of location	Flat
5.	Location of structure	>200km away from the sea coast

Table 3.2. Parameters involving wind load according to I.S. code 875 (part-3)

Chapter – 4
WIND LOAD ANALYSIS – SQUARE SHAPE PLAN

4.1 GENERAL

The response of square shape tall building with different bracing systems subjected to wind loads is evaluated for three wind directions namely 0°, 30º and 60°. The influence of wind incidence at different angle is studied by the stresses, moments and maximum deflection produced in the building with MRF and Bracings.

4.2 BUILDING DIMENSIONS

The plan of the structure has a floor area of 625 m^2 and the elevation is kept to be 60 m. The building has 20 storeys of each 3 m high. The columns, beams and bracings are of steel and the roof and floors are made of R.C.C, overall the structure is of the steel frame. Grade of steel used is Fe-345 and concrete is M30. The depth of the slab is 200 mm.

4.3 WIND LOAD STUDY OF SQUARE PLAN BUILDING

4.3.1 BUILDING WITH MRF

It can be seen from the fig.4.1and fig.4.5 that overturning moment about y-axis and shear force at the base of the structure decreases as the incidence angle of wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.2 shows the comparison of moment along x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.3 shows the effect of wind incidence angle on lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.4. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

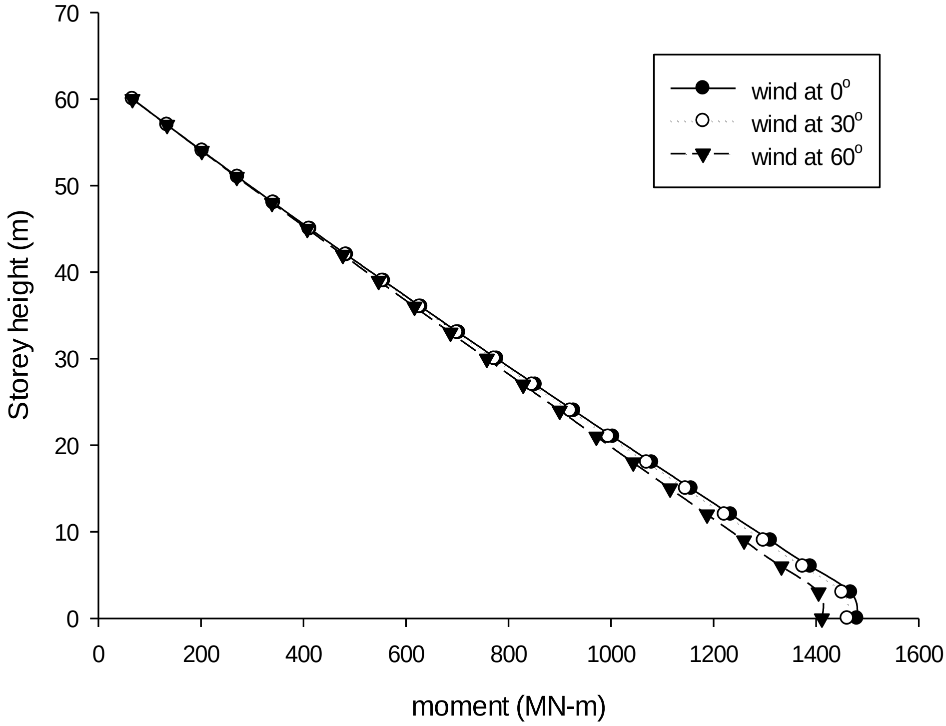

Fig.4.1: Effect of wind incidence angle on the overturning moment (M_Y)

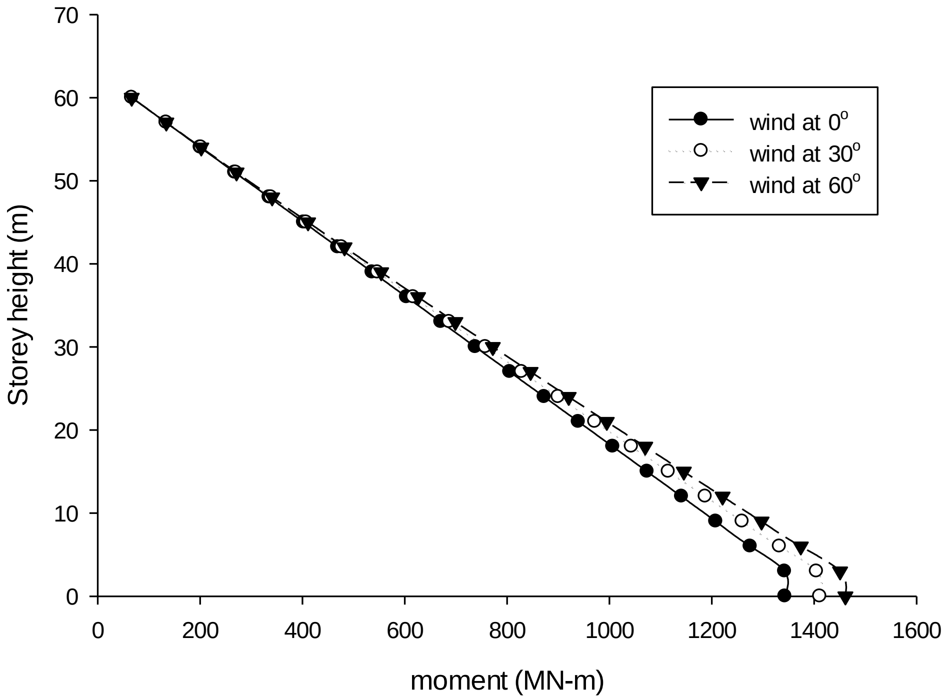

Fig.4.2: Effect of wind incidence angle on the moment (M_X)

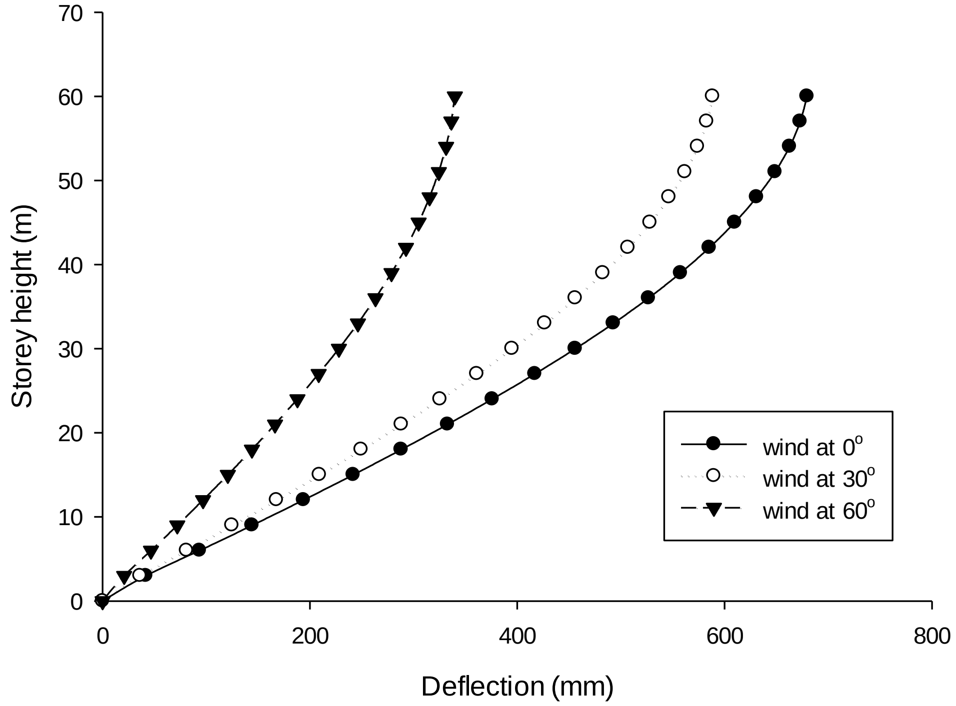

Fig.4.3: Effect of wind incidence angle on the lateral displacement (Δ_X)

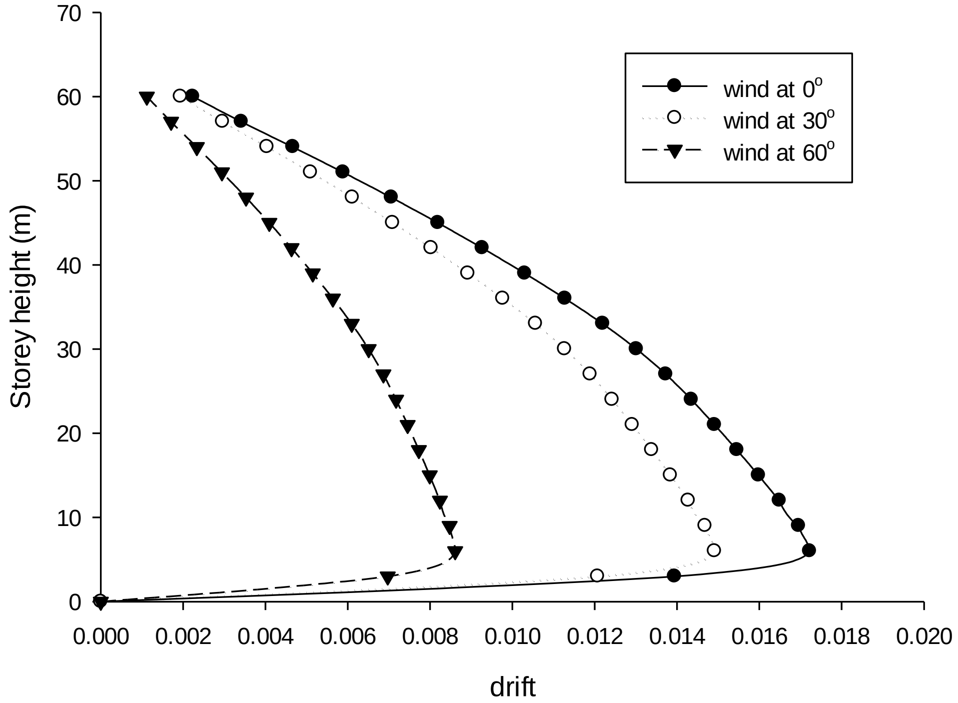

Fig.4.4: Effect of wind incidence angle on storey drift

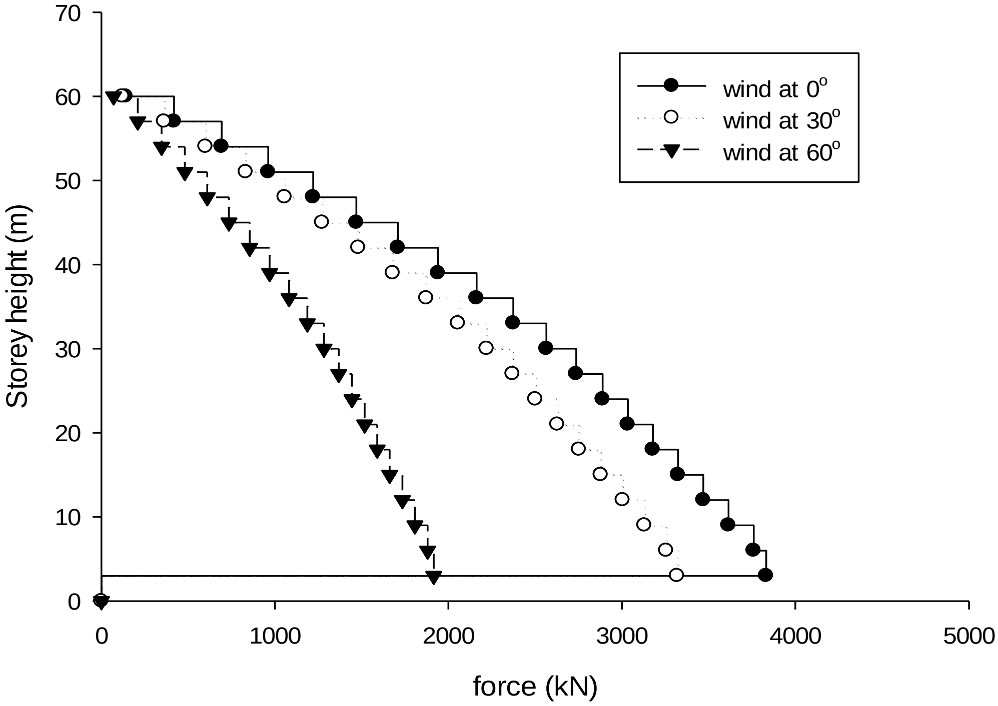

Fig.4.5: Effect of wind incidence angle on base shear (F_X)

4.3.2 BUILDING WITH X-BRACING

Fig.4.6 and fig.4.10 show that overturning moment about the y-axis and shear force at the base of the structure decreases as the incidence angle of the wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.7 shows the comparison of the moment along the x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.8 shows the effect of wind incidence angle on the lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.9. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

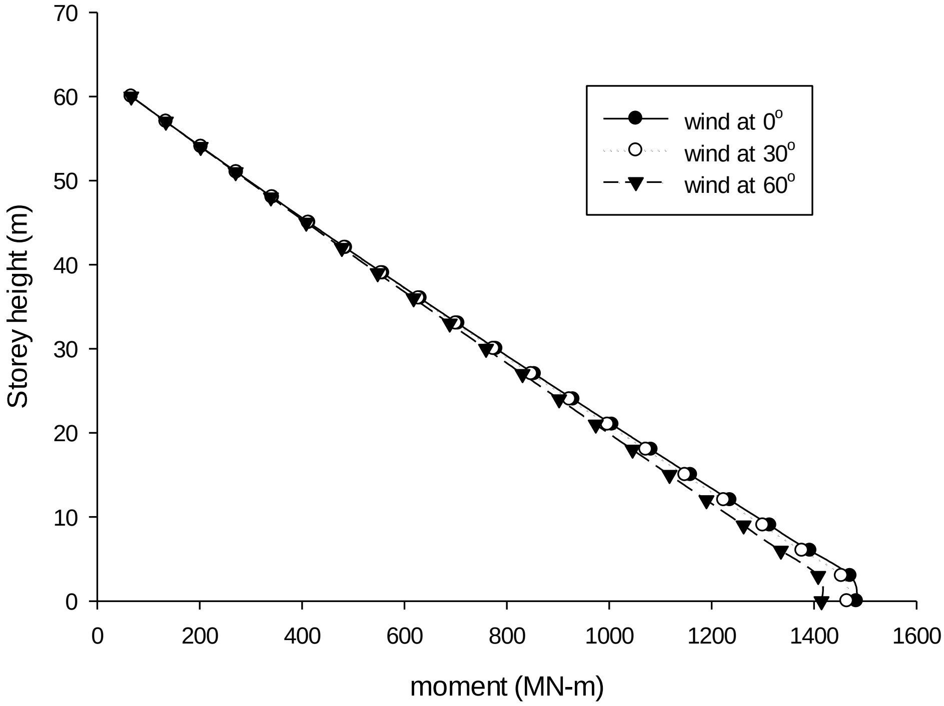

Fig.4.6: Effect of wind incidence angle on the overturning moment (M_Y)

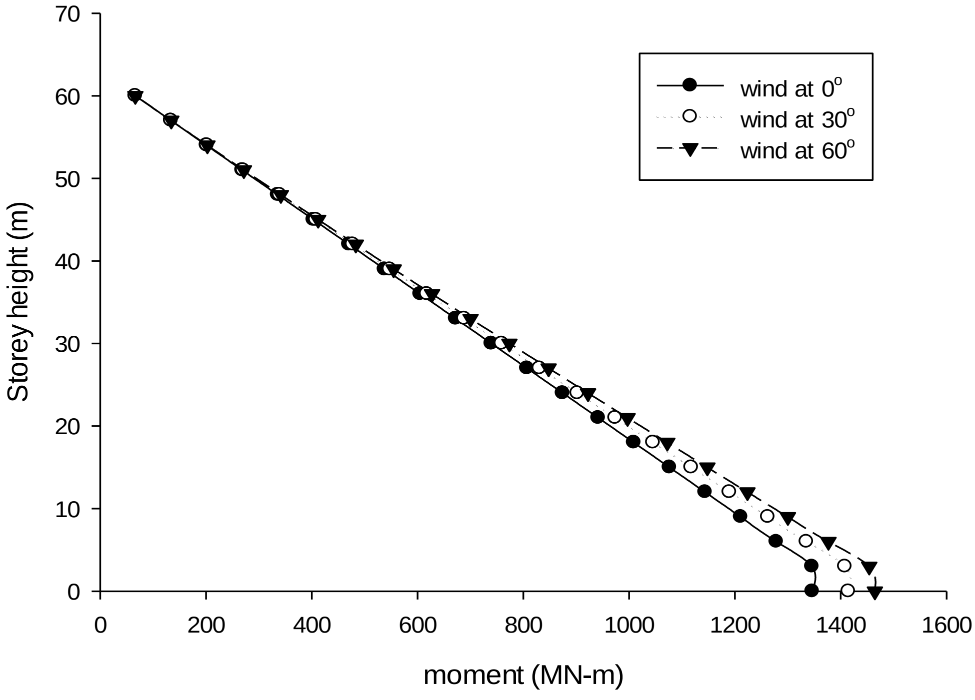

Fig.4.7: Effect of wind incidence angle on the moment (M_X)

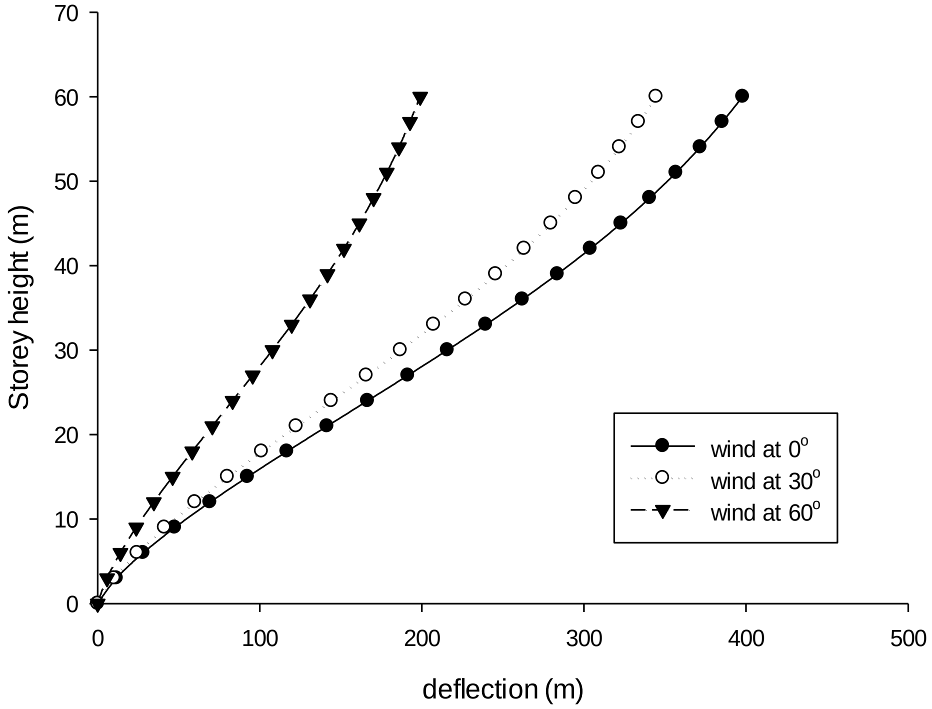

Fig.4.8: Effect of wind incidence angle on lateral displacement (ΔX)

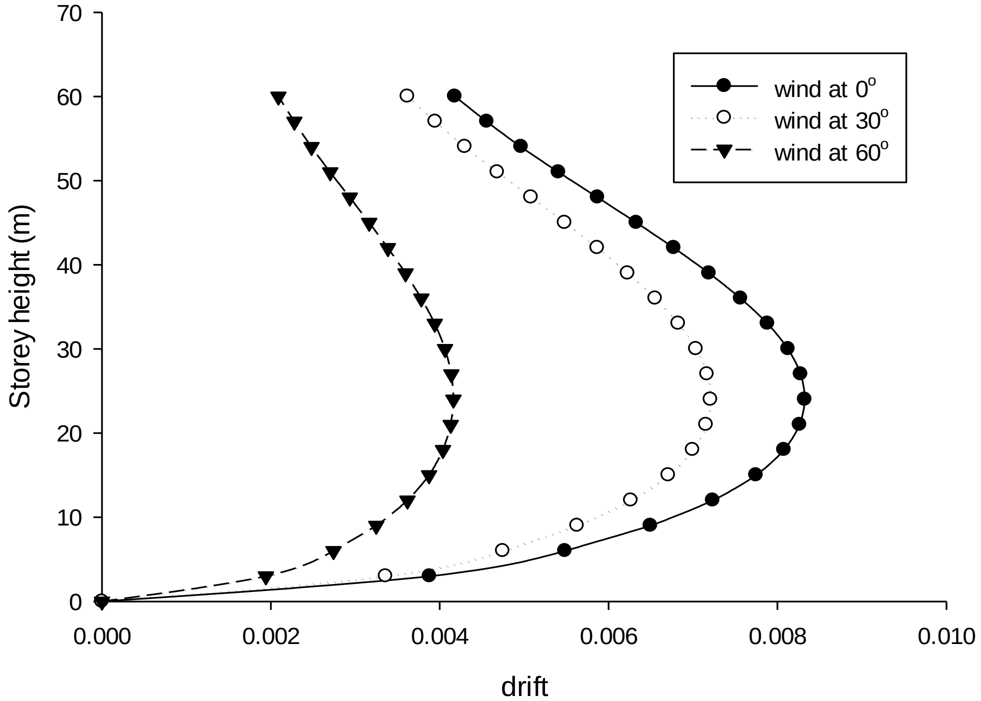

Fig.4.9: Effect of wind incidence angle on storey drift

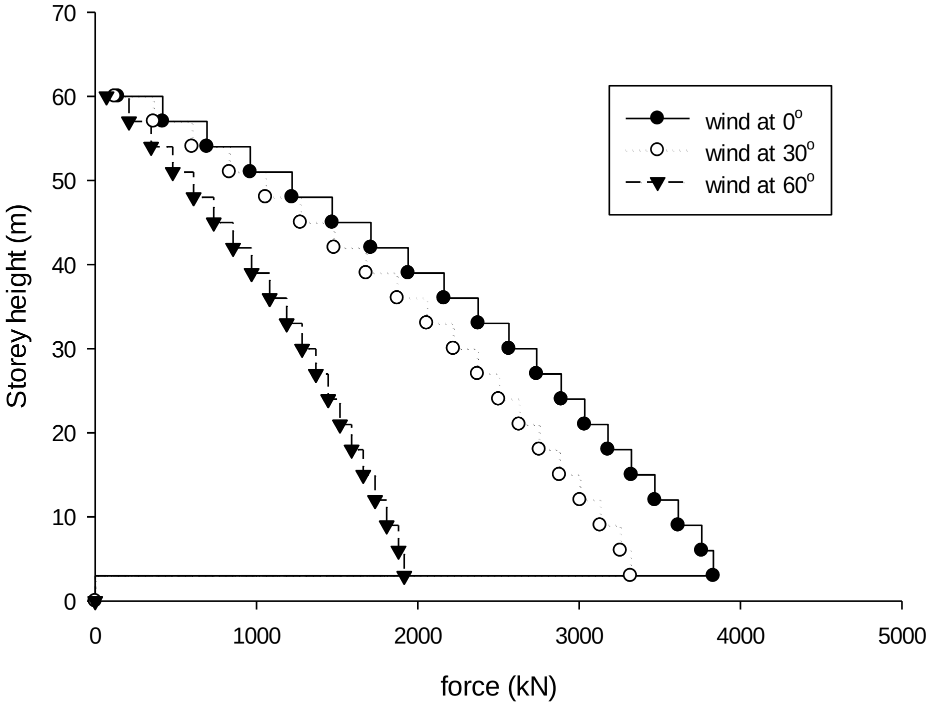

Fig.4.10: Effect of wind incidence angle on base shear (F_X)

4.3.3 BUILDING WITH V-BRACING

It can be seen from the fig.4.11 and fig.4.15 that overturning moment about the y-axis and shear force at the base of the structure decreases as the incidence angle of the wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.12 shows the comparison of the moment along the x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.13 shows the effect of wind incidence angle on the lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.14. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

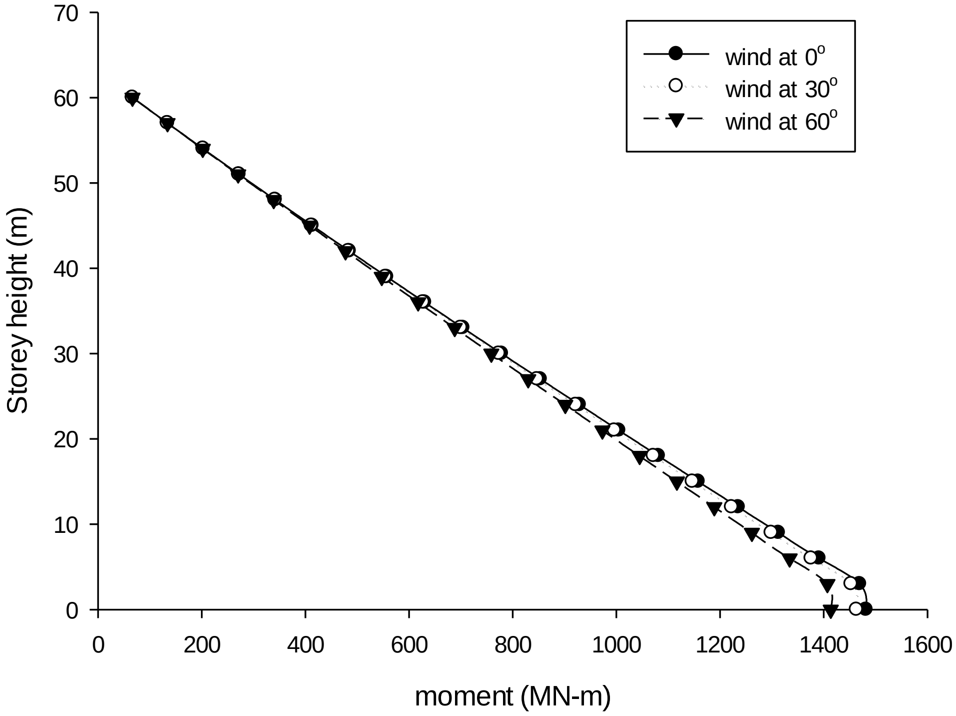

Fig.4.11: Effect of wind incidence angle on the overturning moment (M_Y)

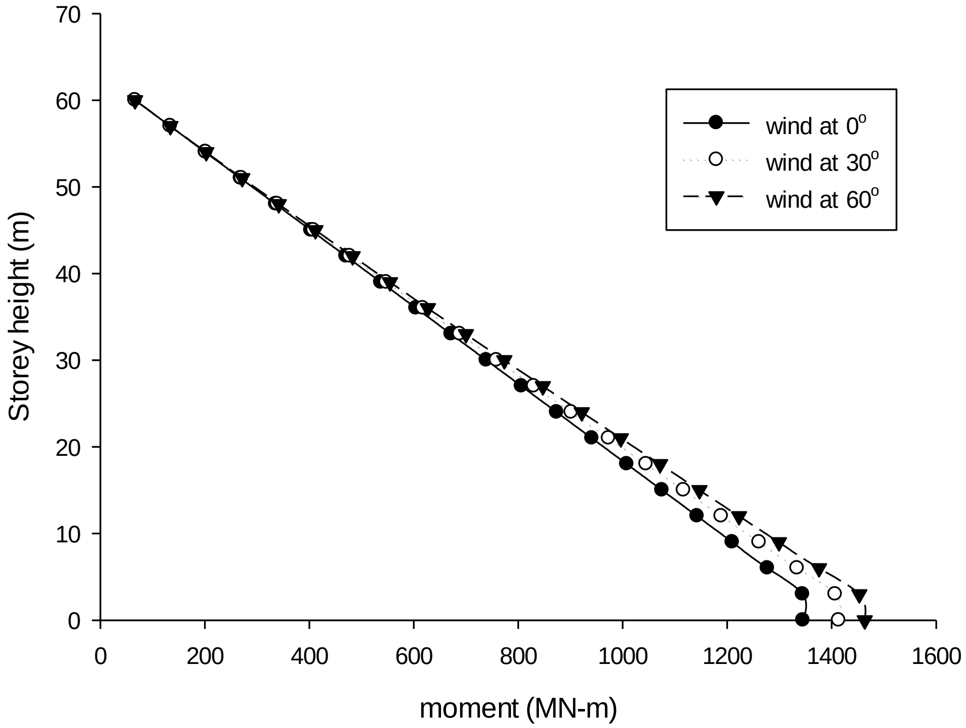

Fig.4.12: Effect of wind incidence angle on the moment (M_X)

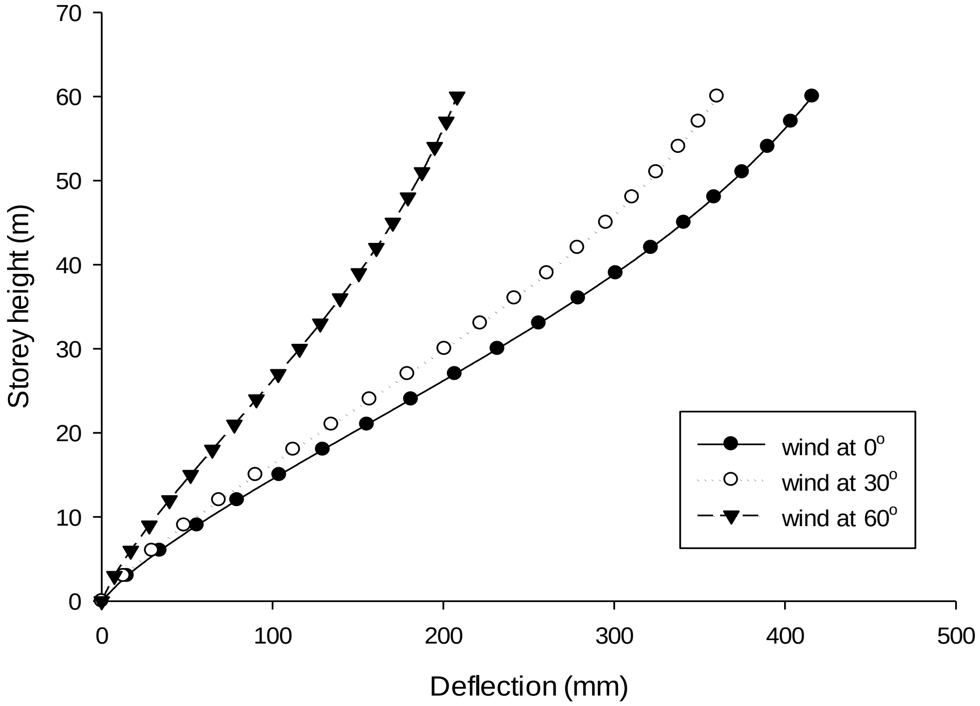

Fig.4.13: Effect of wind incidence angle on lateral displacement (Δ_X)

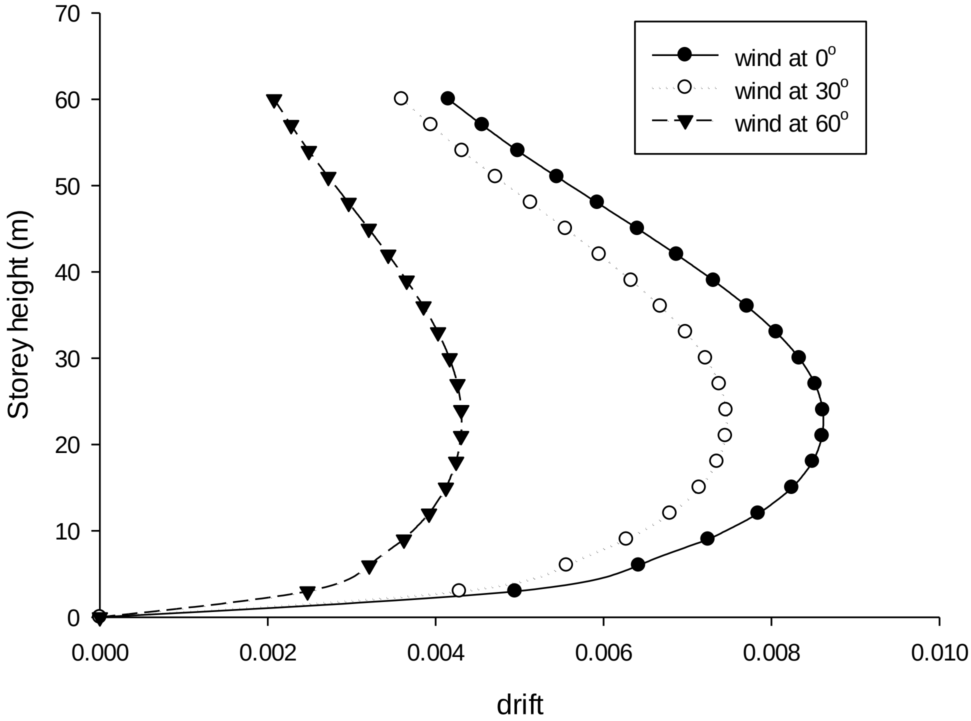

Fig.4.14: Effect of wind incidence angle on storey drift

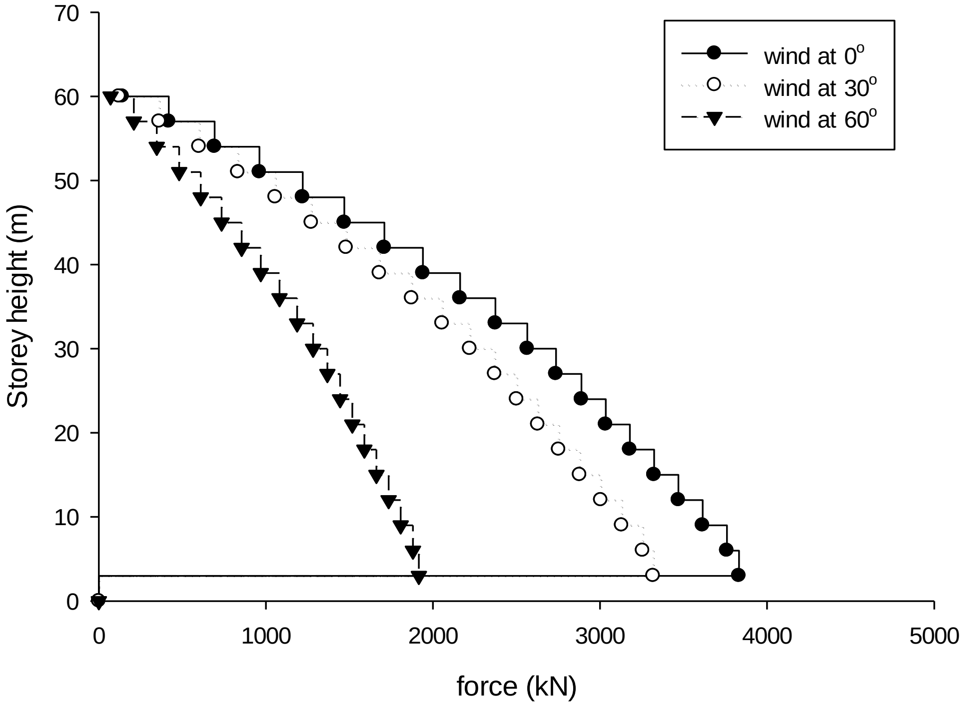

Fig.4.15: Effect of wind incidence angle on base shear (F_X)

4.3.4 BUILDING WITH INVERTED V-BRACING

Fig.4.16 and fig.4.20 show that overturning moment about the y-axis and shear force at the base of the structure decreases as the incidence angle of the wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.17 shows the comparison of the moment along the x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.18 shows the effect of wind incidence angle on the lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.19. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

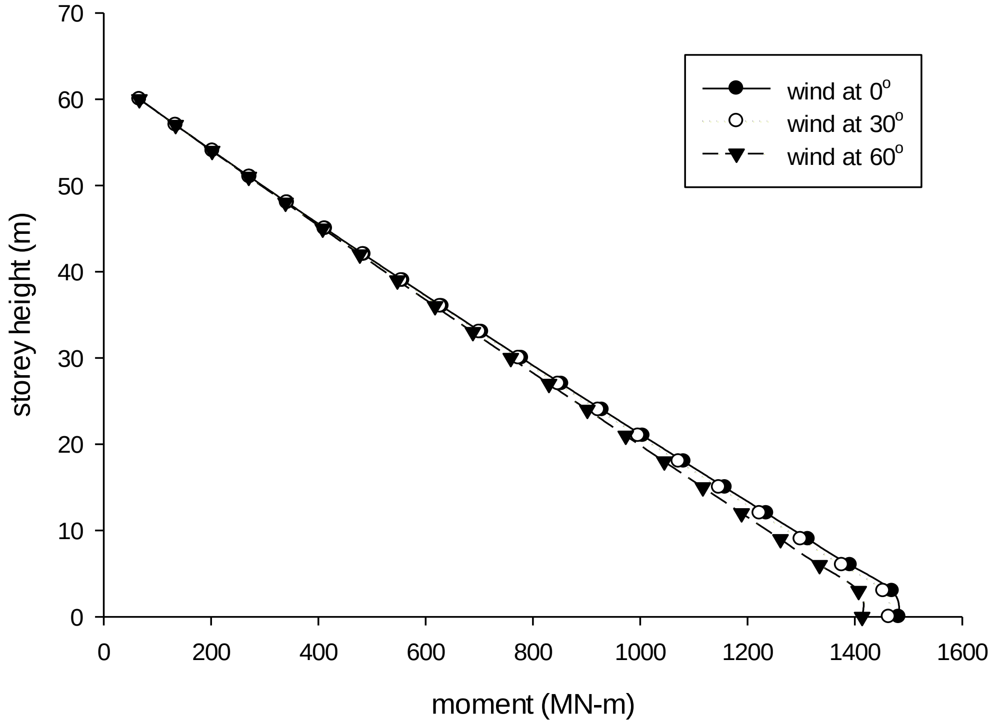

Fig.4.16: Effect of wind incidence angle on the overturning moment (M_Y)

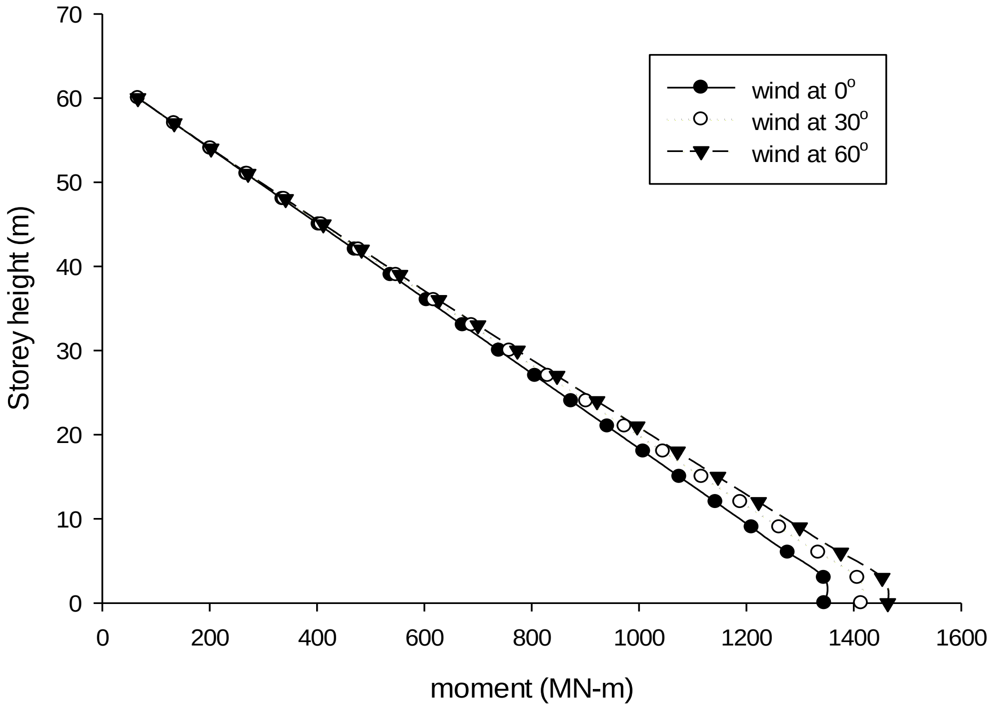

Fig.4.17: Effect of wind incidence angle on the moment (M_X)

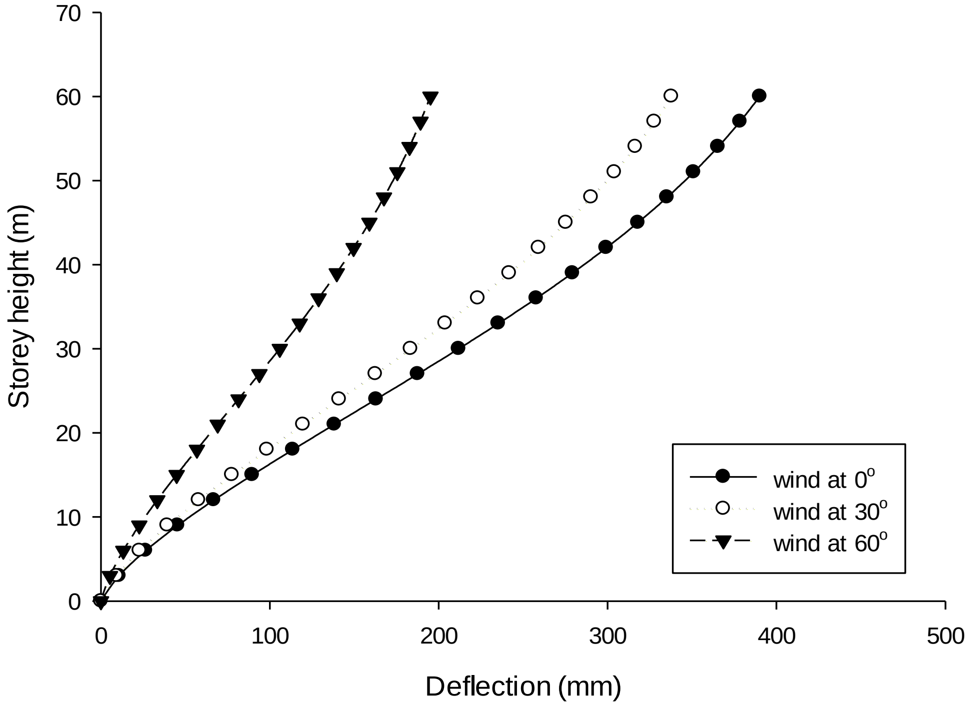

Fig.4.18: Effect of wind incidence angle on lateral displacement (Δ_X)

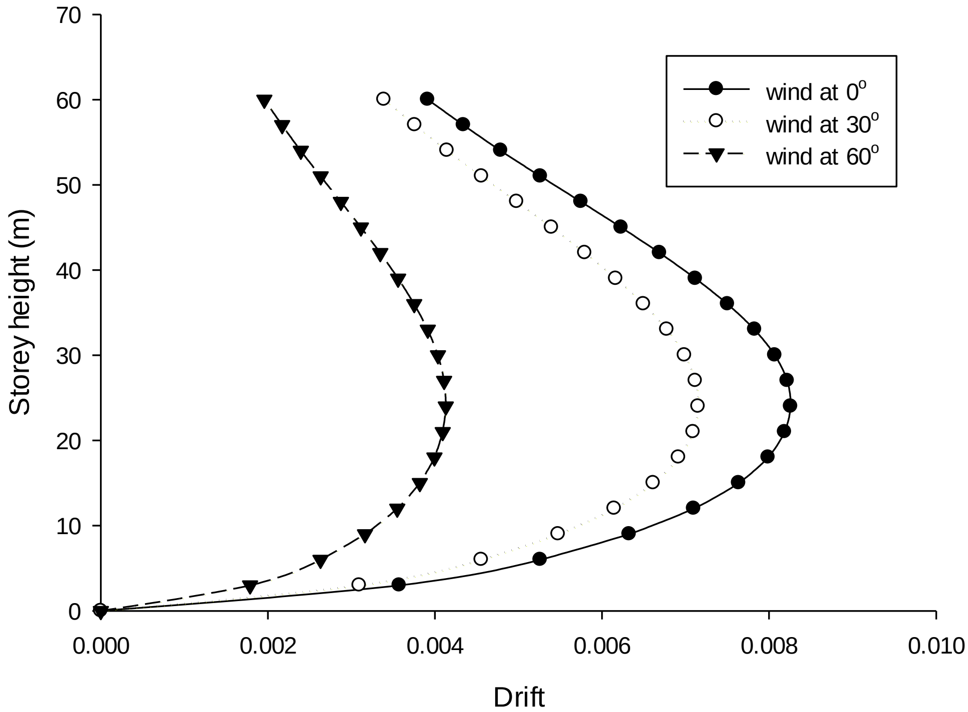

Fig.4.19: Effect of wind incidence angle on storey drift

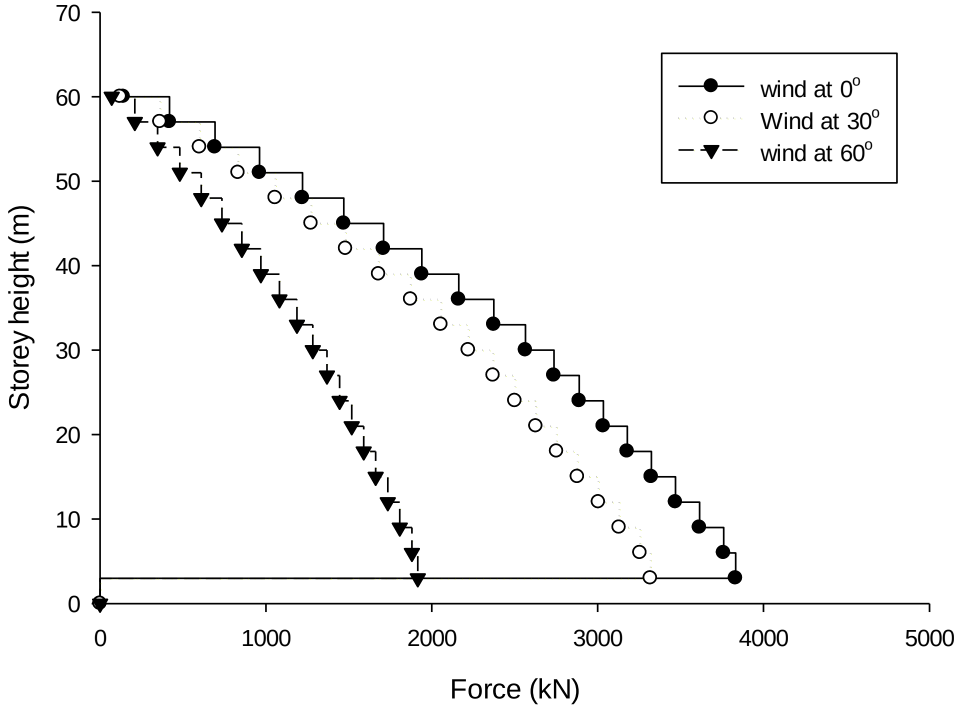

Fig.4.20: Effect of wind incidence angle on base shear (F_X)

4.3.5 BUILDING WITH K-BRACING

It can be seen from the fig.4.21 and fig.4.25 that overturning moment about the y-axis and shear force at the base of the structure decreases as the incidence angle of the wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.22 shows the comparison of the moment along the x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.23 shows the effect of wind incidence angle on the lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.24. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

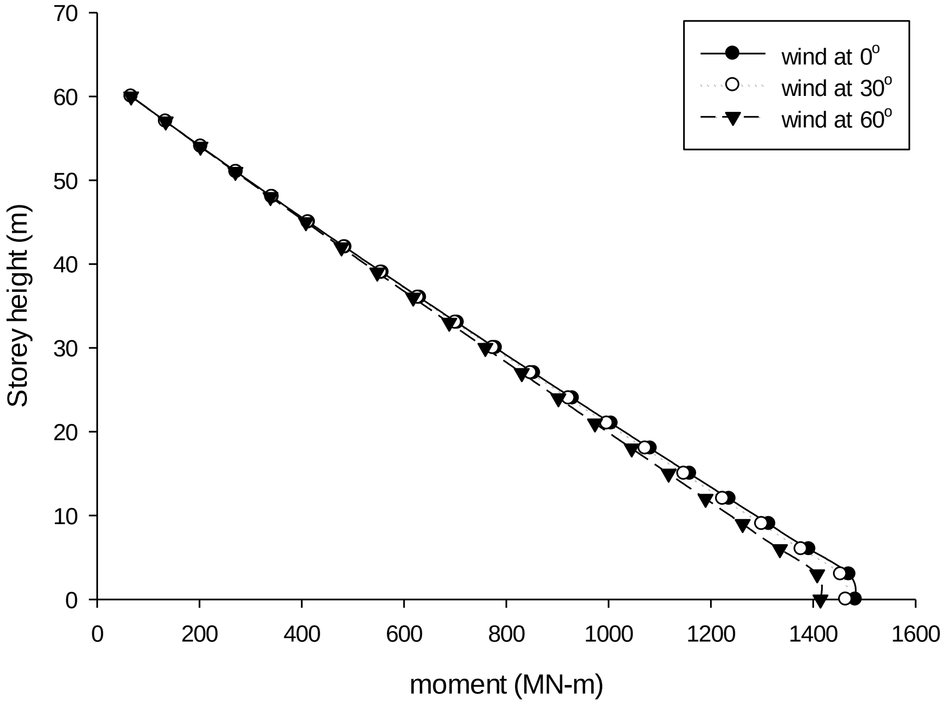

Fig.4.21: Effect of wind incidence angle on the overturning moment (M_Y)

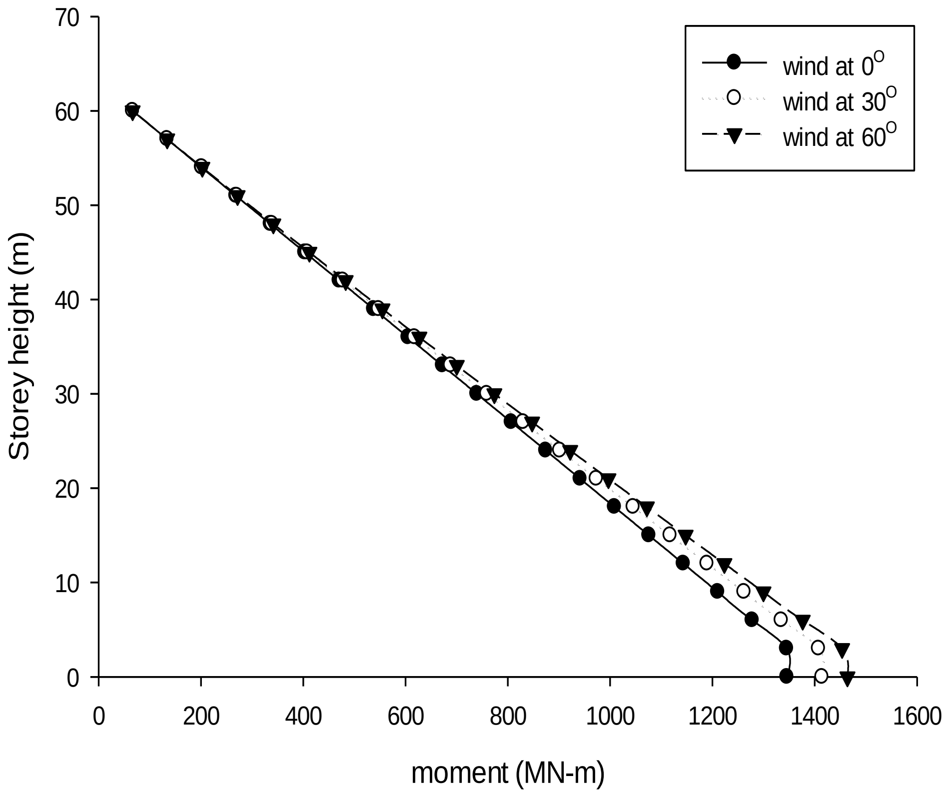

Fig.4.22: Effect of wind incidence angle on the moment (M_X)

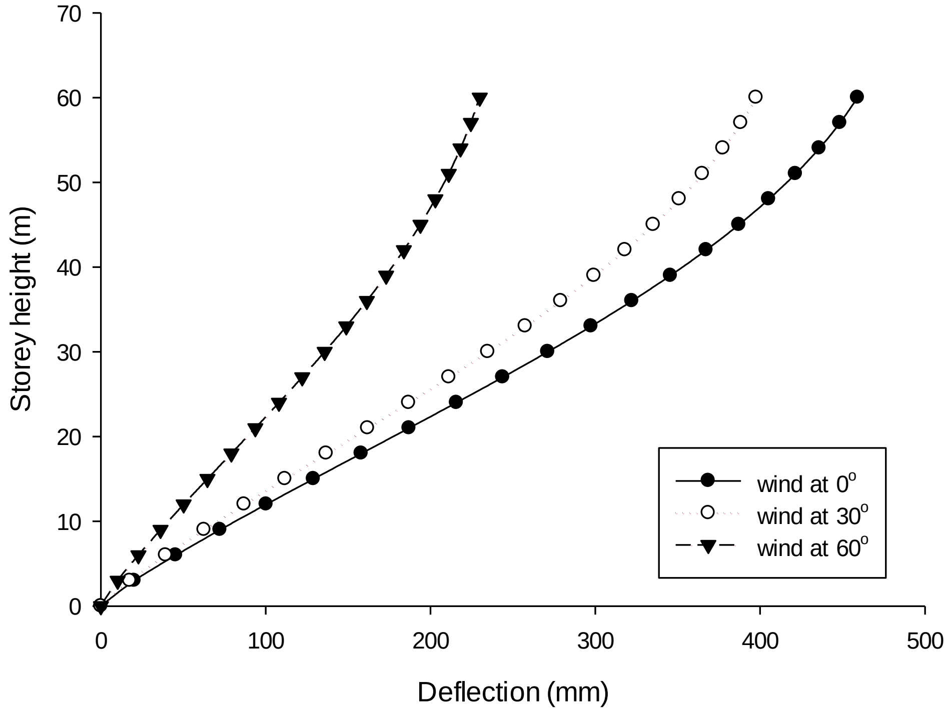

Fig.4.23: Effect of wind incidence angle on the lateral displacement (Δ_X)

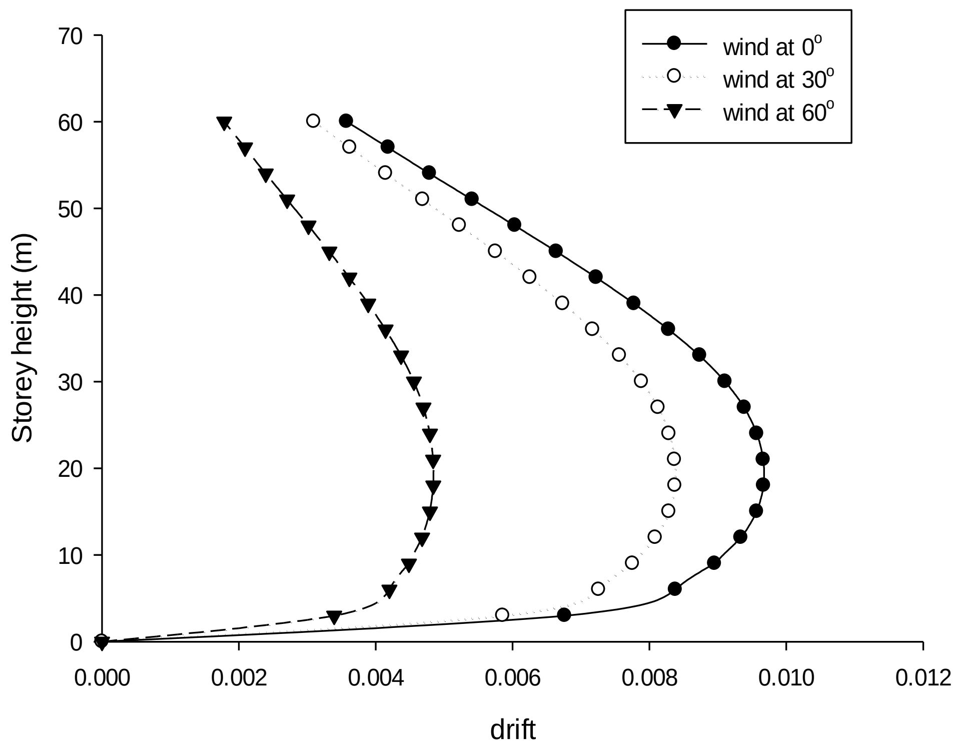

Fig.4.24: Effect of wind incidence angle on storey drift

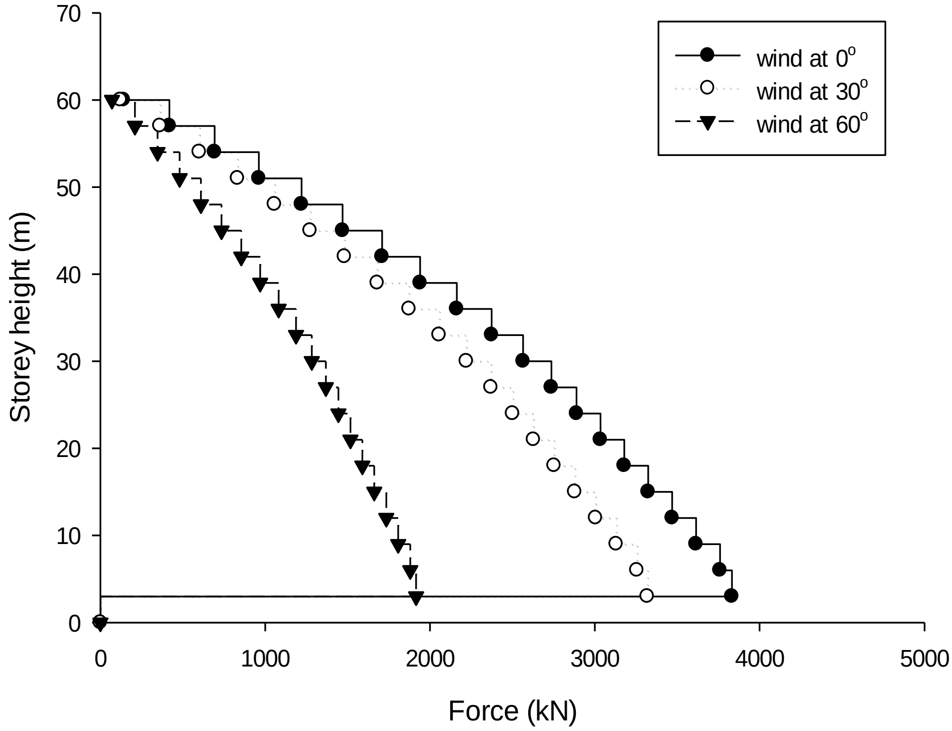

Fig.4.25: Effect of wind incidence angle on base shear (F_X)

4.3.6 BUILDING WITH DIAGONAL BRACING

Fig.4.26 and fig.4.30 show that overturning moment about the y-axis and shear force at the base of the structure decreases as the incidence angle of the wind is increased. The maximum moment and maximum shear is observed at 0° angle of incidence and minimum at 60° angle of incidence for the structure.

Fig.4.27 shows the comparison of the moment along the x-axis for different wind incidence angle. The moment is maximum for 60° and minimum for 0° angle of incidence of wind.

Fig.4.28 shows the effect of wind incidence angle on the lateral deflection at the top of the structure which decreases as the angle of incidence increases. Maximum deflection occurs for 0° angle of incidence and minimum at 60° angle of incidence.

Fig.4.29. shows the inter storey drift ratio which is maximum at 0° angle of incidence and minimum at 60° angle of incidence.

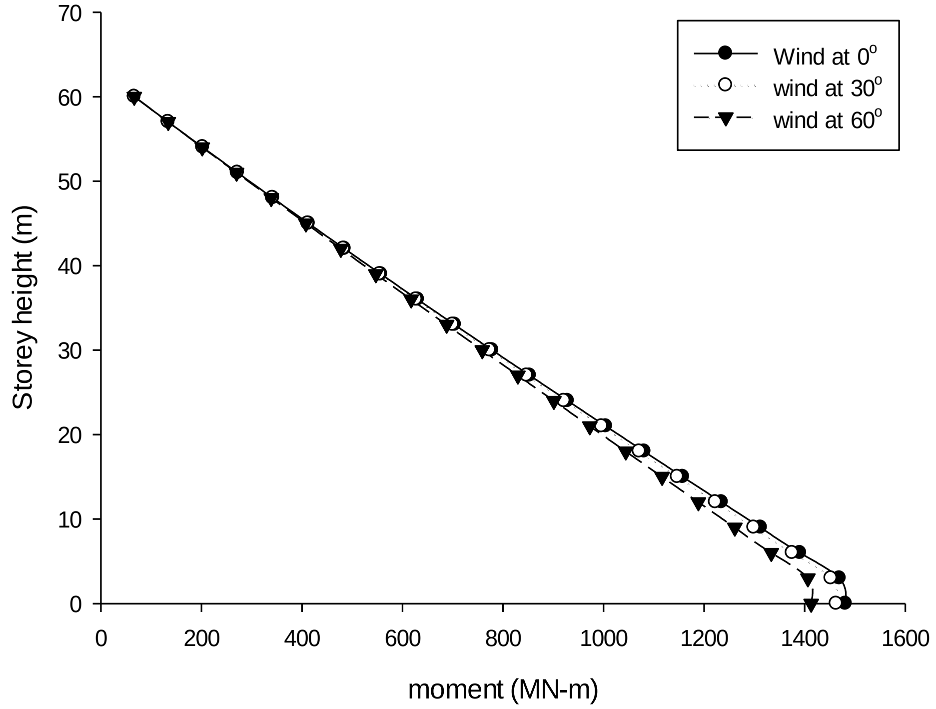

Fig.4.26: Effect of wind incidence angle on Overturning moment (M_Y)

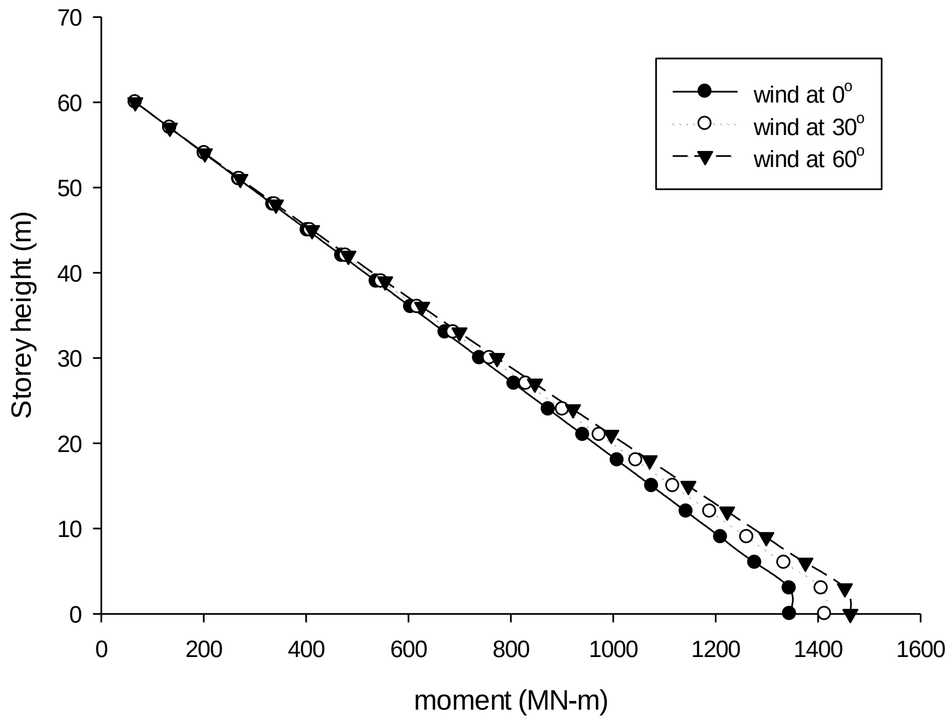

Fig.4.27: Effect of wind incidence angle on the moment (M_X)

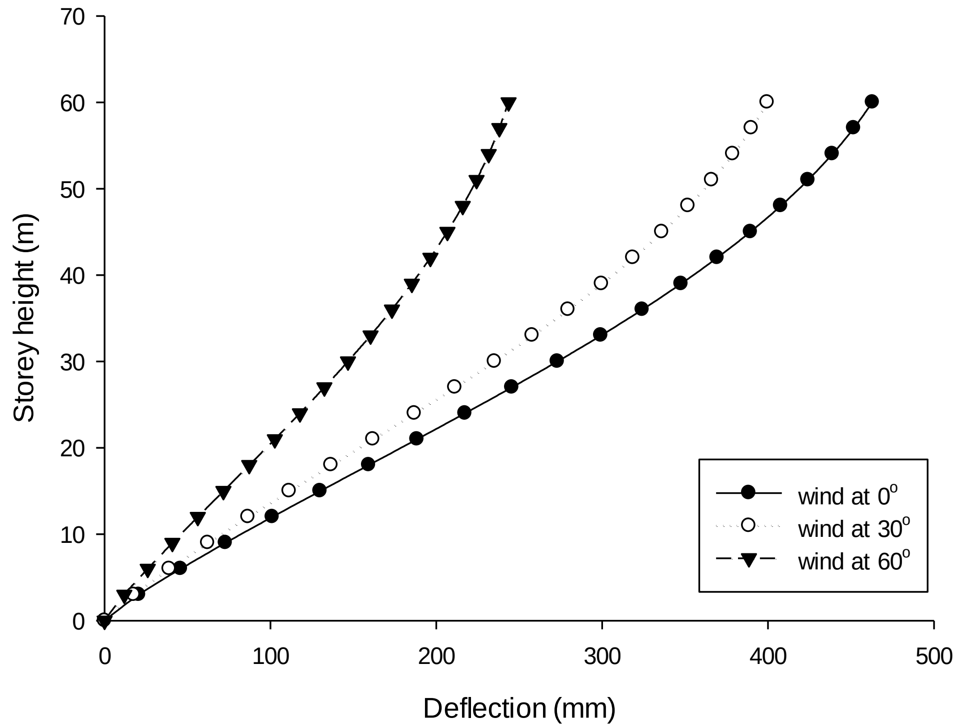

Fig.4.28: Effect of wind incidence angle on lateral displacement (Δ_X)

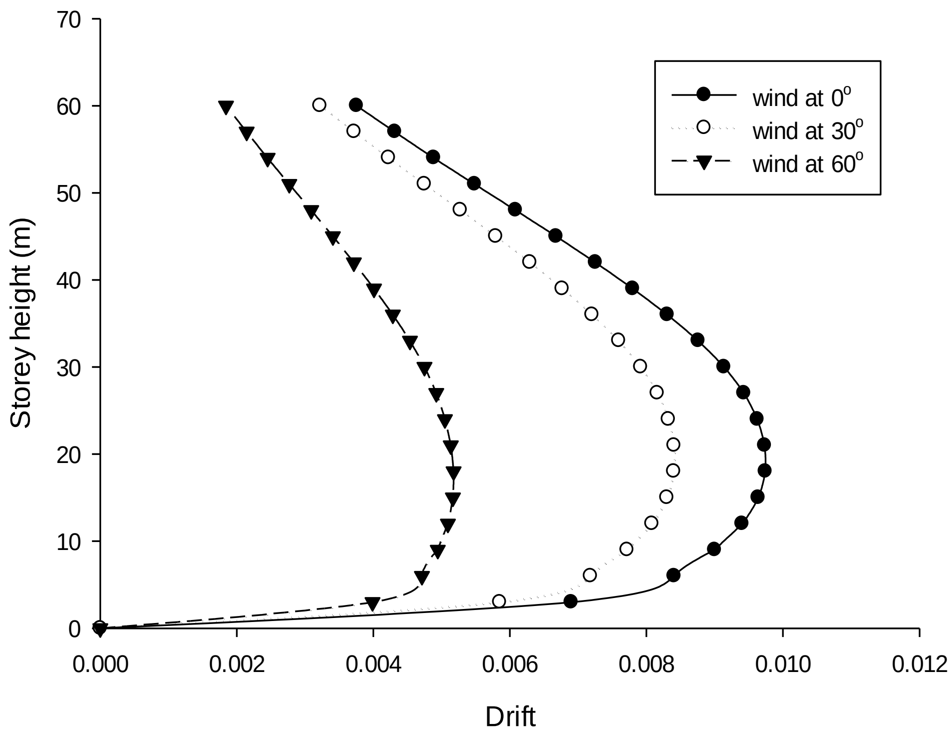

Fig.4.29: Effect of wind incidence angle on storey drift

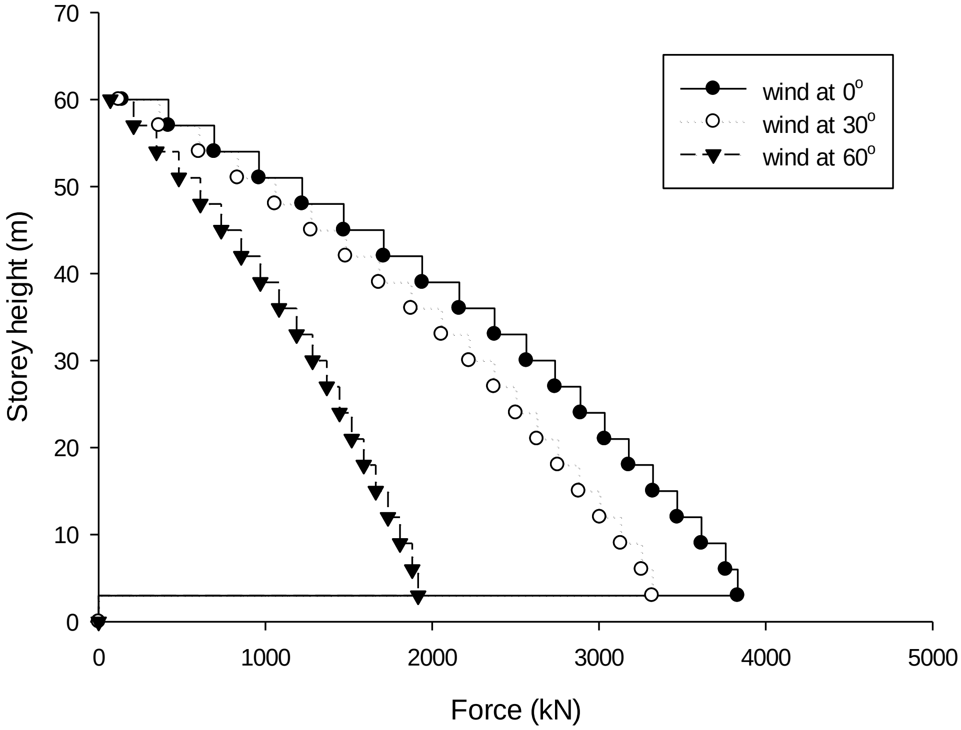

Fig.4.30: Effect of wind incidence angle on base shear (F_X)

4.4 COMPARATIVE STUDY OF ALL THE BRACINGS

4.4.1 0° wind incidence angle

The below graphs show the comparison of moments, deflection and inter storey drift for buildings with and without bracing at 0° wind incidence angle.

It can be seen from fig.4.31 and fig.4.32 that buildings with V-bracing and I.V- bracing have least overturning moment (M_Y) and moment (M_X) for wind at 0° angle of incidence.

The maximum horizontal deflection and storey drift for buildings with I.V-bracing and x-bracing are least and quite close in comparison to other types of braces. Fig 4.33 and 4.34 show considerable decrease in lateral deflection and inter storey drift in case of buildings with bracing than building without bracing.

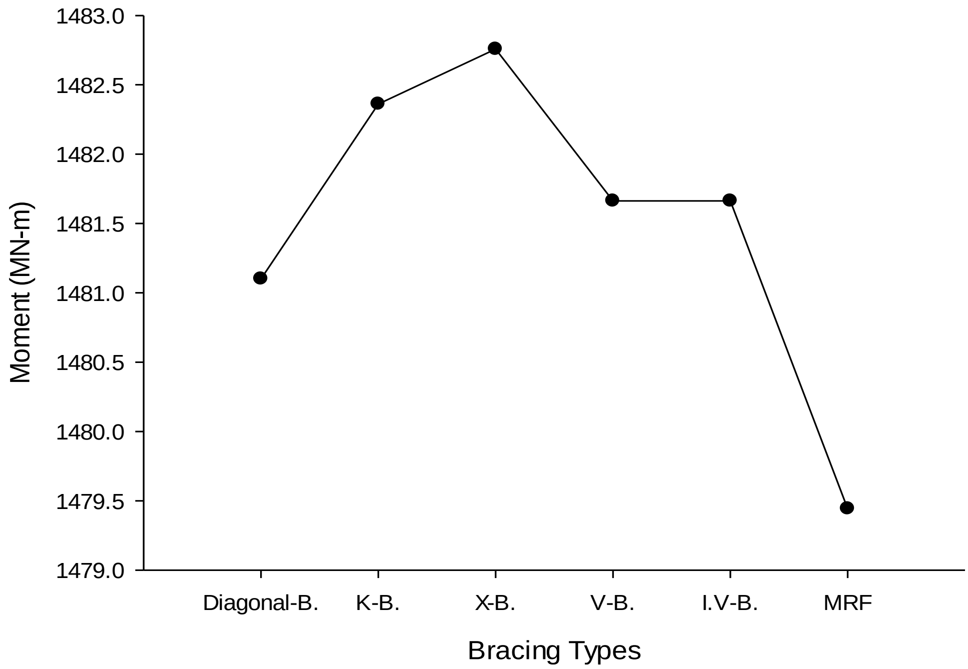

Fig.4.31: Effect of bracings on the overturning moment (M_Y)

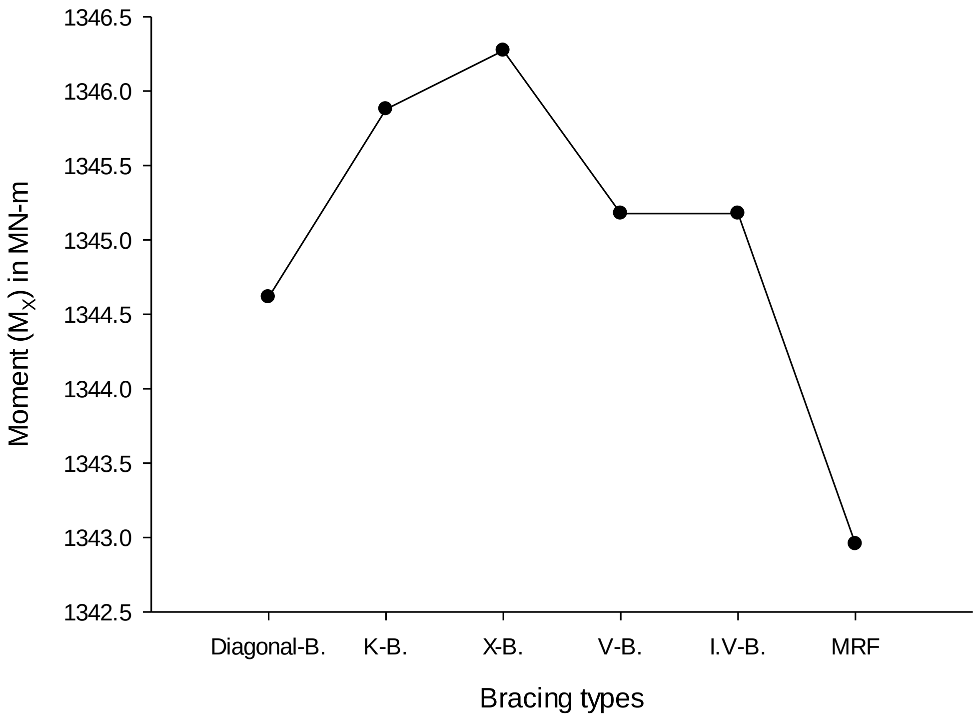

Fig.4.32: Effect of bracings on the moment (M_X) generated along wind incidence

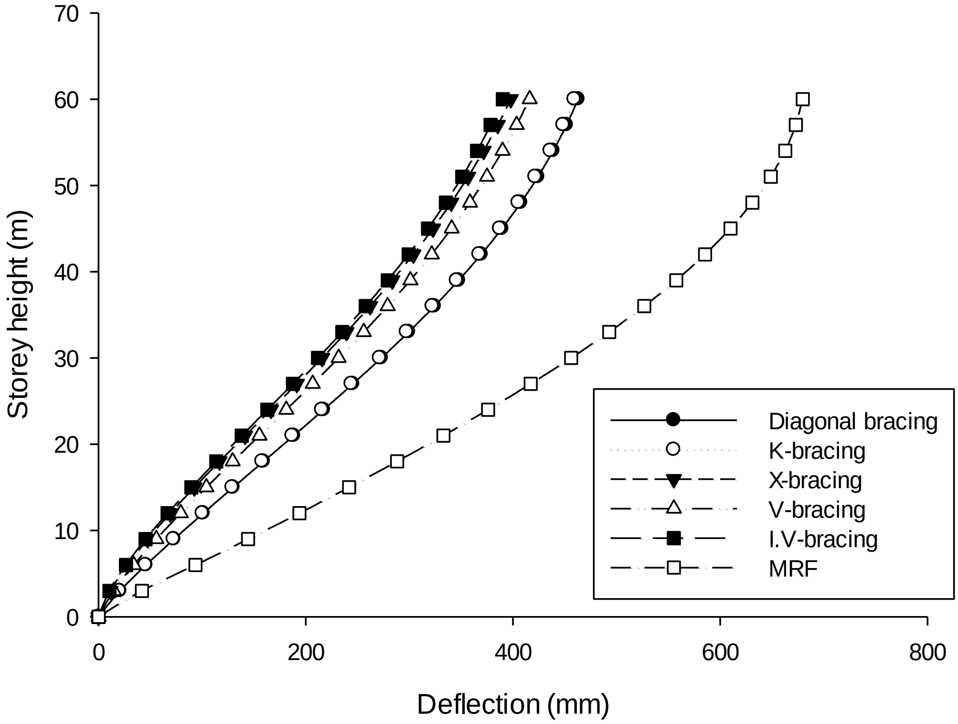

Fig.4.33: Effect of bracing on lateral displacement (Δ_x) along wind incidence direction.

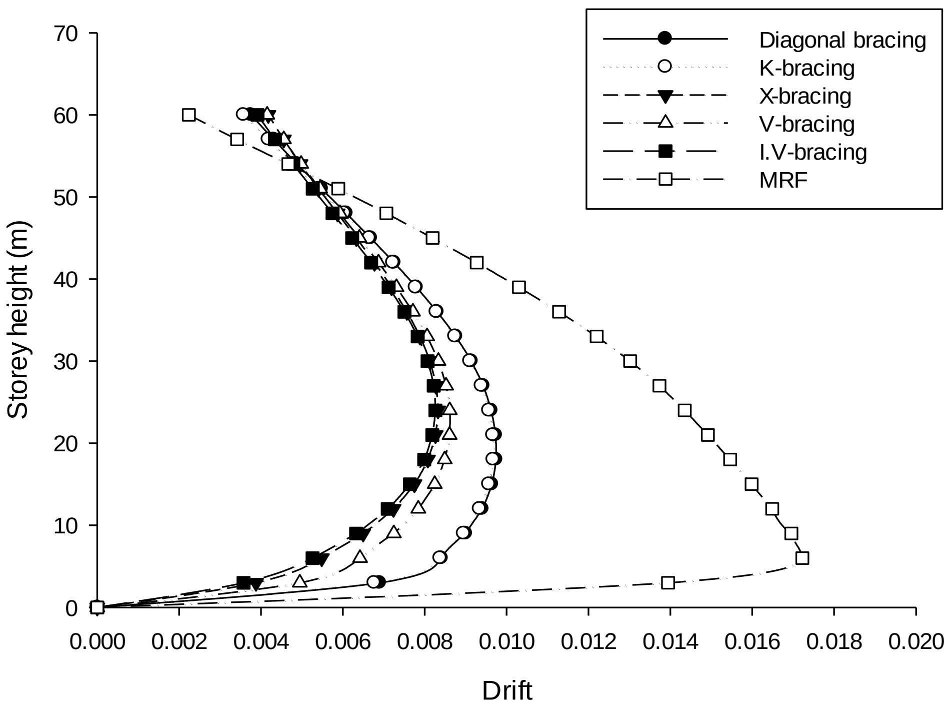

Fig.4.34: Effect of bracing on storey drift along wind incidence direction.

4.4.2 30° wind incidence angle

The below graphs show the comparison of moments, deflection and inter storey drift for buildings with and without bracing at 30° wind incidence angle.

It can be seen from fig.4.35 and fig.4.36 that buildings with V-bracing and I.V- bracing have least overturning moment (M_Y) and moment (M_X) along wind at 0° angle of incidence.

The maximum horizontal deflection and storey drift for buildings with I.V-bracing and x-bracing are least and quite close in comparison to other types of braces. Fig 4.37 and 4.38 show a considerable decrease in lateral deflection and inter storey drift in case of buildings with bracing than building without bracing.

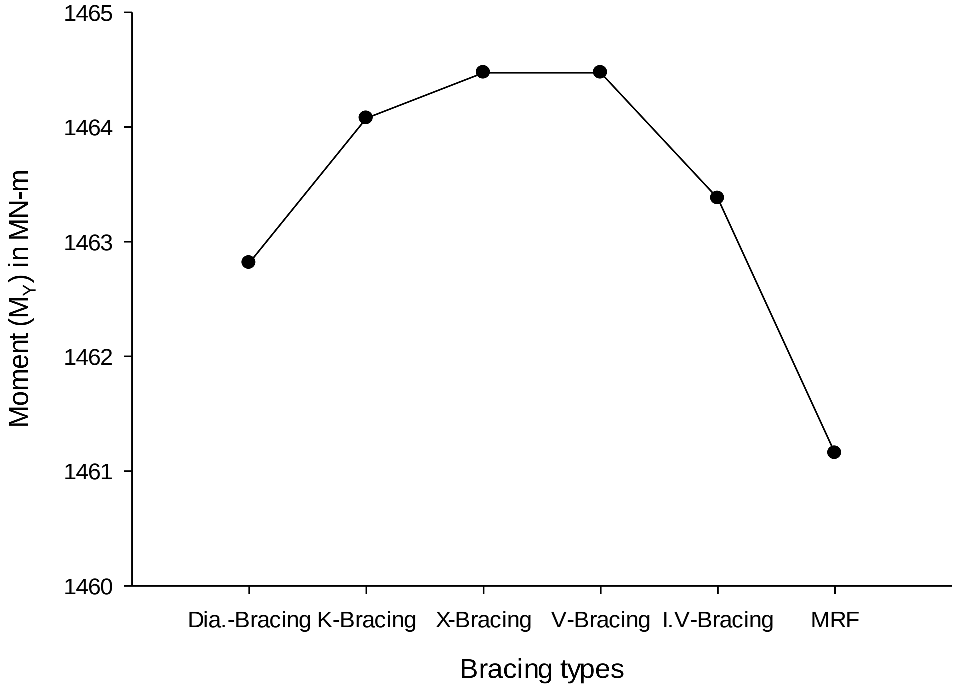

Fig.4.35: Effect of bracing on the overturning moment (M_Y)

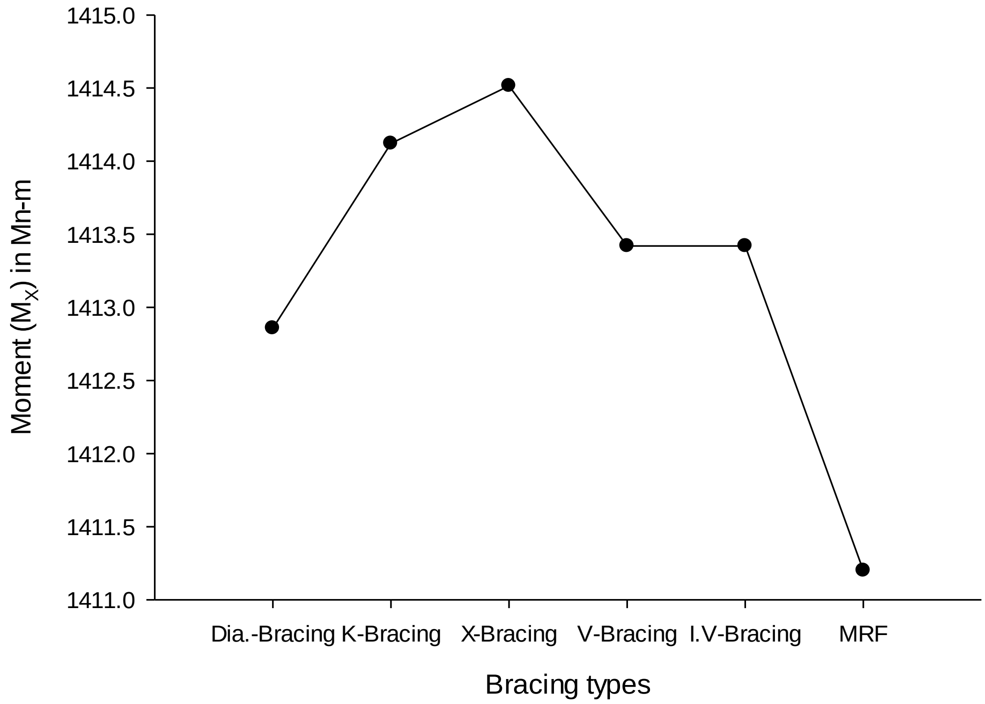

Fig.4.36: Effect of bracing on the moment (M_X)

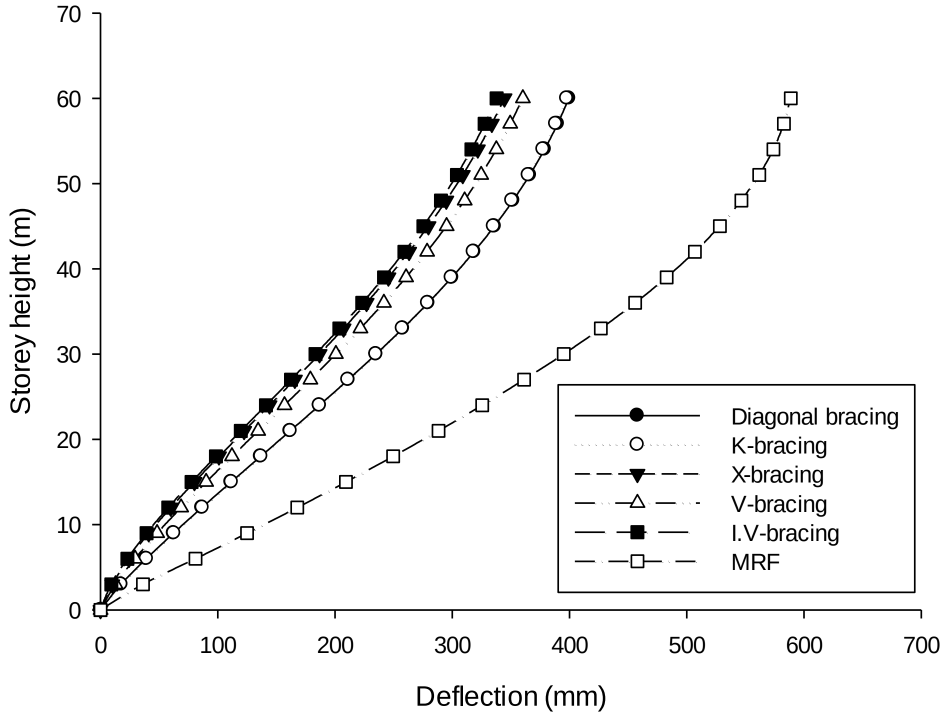

Fig.4.37: Effect of bracing on lateral displacement (Δ_x).

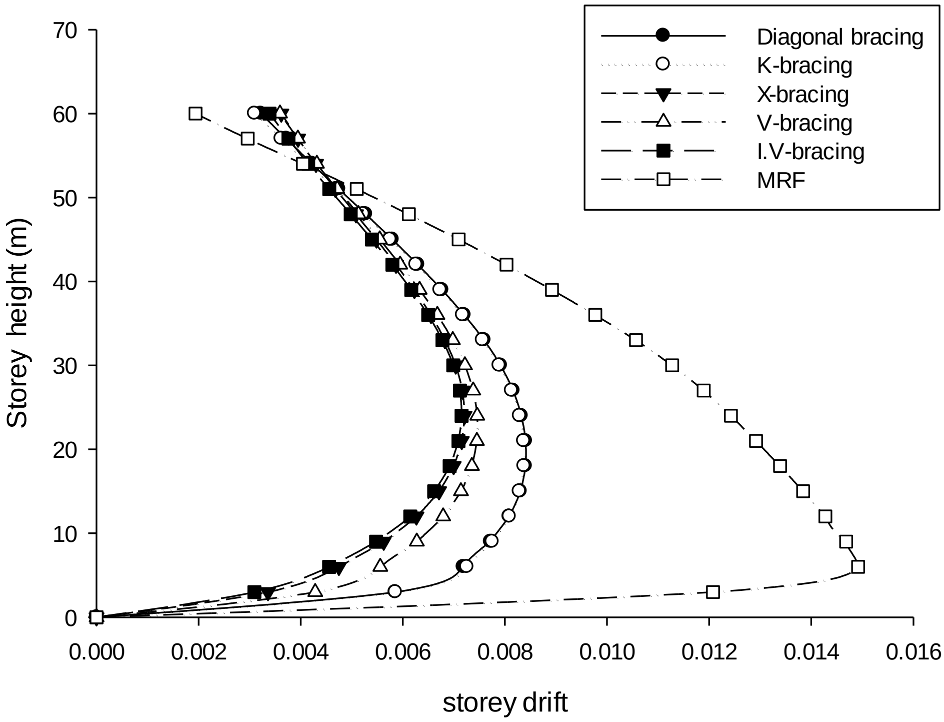

Fig.4.38: Effect of bracing on storey drift along the x-direction

4.4.3 60° wind incidence angle

The below graphs show the comparison of moments, deflection and inter storey drift for buildings with and without bracing at 60° wind incidence angle.

It can be seen from fig.4.39 and fig.4.40 that buildings with V-bracing and I.V- bracing have least overturning moment (M_Y) and moment (M_X) along wind at 0° angle of incidence.

The maximum horizontal deflection and storey drift for buildings with I.V-bracing and x-bracing are least and quite close in comparison to other types of braces. Fig 4.41 and 4.42 show a considerable decrease in lateral deflection and inter storey drift in case of buildings with bracing than building without bracing.

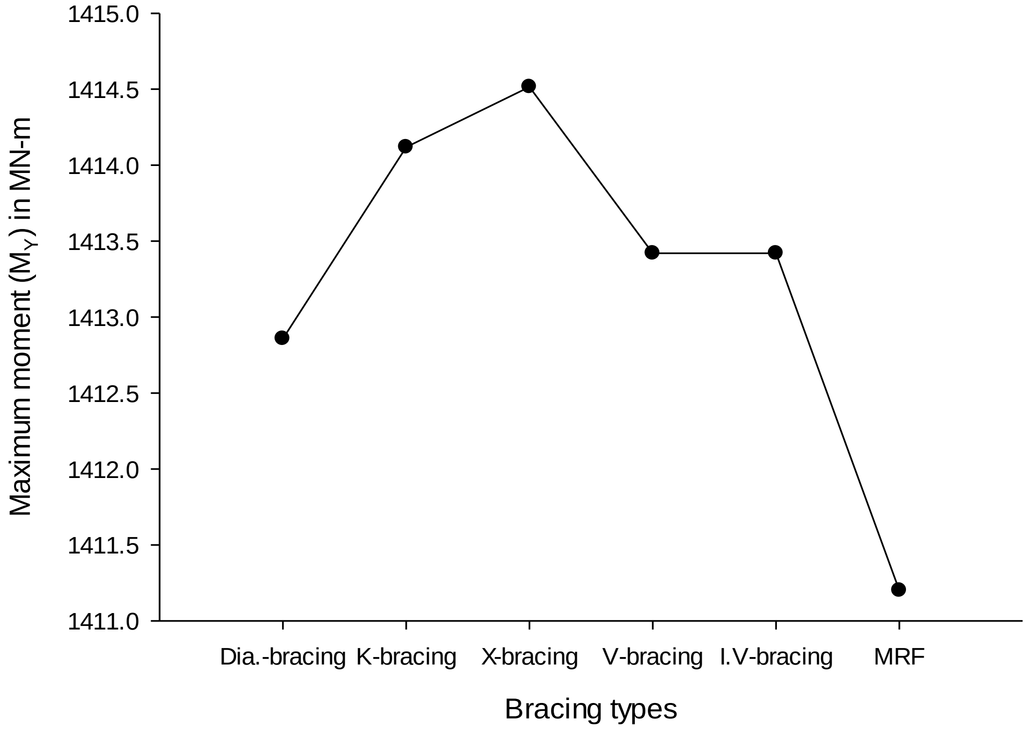

Fig.4.39: Effect of bracing on the overturning moment (M_Y)

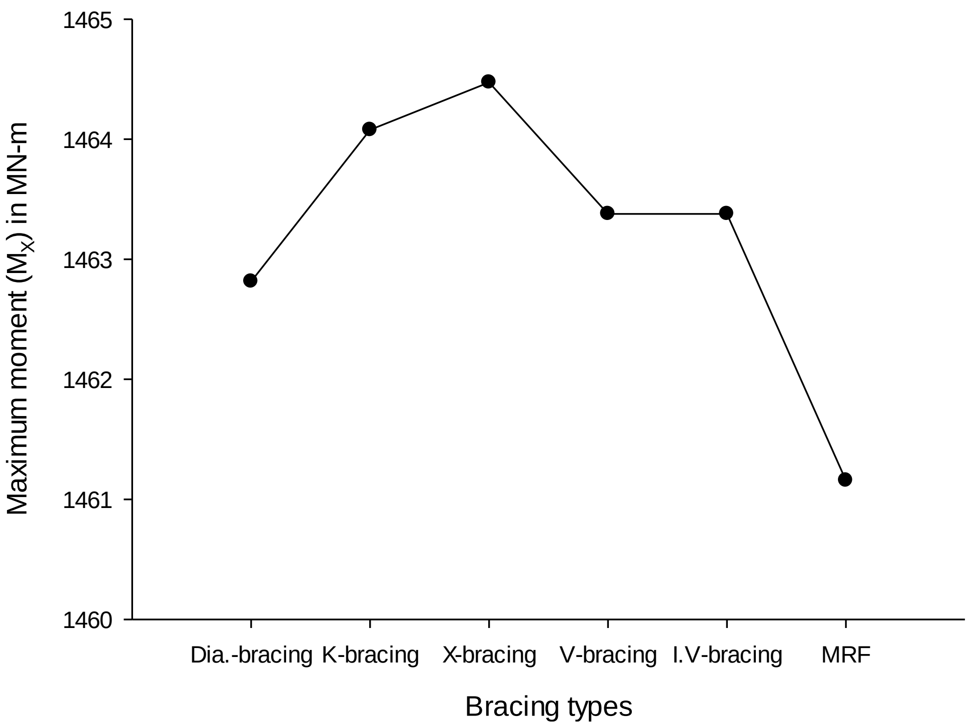

Fig.4.40: Effect of bracing on the maximum moment (M_X) generated at the base.

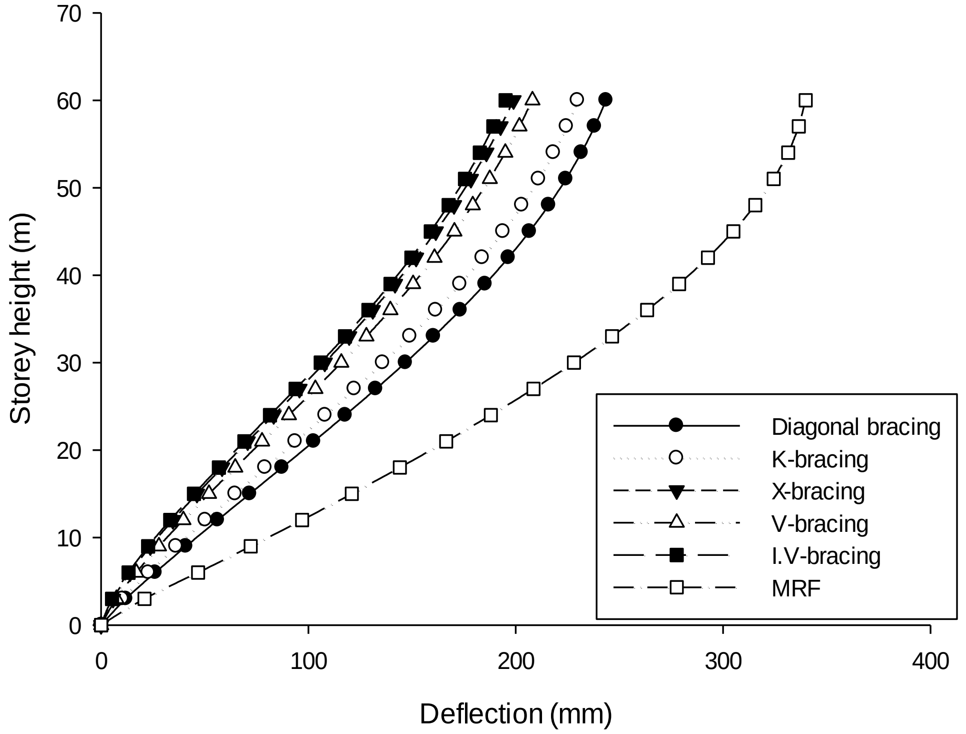

Fig.4.41: Effect of bracing on lateral displacement (Δ_X)

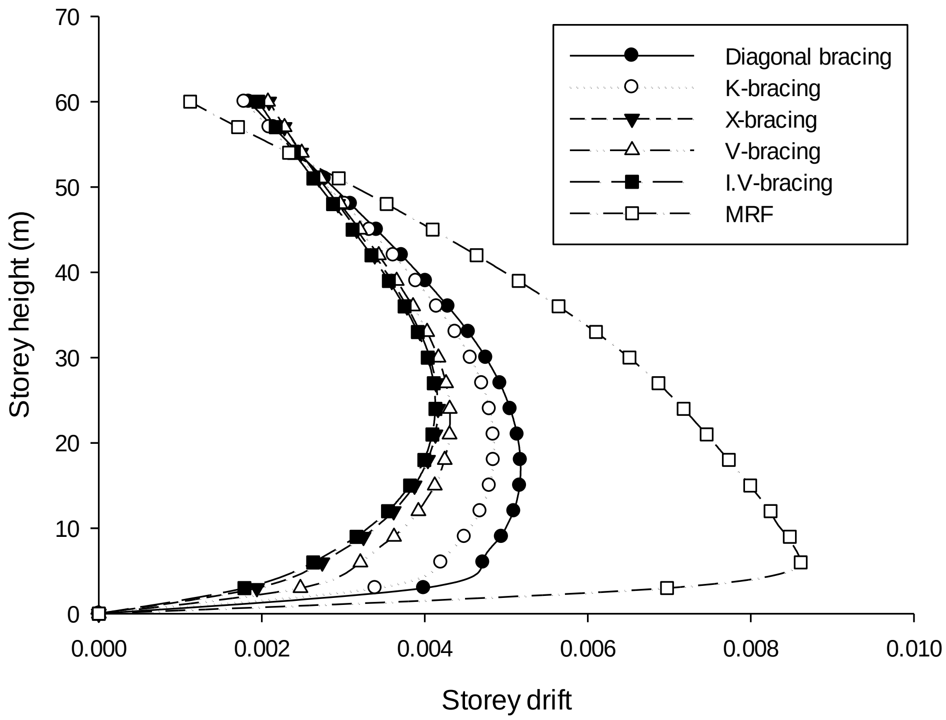

Fig.4.42: Effect of bracing on storey drift along the x-direction

Chapter-5
WIND LOAD ANALYSIS – PLUS SHAPE PLAN

5.1 GENERAL

The response of plus shape tall building with different bracing systems subjected to wind loads is evaluated for three wind directions namely 0°, 30° and 60°. The influence of wind incidence at different angle is studied by the stresses, moments and maximum deflection produced in the building with MRF and Bracings.

5.2 BUILDING DIMENSIONS

The plan of the structure has a floor area of 825 m^2 and the elevation is kept to be 60 m. The building has 20 storeys of each 3 m high. The columns, beams and bracings are of steel and the roof and floors are made of R.C.C, overall the structure is of steel frame. Grade of steel used is Fe-345 and concrete is M30. The depth of the slab is 200 mm.

5.3 PLUS SHAPE PLAN BUILDINGS WITH DIFFERENT BRACING TYPES

The results obtained from E-tabs analysis of structure induced to live load, dead load and wind load at different angles of incidence are shown by graphs presented below.

A comparison was done among the structures with moment resisting frames. It can be seen from fig. 5.1 to 5.30 that overturning moment (M_Y) generated across the wind is greatest for 0° wind direction and the value decreases as the angle of incidence is increased.

While moment (M_X) along the wind direction is greatest for 60° wind incidence this leads to an increase in the moment with an increase in incidence angle.

The base shear, inter storey drift and horizontal deflection at the top of the structure is greatest along the wind direction in comparison to wind at any given angle.

After studying the below graphs, it is found that wind incidence angle has more influence on base shear, storey drift and lateral deflection than the moment of resistance in both directions (X, Y). The study reveals the increase in base shear, moment from top to bottom and decrease with wind incidence angle.

5.3.1 BUILDING WITH MRF

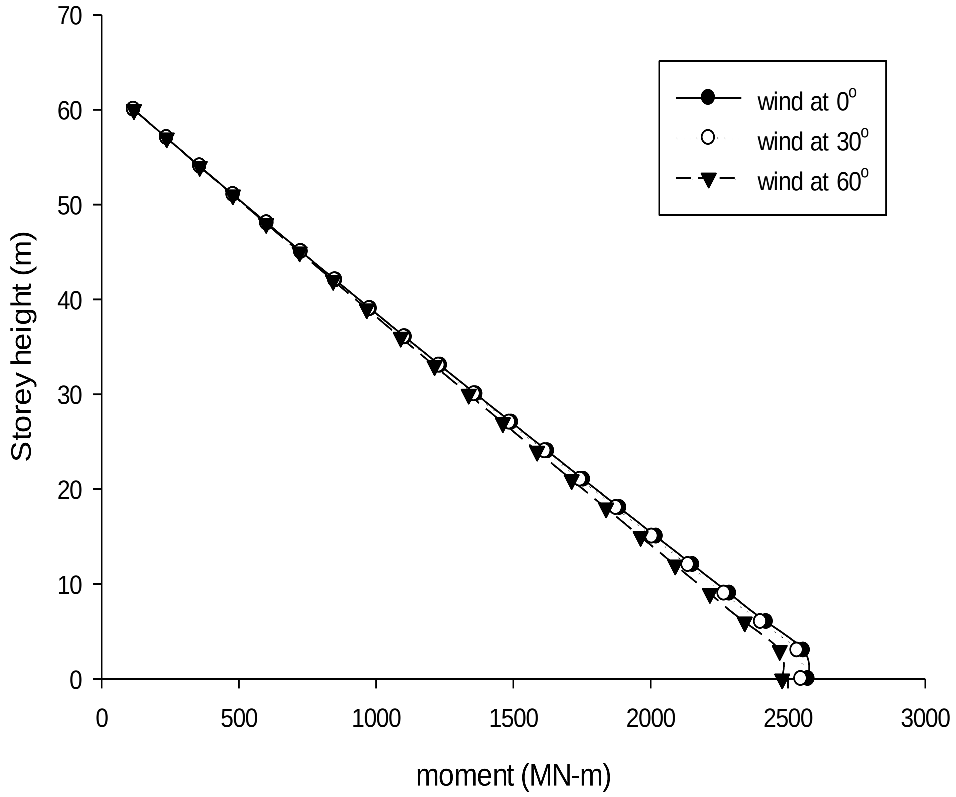

Fig.5.1: Effect of wind incidence angle on overturning moment (M_Y) of the structure.

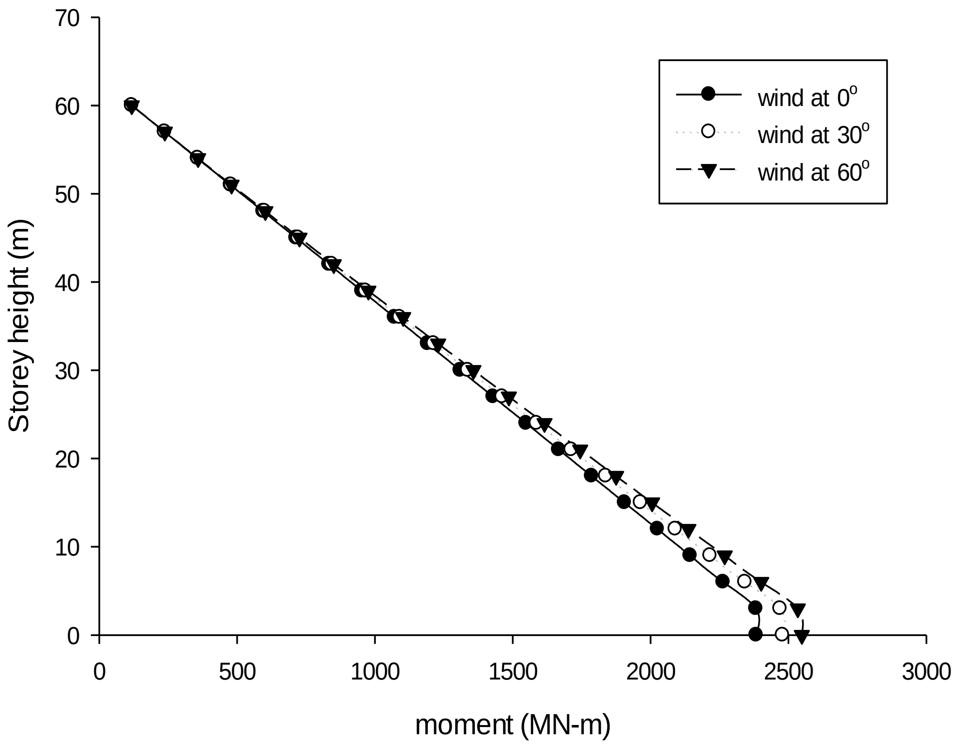

Fig.5.2: Effect of wind incidence angle on the moment (M_X)

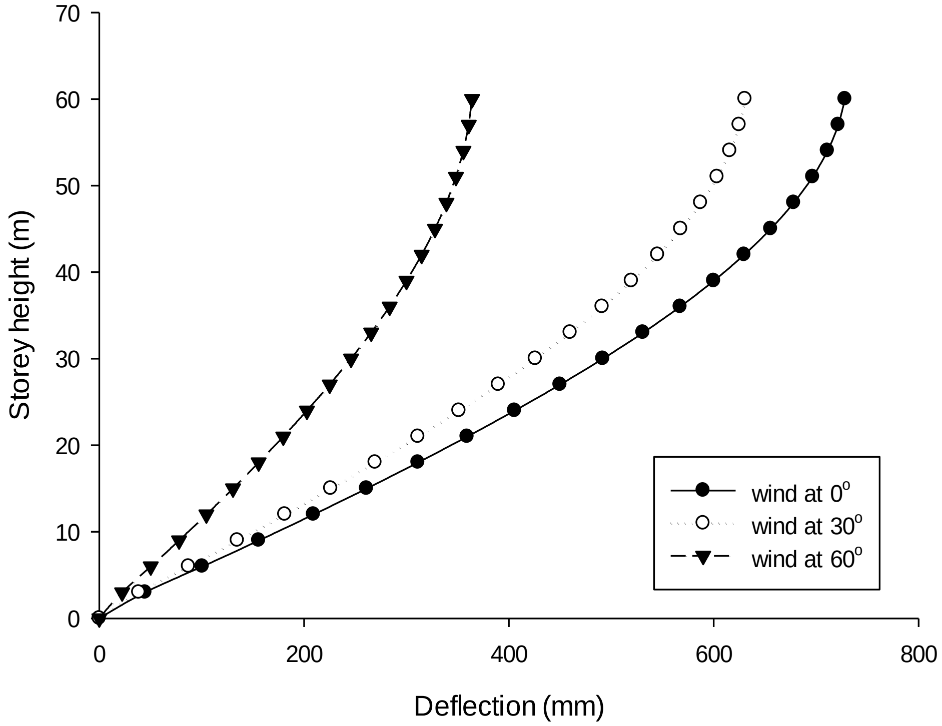

Fig.5.3: Effect of wind incidence angle on the lateral deflection at height.

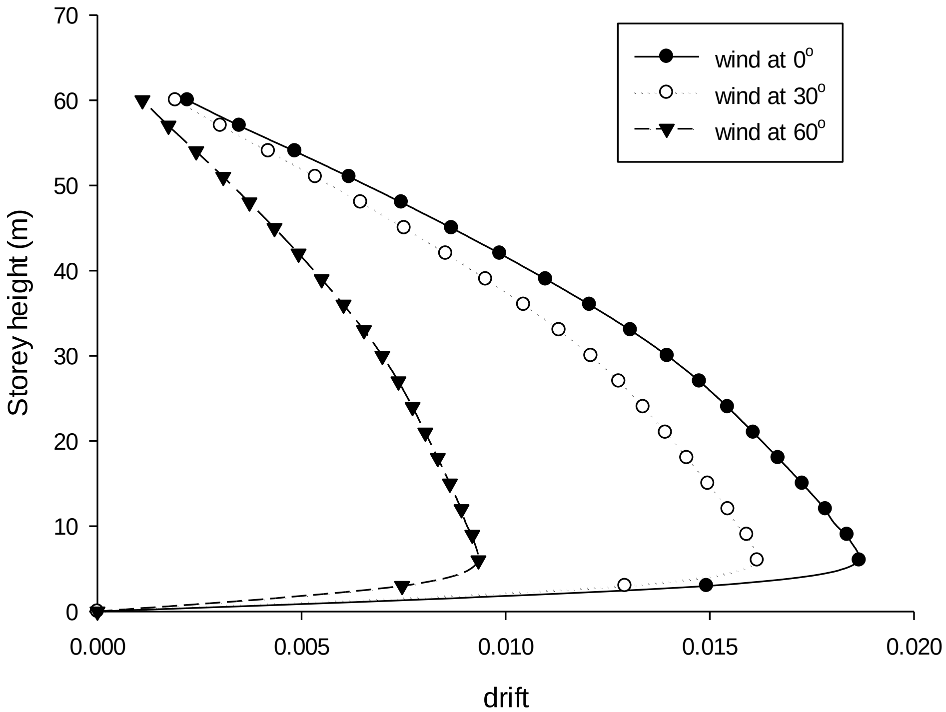

Fig.5.4: Effect of wind incidence angle on the storey drift.

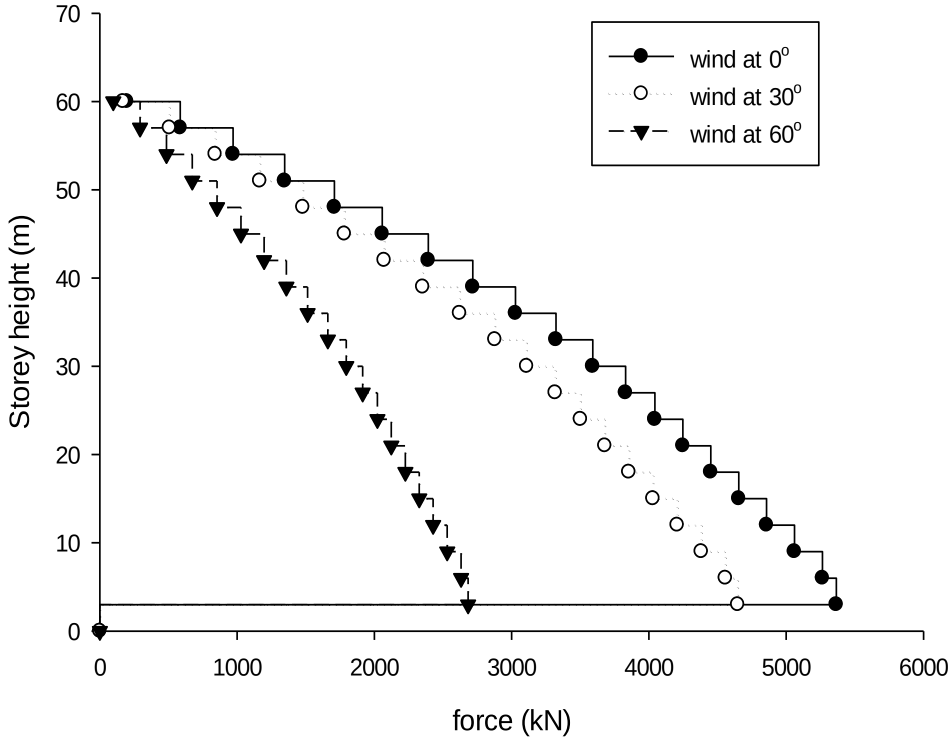

Fig.5.5: Effect of wind incidence angle on Base shear (F_X).

5.3.2 BUILDING WITH X-BRACING

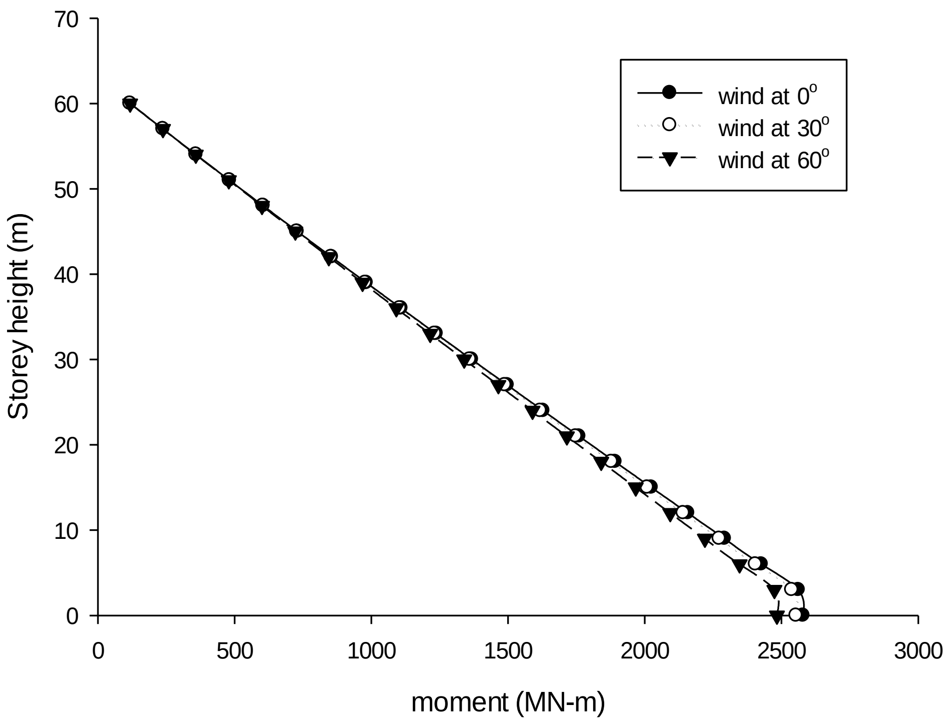

Fig.5.6: Effect of wind incidence angle on the overturning moment (M_Y).

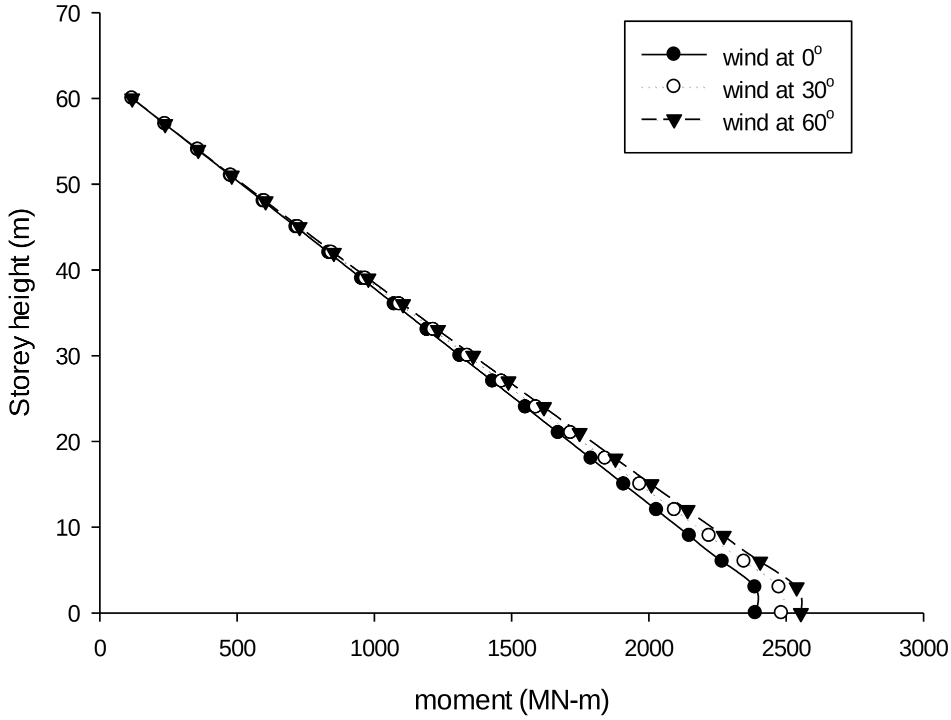

Fig.5.7: Effect of wind incidence angle on moment (M_X)

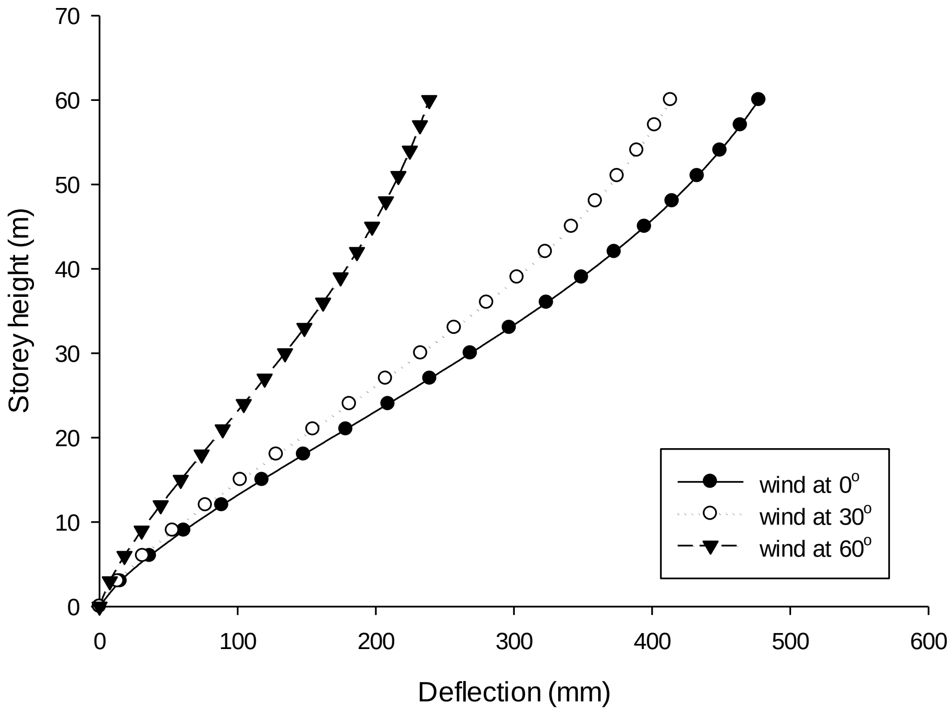

Fig.5.8: Effect of wind incidence angle on lateral displacement in the X-bracing system.

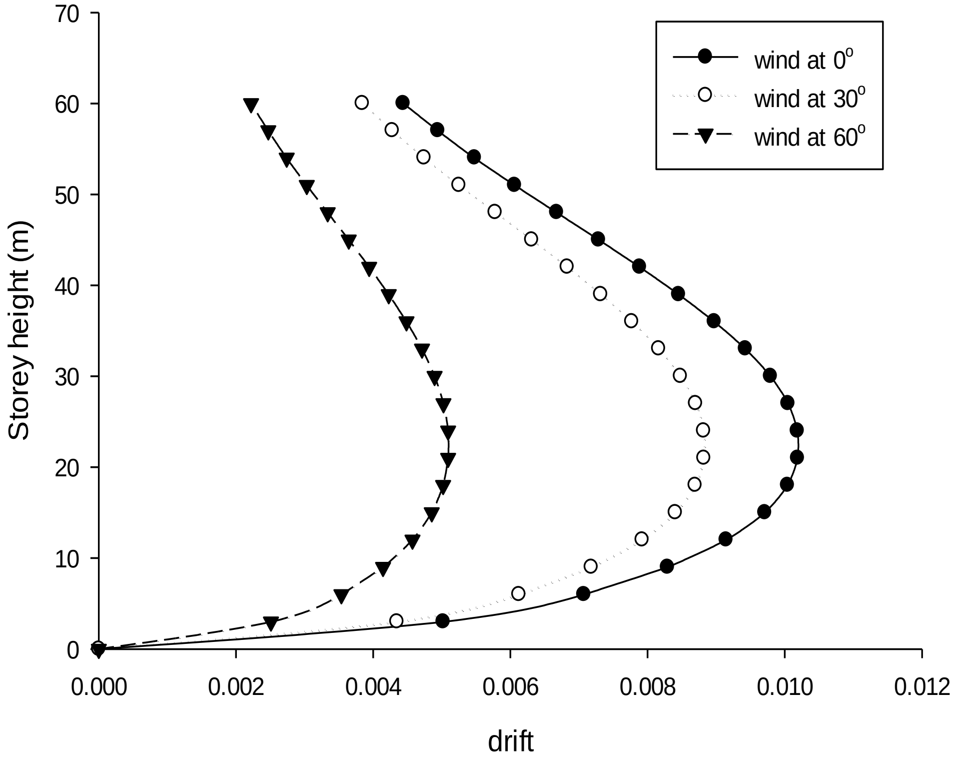

Fig.5.9: Effect of wind incidence angle on storey drift

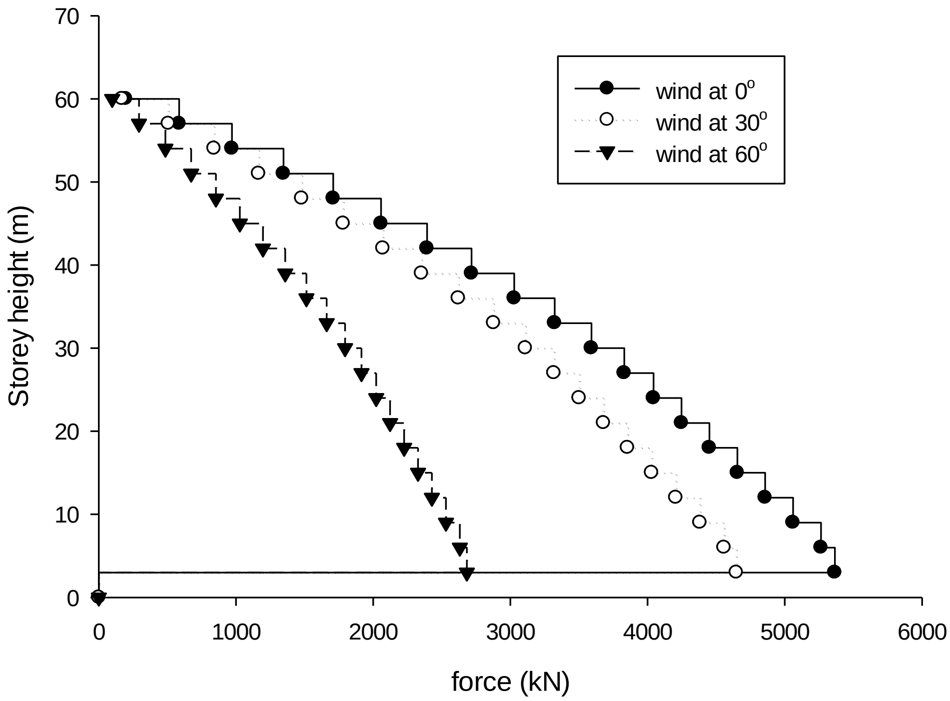

Fig.5.10: Effect of wind incidence angle on base shear (F_X).

5.3.3 BUILDING WITH V-BRACING

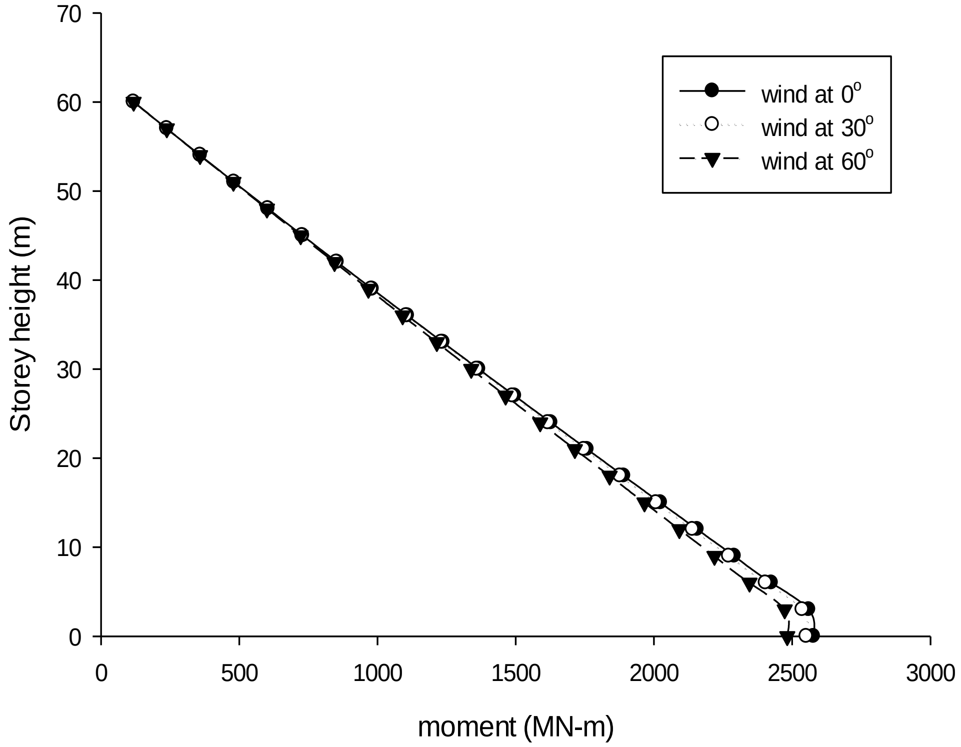

Fig.5.11: Effect of wind incidence angle on the overturning moment (M_Y).

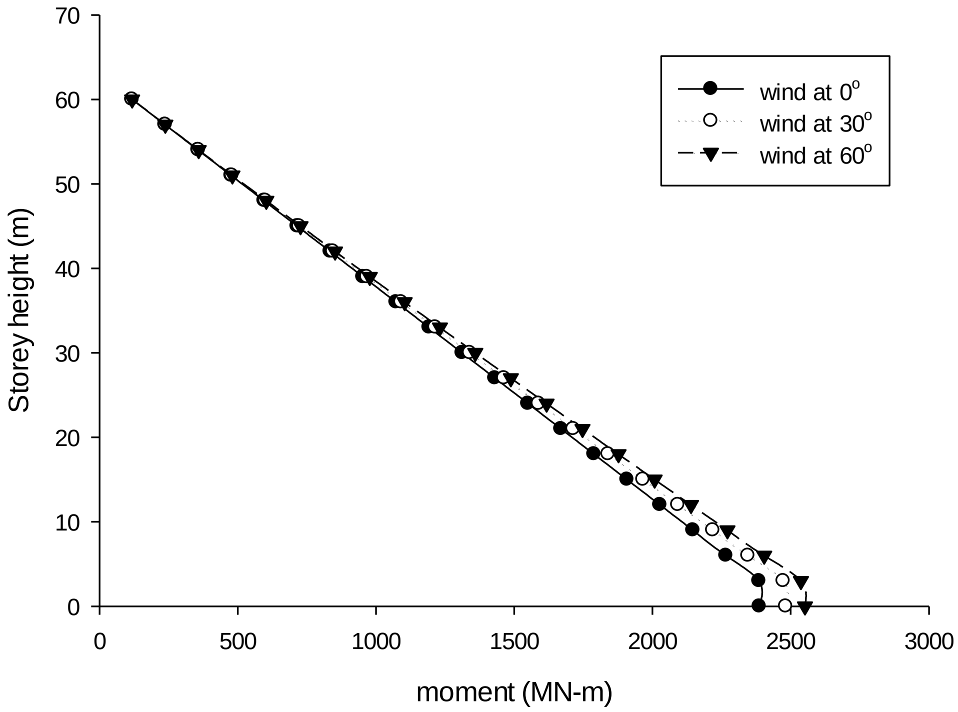

Fig.5.12: Effect of wind incidence angle on the moment (M_X)

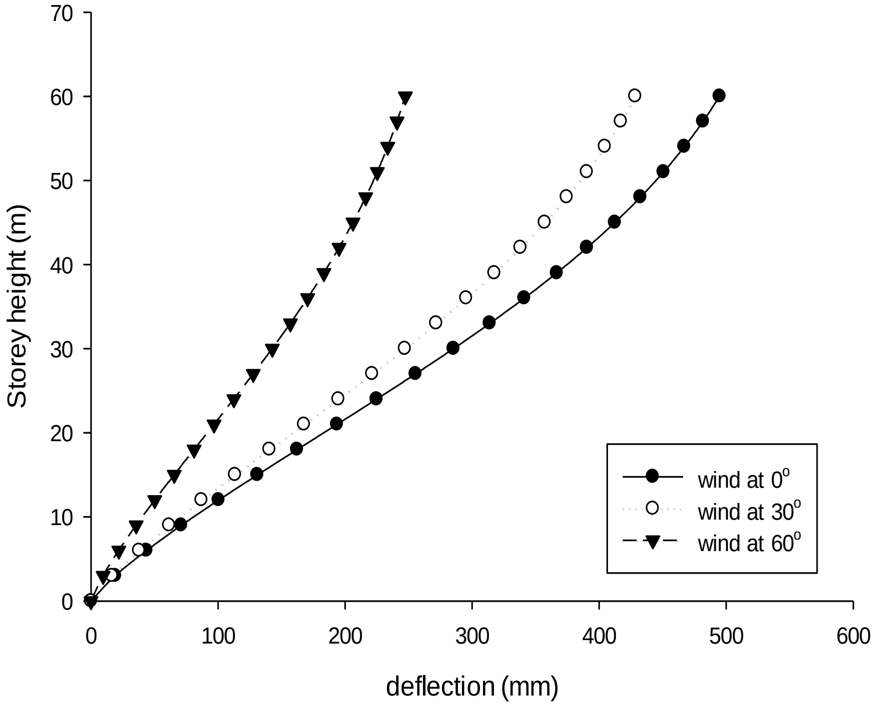

Fig.5.13: Effect of wind incidence angle on the lateral deflection at height.

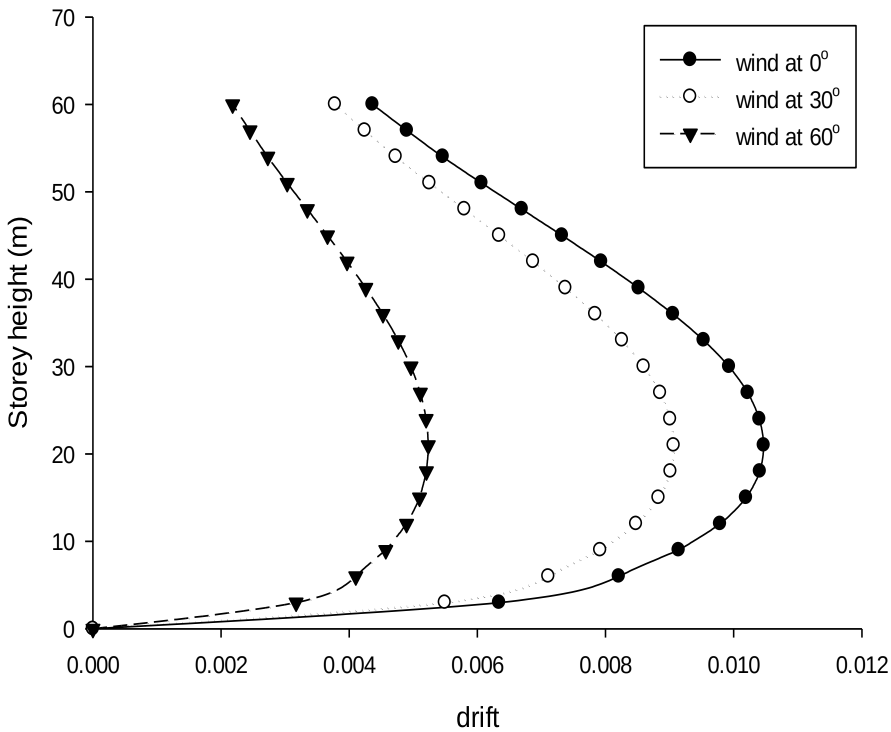

Fig.5.14: Effect of wind incidence angle on storey drift

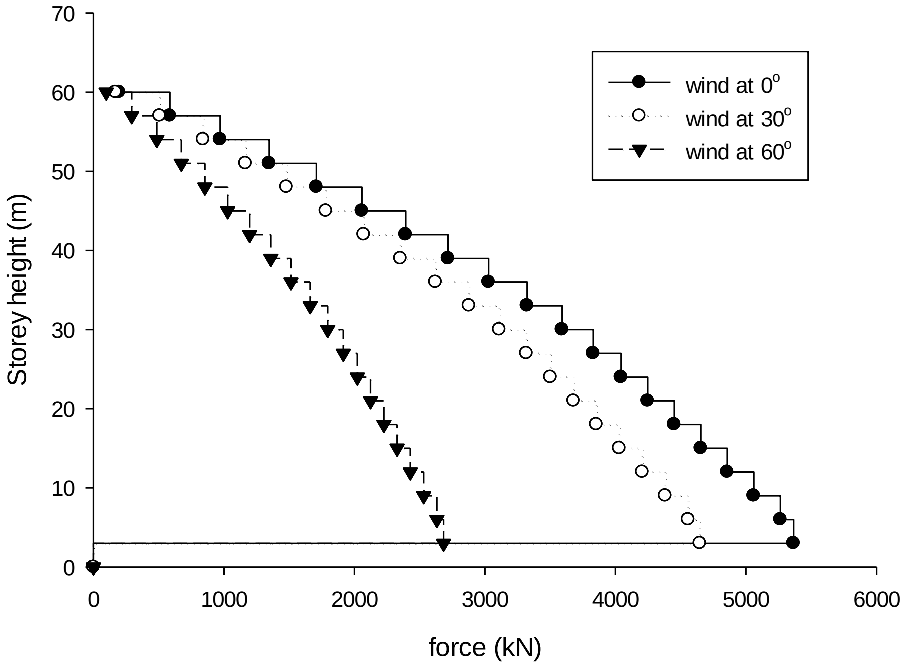

Fig.5.15: Effect of wind incidence angle on base shear (F_X)

5.3.4 BUILDING WITH I.V-BRACING

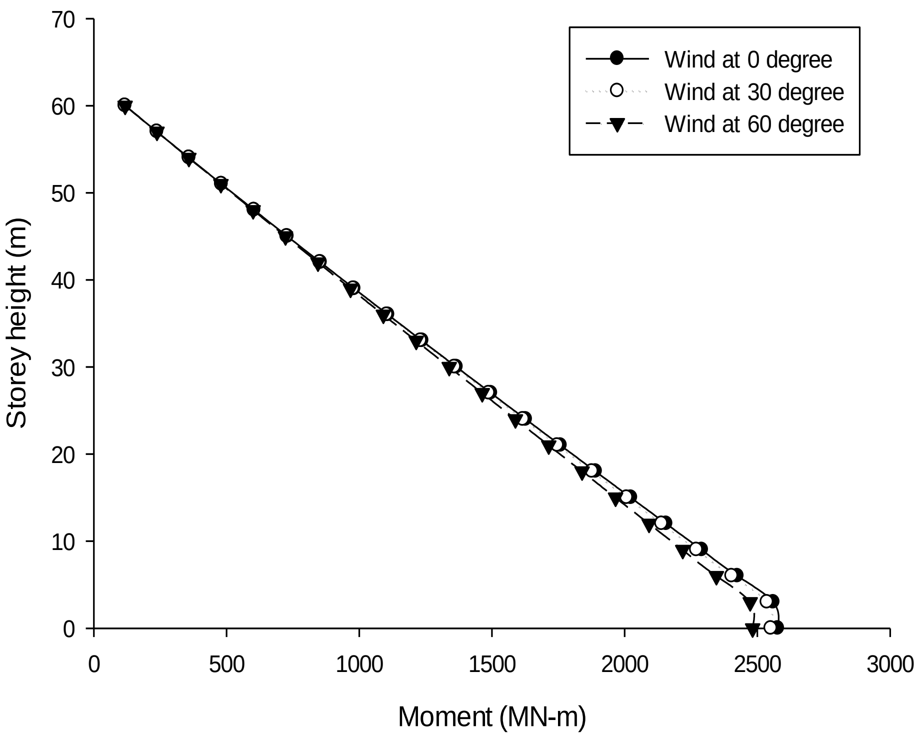

Fig.5.16: Effect of wind incidence angle on the overturning moment (M_Y).

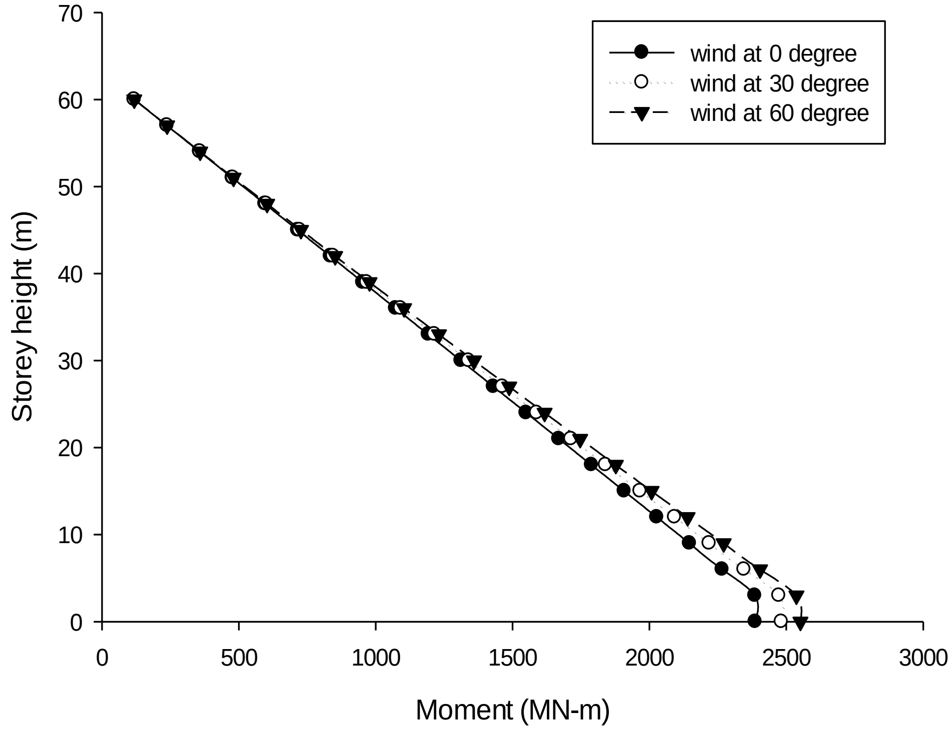

Fig.5.17: Effect of wind incidence angle on the moment (M_X)

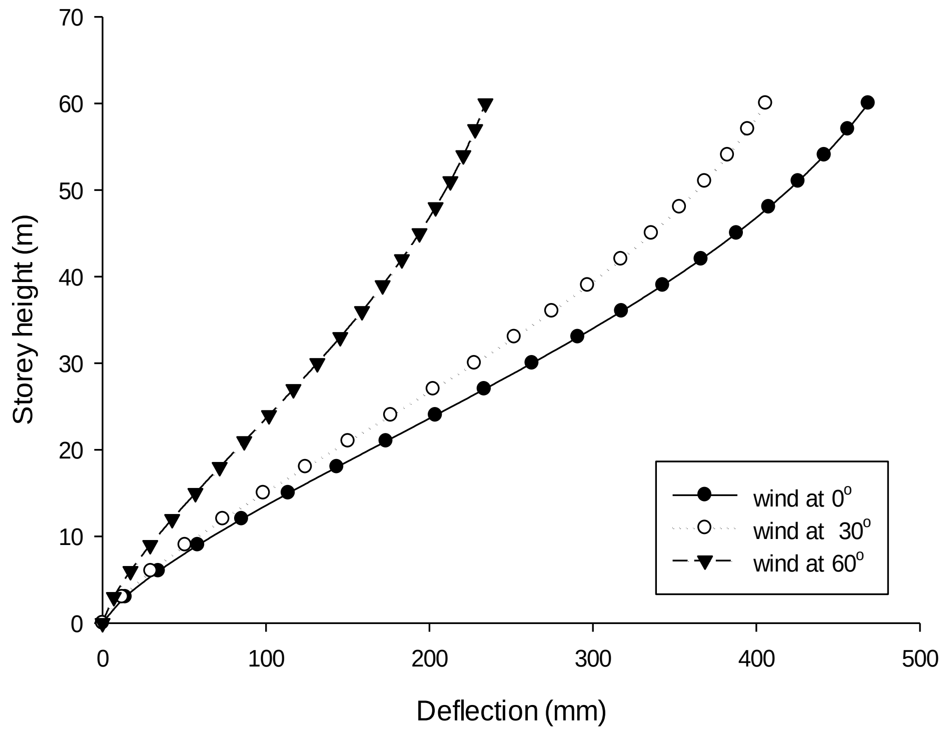

Fig.5.18: Effect of wind incidence angle on the lateral deflection at height

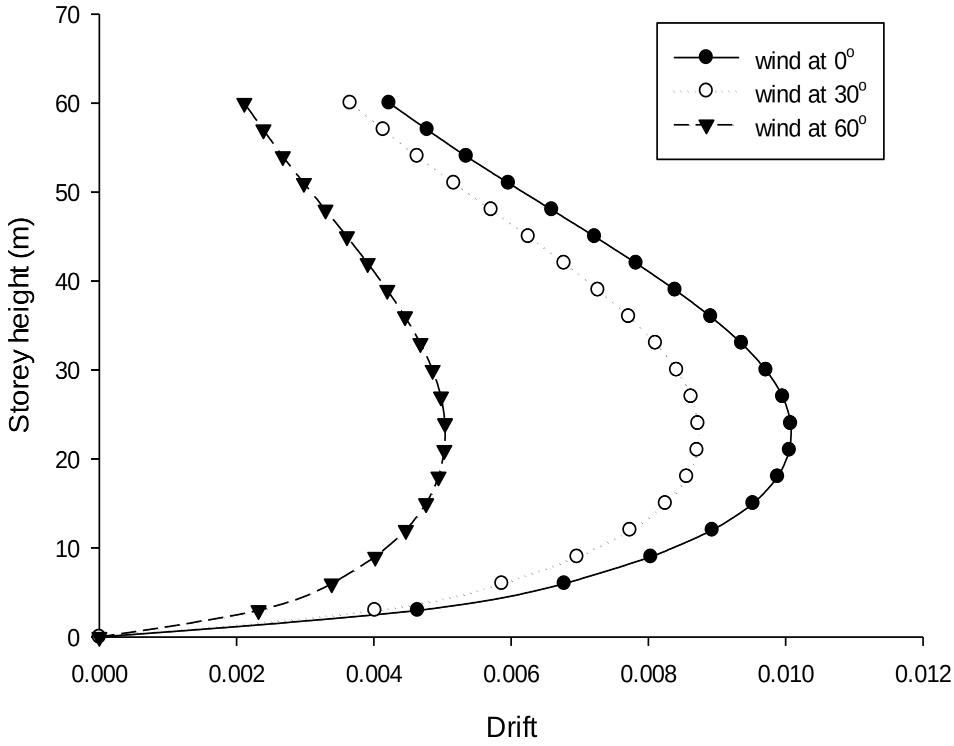

Fig.5.19: Effect of wind incidence angle on storey drift

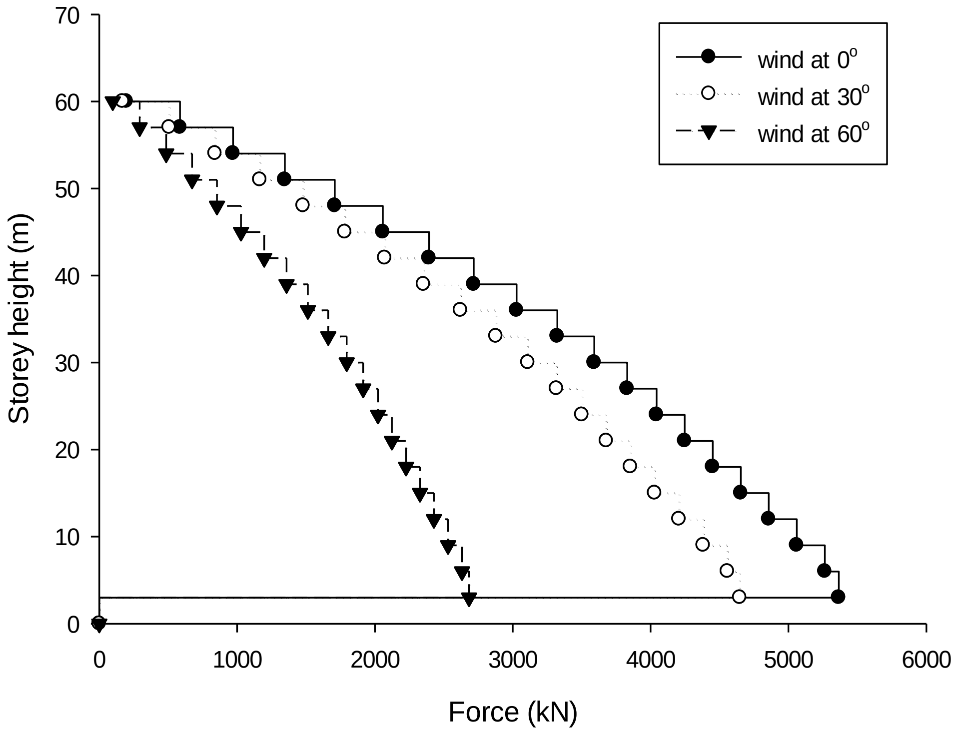

Fig.5.20: Effect of wind incidence angle on base shear (F_X).

5.3.5 BUILDING WITH K-BRACING

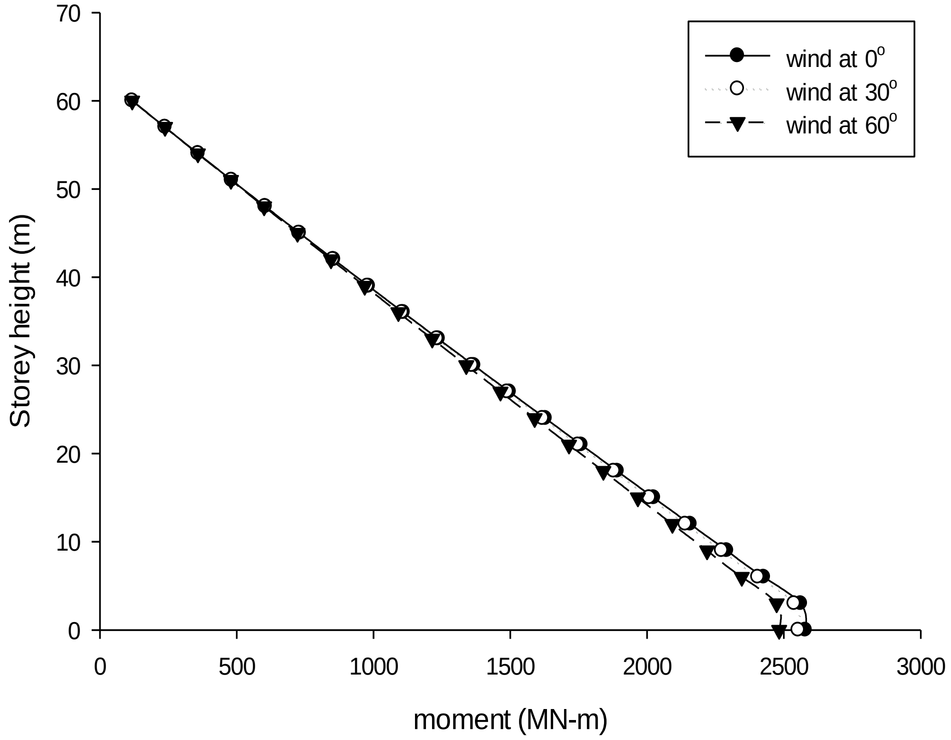

Fig.5.21: Effect of wind incidence angle on the overturning moment (M_Y).

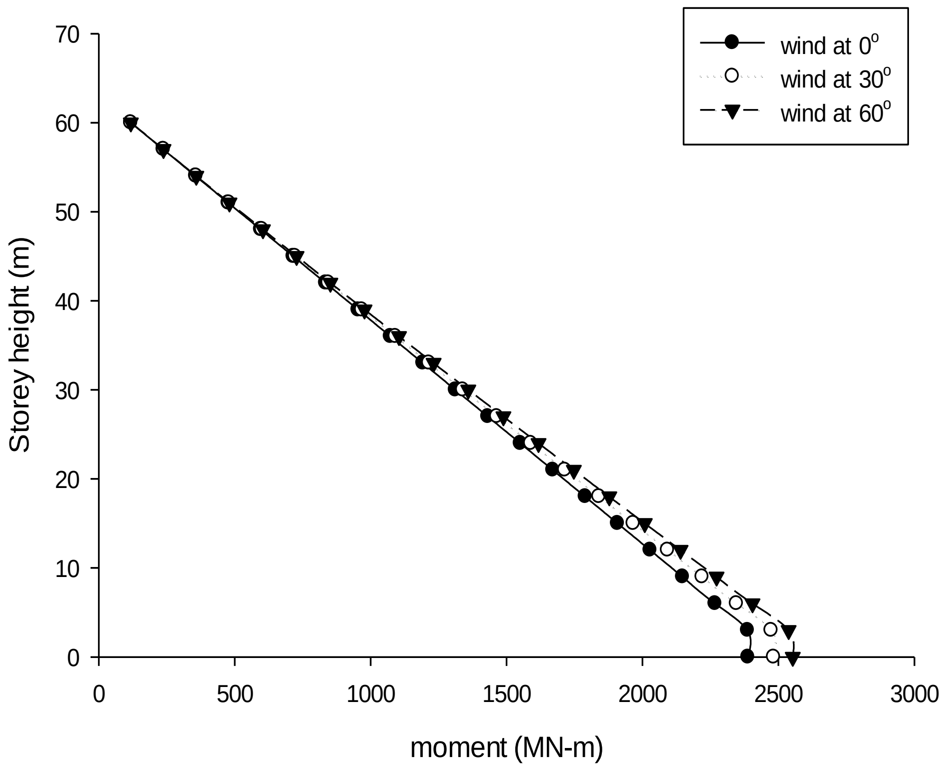

Fig.5.22: Effect of wind incidence angle on the moment (M_X)

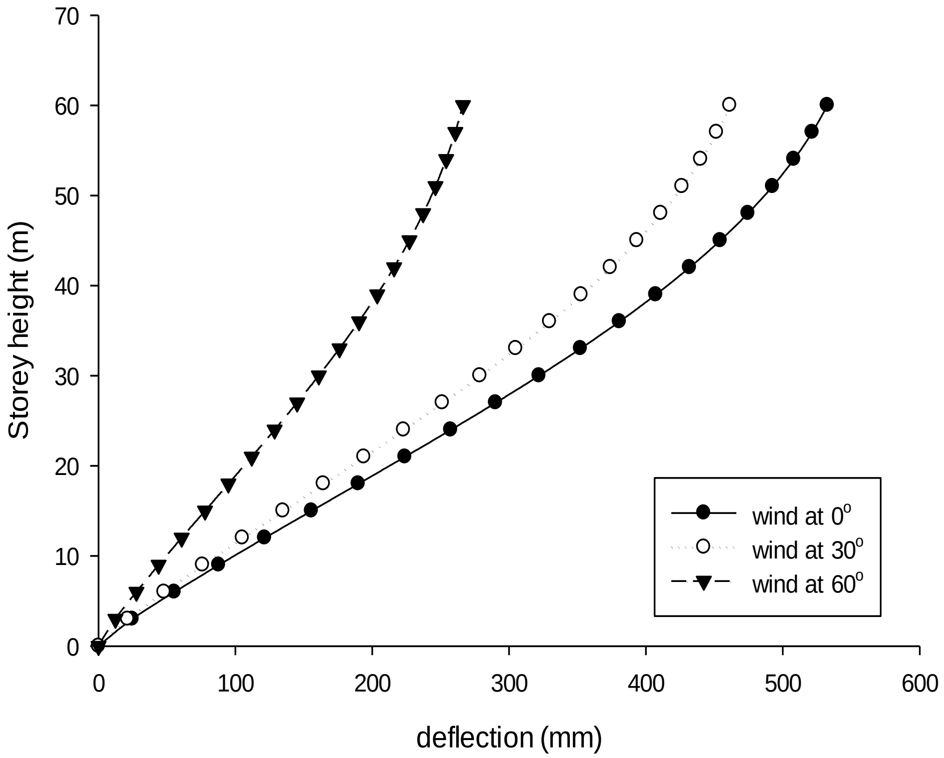

Fig.5.23: Effect of wind incidence angle on the lateral deflection at height.

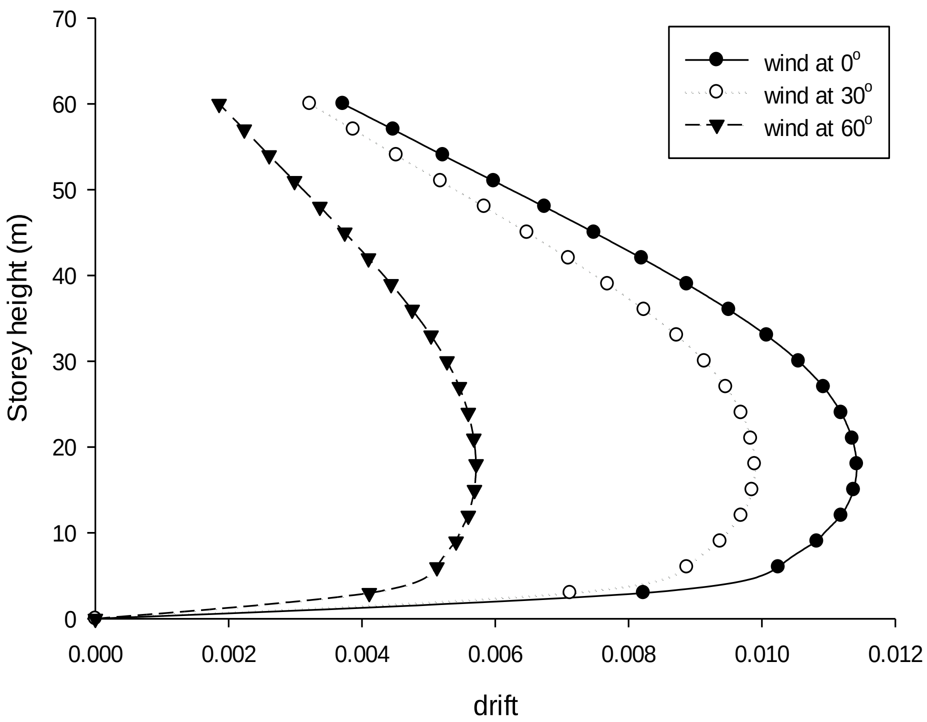

Fig.5.24: Effect of wind incidence angle on storey drift

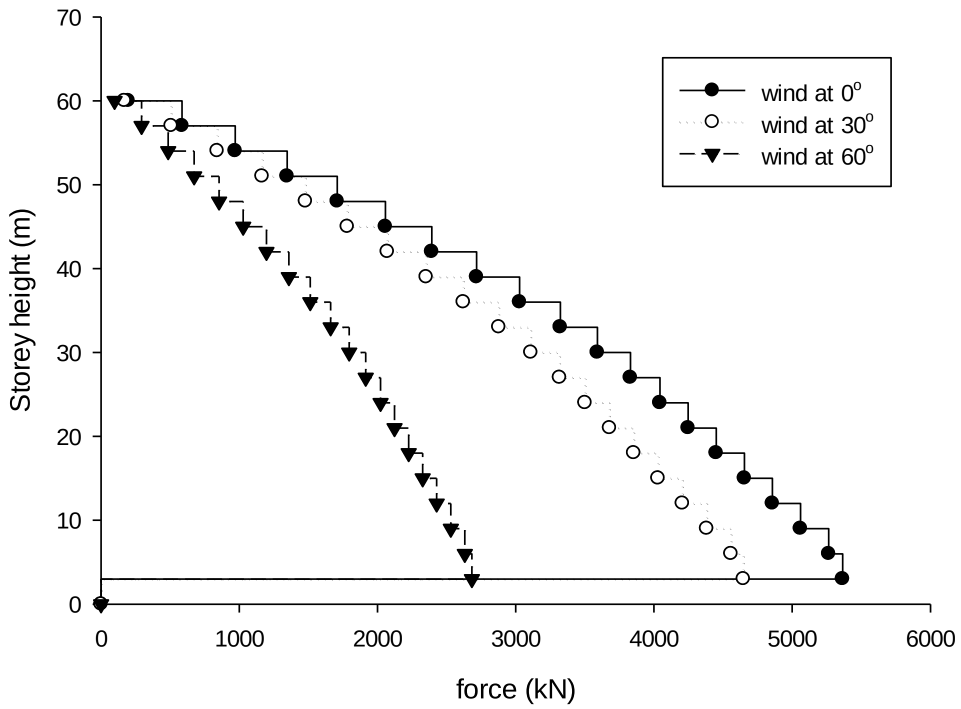

Fig.5.25: Effect of wind incidence angle on base shear (F_X).

5.3.6 BUILDING WITH DIAGONAL BRACING

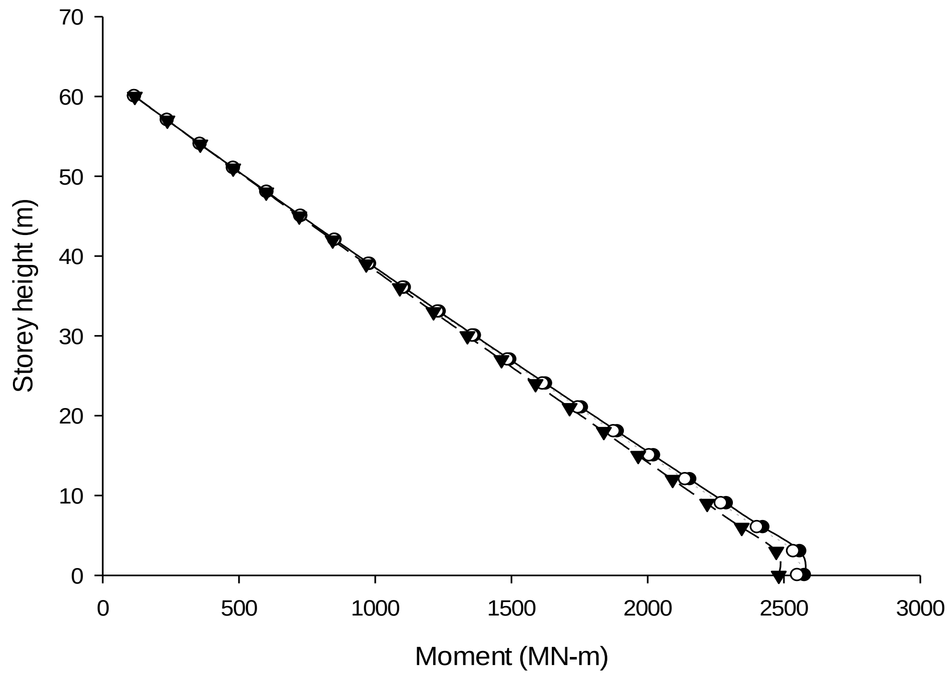

Fig.5.26: Effect of wind incidence angle on the overturning moment (M_Y).

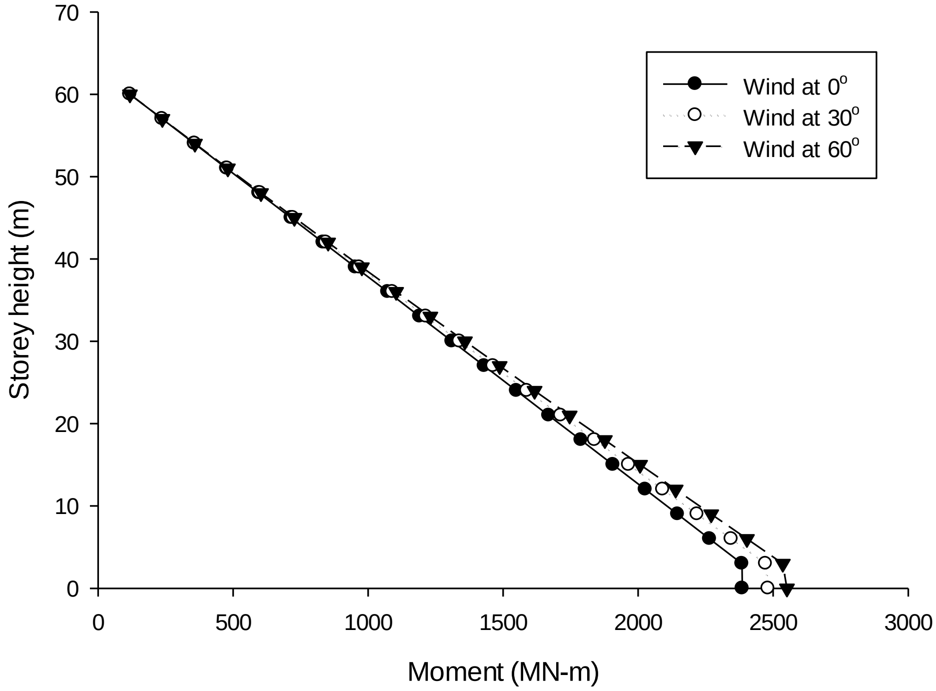

Fig.5.27: Effect of wind incidence angle on the moment (M_X)

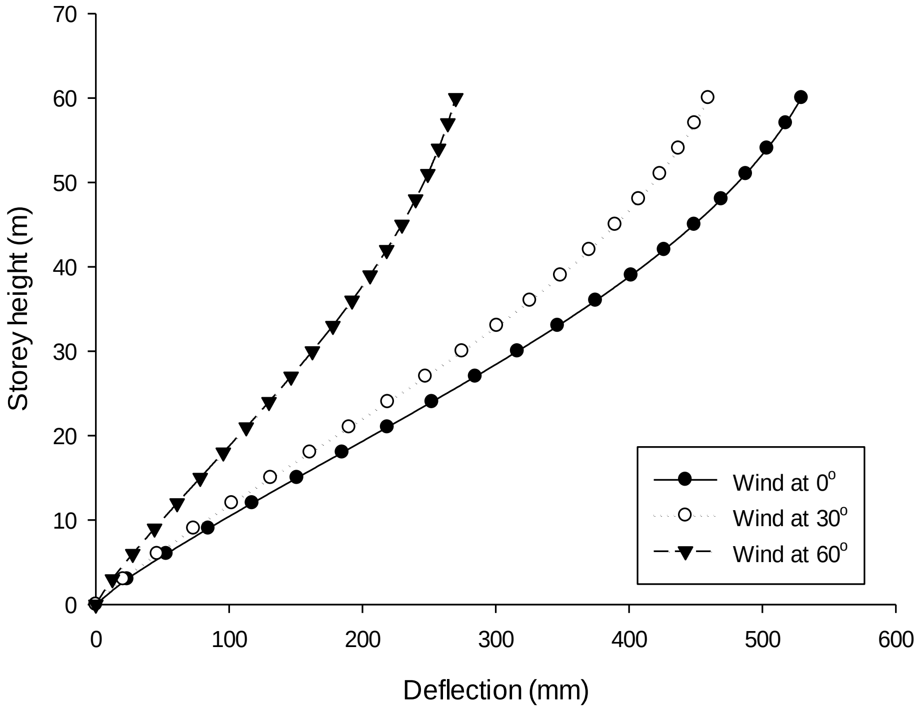

Fig.5.28: Effect of wind incidence angle on the lateral deflection at height.

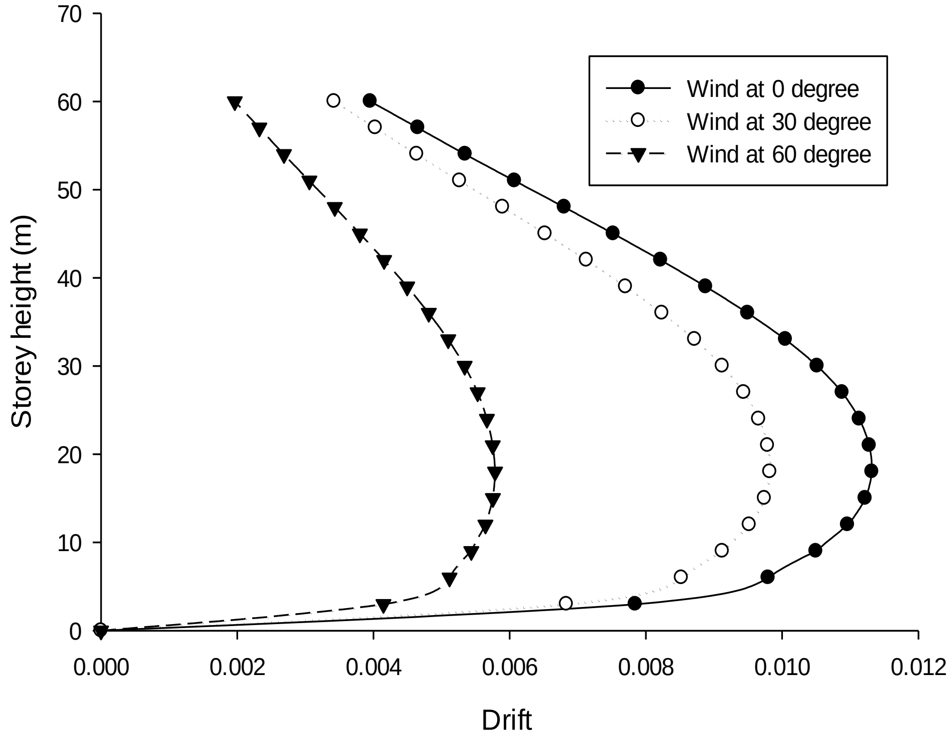

Fig.5.29: Effect of wind incidence angle on storey drift

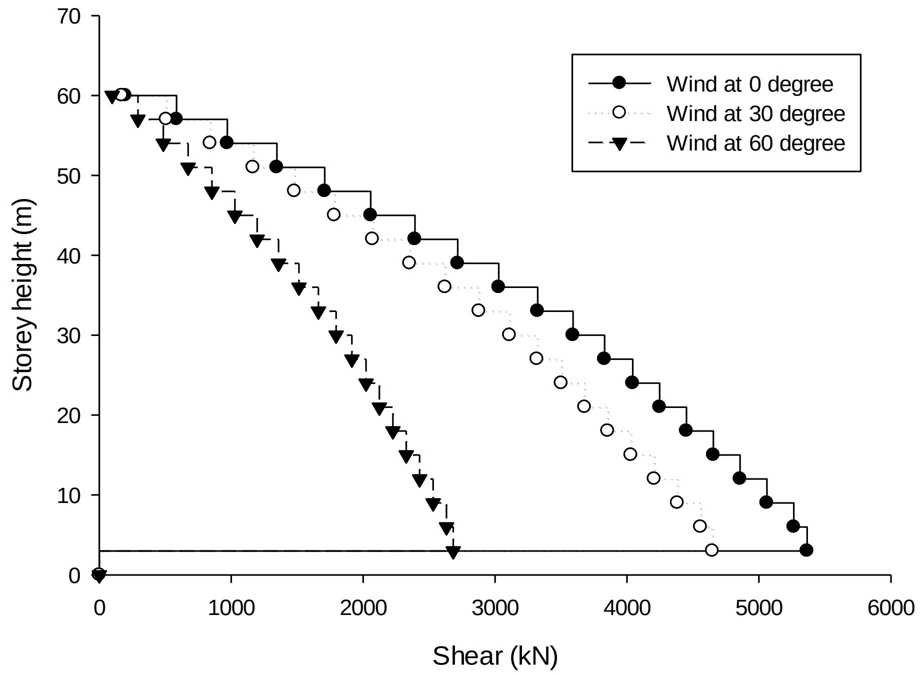

Fig.5.30: Effect of wind incidence angle on base shear (F_X).

5.4. COMPARATIVE STUDY OF ALL BRACINGS

The below graphs show the comparison of moments, deflection and inter storey drift for buildings with and without bracing for different wind incidence angle.

It can be seen from fig.5.31 to 5.42 that buildings with V-bracing and I.V- bracing have least overturning moment (M_Y) and moment (M_X) along wind for any direction of wind incidence.

The maximum horizontal deflection and storey drift for buildings with I.V-bracing and x-bracing are least and quite close in comparison to other types of braces.

5.4.1. 0° wind incidence angle

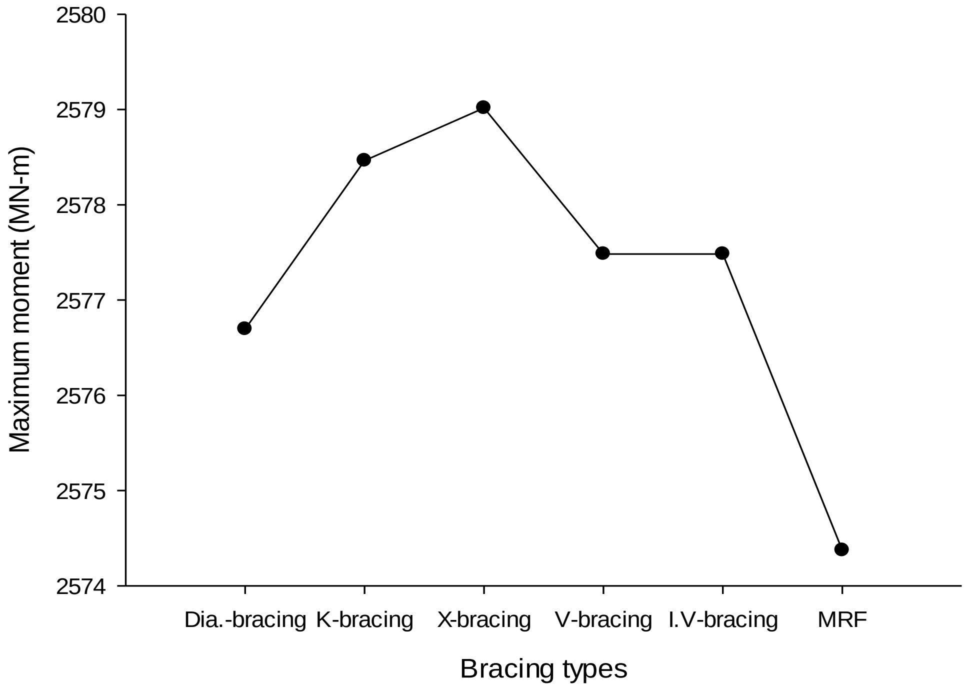

Fig.5.31: Effect of bracings on the overturning moment (M_Y)

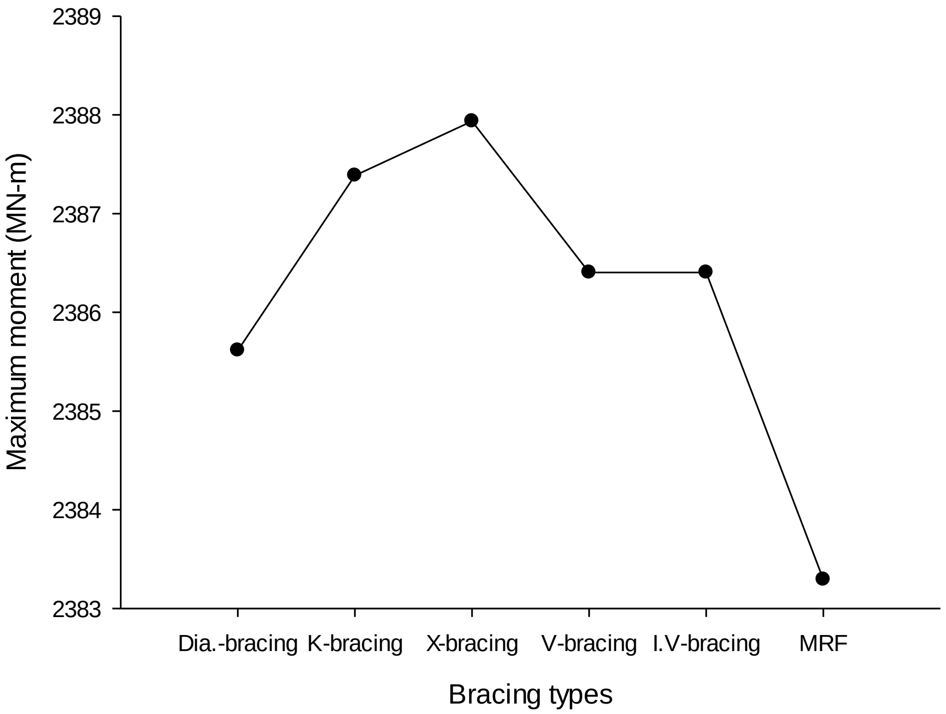

Fig.5.32: Effect of bracings on moment (M_X) generated along wind incidence

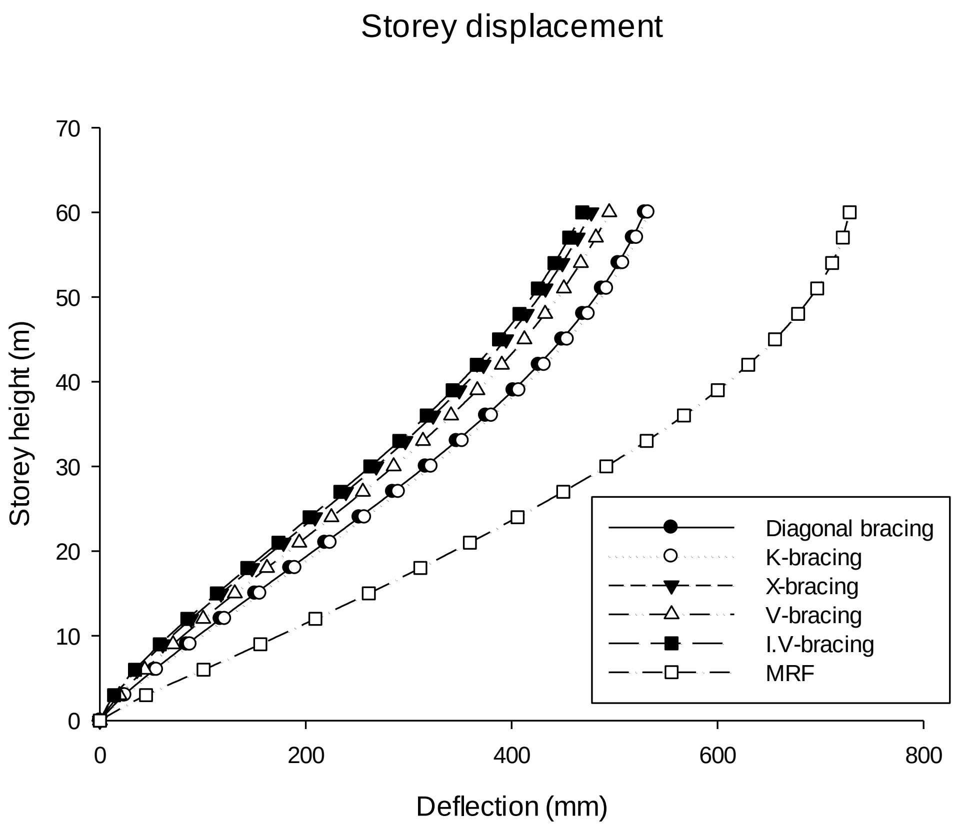

Fig.5.33: Effect of bracing on lateral displacement (Δ_x) along wind incidence.

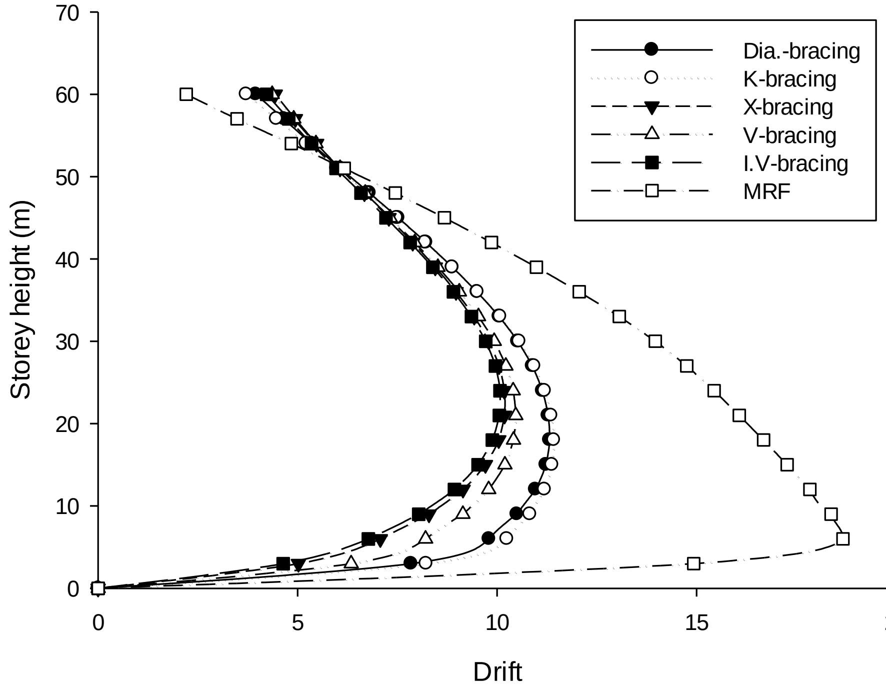

Fig.5.34: Effect of bracing on storey drift along wind incidence direction.

5.4.2. 30° wind incidence angle

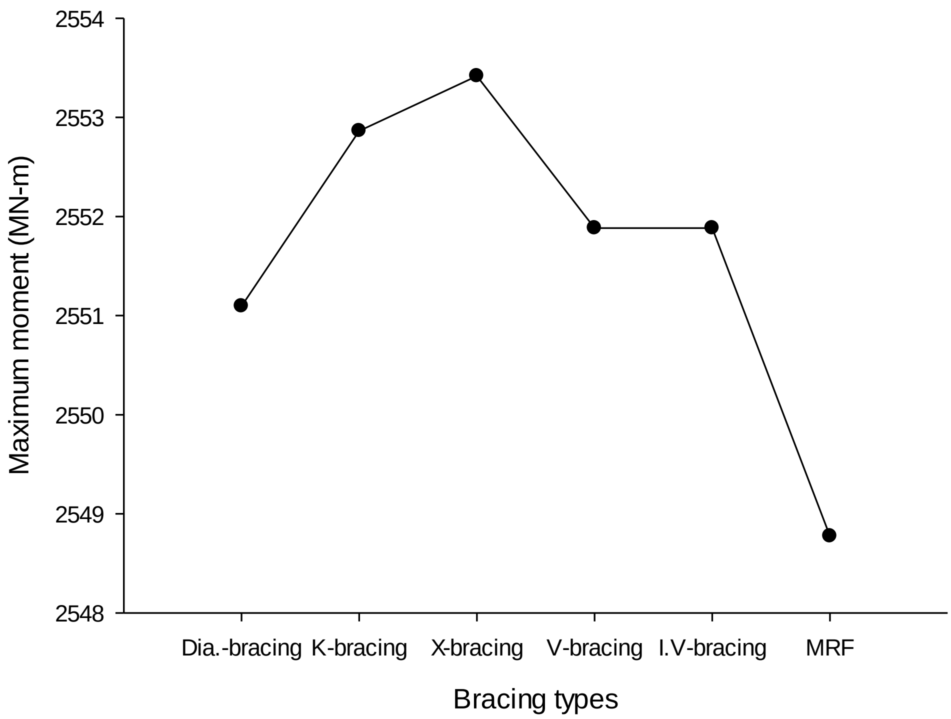

Fig.5.35: Effect of bracing on the overturning moment (M_Y)

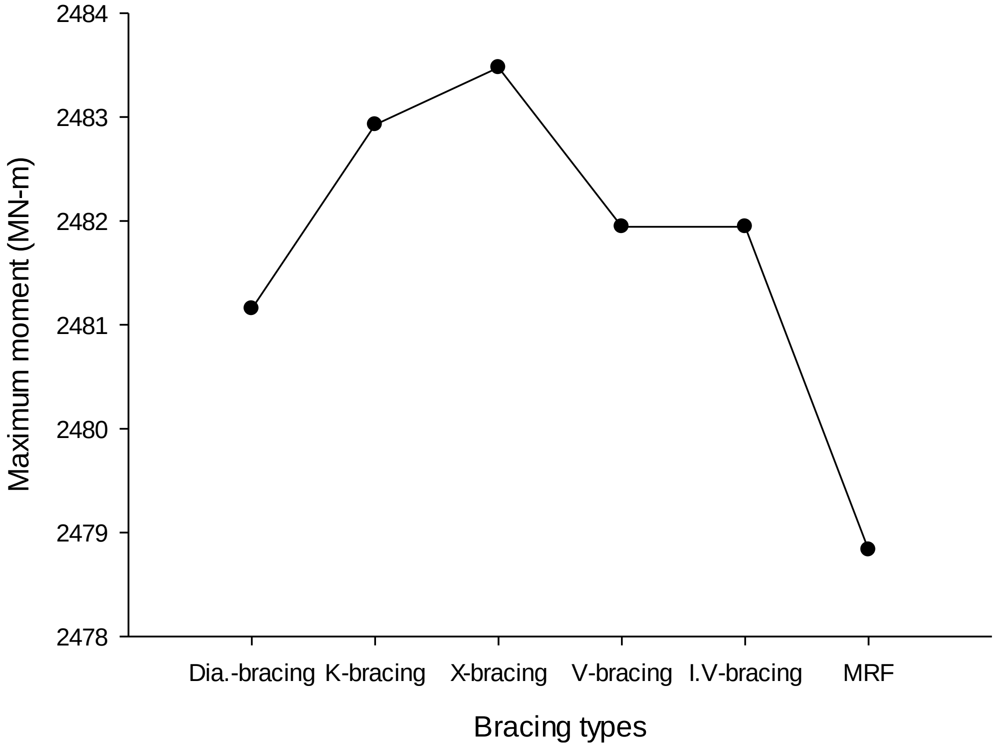

Fig.5.36: Effect of bracing on the moment (M_X)

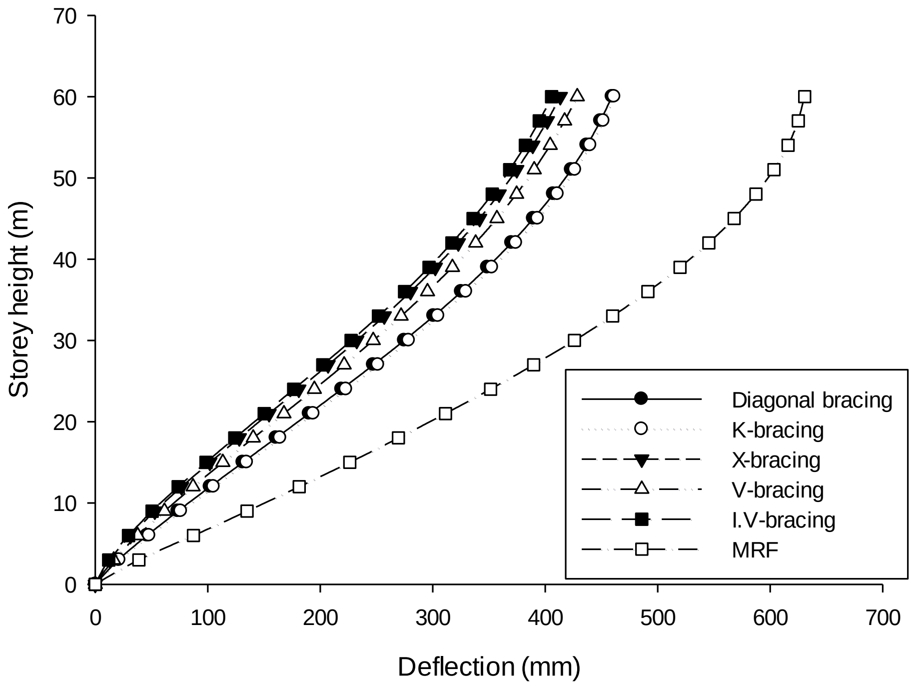

Fig.5.37: Effect of bracing on the lateral displacement (Δ_x).

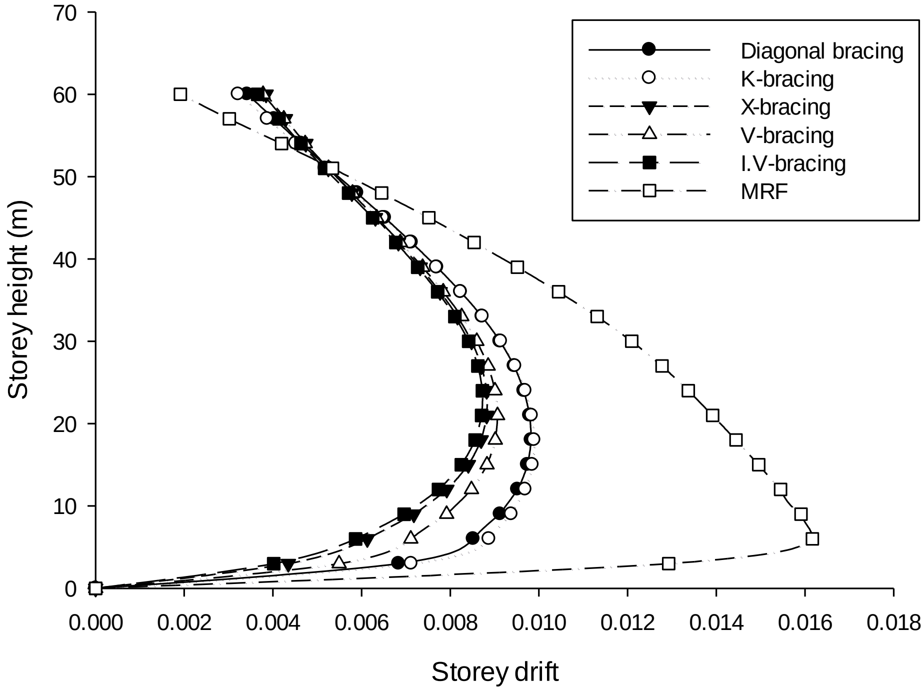

Fig.5.38: Effect of bracing on storey drift along the x-direction

5.4.3. 60° wind incidence angle

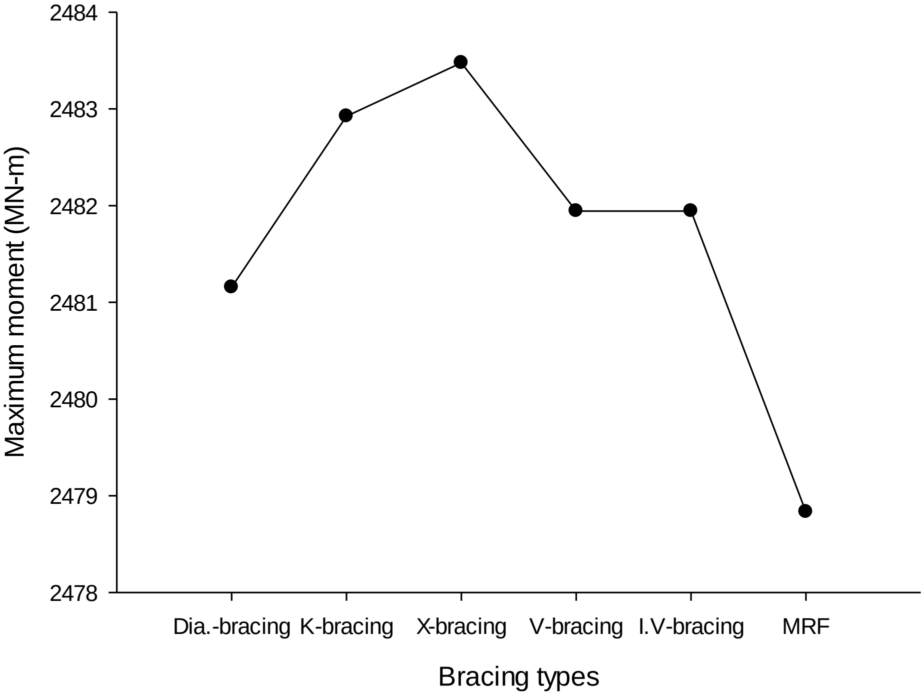

Fig.5.39: Effect of bracing on the overturning moment (M_Y)

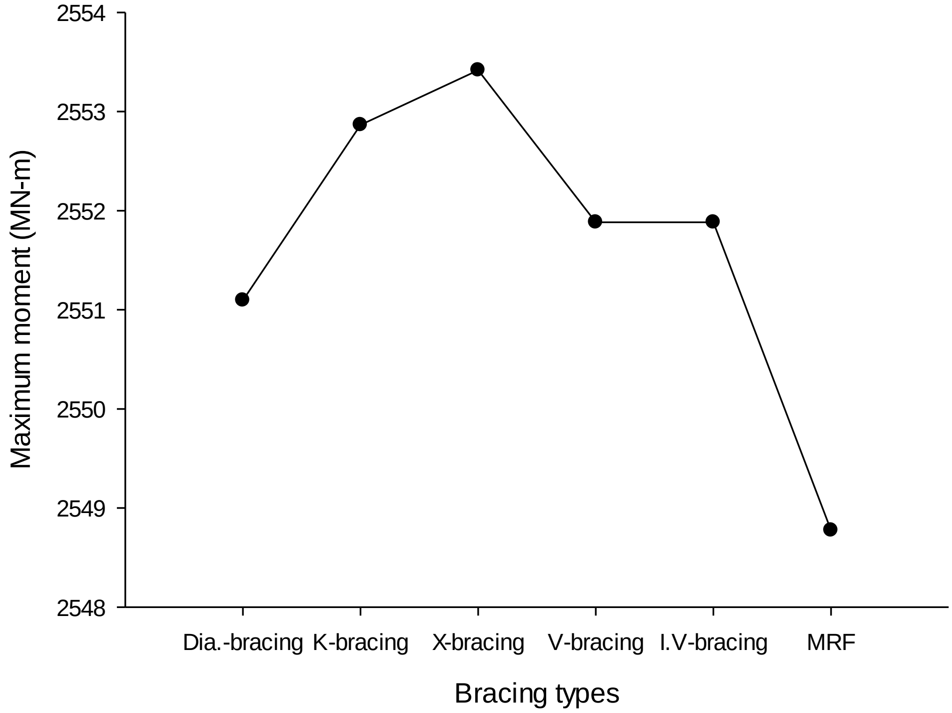

Fig.5.40: Effect of bracing on the maximum moment (M_X) generated at the base.

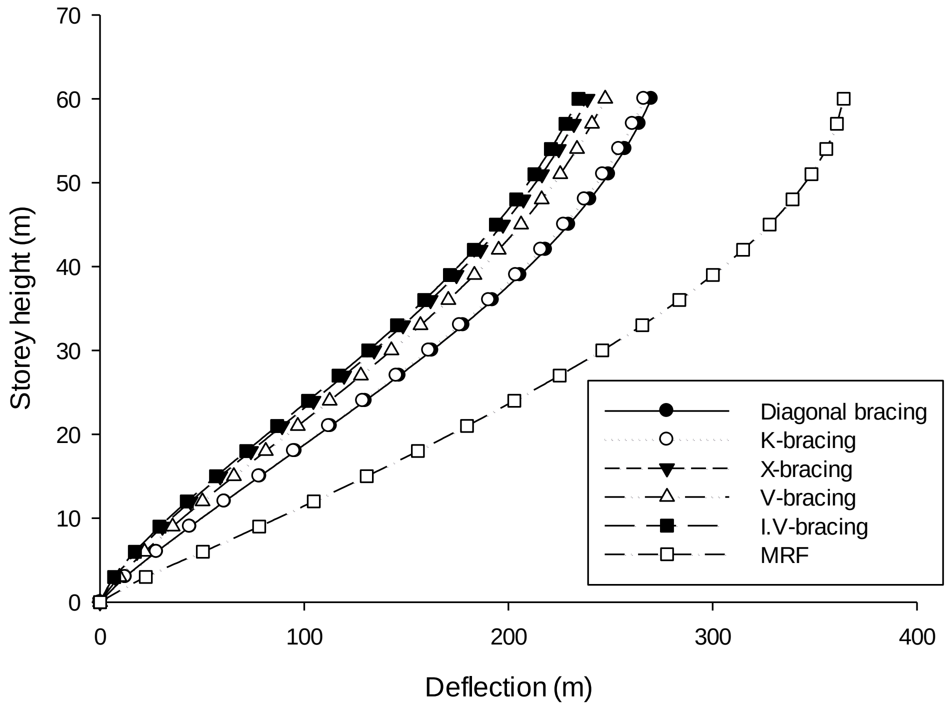

Fig.5.41: Effect of bracing on the lateral displacement (Δ_X)

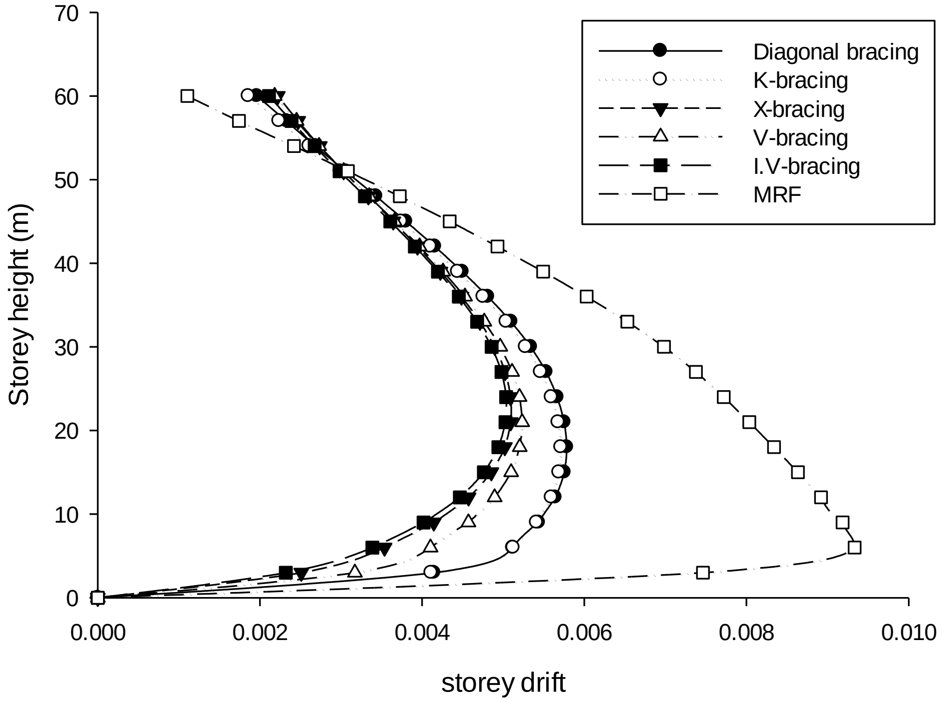

Fig.5.42: Effect of bracing on storey drift along the x-direction

Chapter-6
RESULT AND CONCLUSION

The detailed study of the effect of wind incidence angle on buildings with and without bracings is covered in preceding chapters. The comparative response study shows that moment generated about x and y axis is minimum for I.V-bracing and V-bracing for all angle of incidence of wind for both square and plus shape plan structures.

The lateral deflection at the top of the building which the major criteria of lateral stability of the building is observed to reduce considerably for buildings with bracing than without bracing. It is found to be minimum for I.V-bracing and X-bracing. The maximum reduction in lateral displacement is observed to be 35.65%. Table 6.1 shows the maximum lateral deflection that occur in building with bracings and percentage reduction in lateral displacement.

The increase in weight of overall structure due to bracing is least for DBF and the weight of the structure with Inverted VBF and VBF are lower than XBF, KBF and MRF. Table 6.2 shows the weight of structures with different bracing and their percentage increase.

The I.VBF and VBF are more efficient to resist lateral load due to wind load as stabilised from literature in chapter 2.

Type of bracings	Max. displacement(mm)	Change in displacement (%)
Diagonal	529.363	27.31
X-bracing	477.363	34.45
K-bracing	532.677	26.85
V-bracing	494.854	32.05
I.V-bracing	468.585	35.65
MRF	728.24	0

Table 6.1. Percentage reduction in lateral deflection for buildings with and without bracing

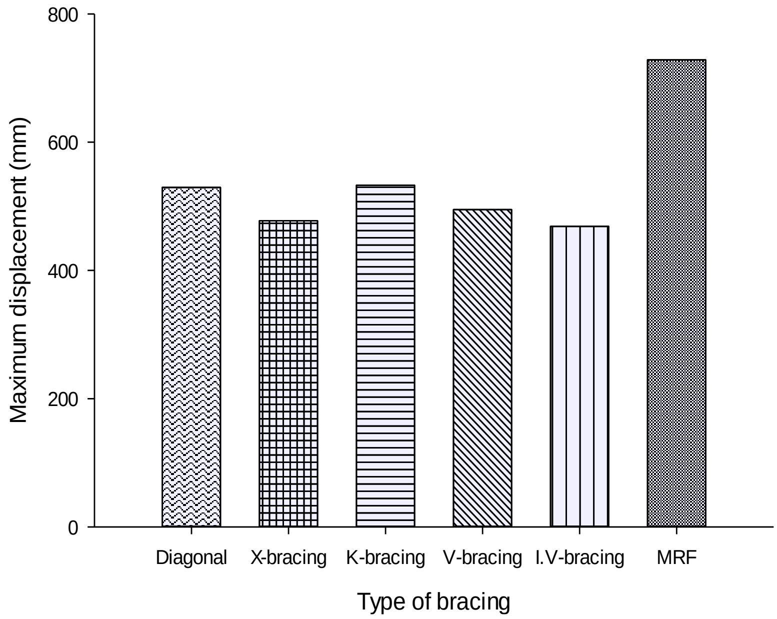

Fig.6.1. Maximum lateral deflection for building with and without bracing

Type of bracings	Weight of str. (kN)	%age reduction in weight
Diagonal	2057.471	0.151
X-bracing	2060.57	0.301
K-bracing	2059.845	0.266
V-bracing	2058.523	0.202
I.V-bracing	2058.523	0.202
MRF	2054.372	0

Table 6.2. Weight of models with different bracing and %age increase.

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