Parametric Study on Performance Based Wind Design of Industrial steel structure

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Abstract.

Now a days, Steel is widely used in the construction of industrial buildings where concrete construction is not feasible or when construction time is critical. It is very tough to define accurate wind load pattern for analysis using nonlinear response history analysis. Therefore, there is need to investigate defined method and steps for design and analysis of industrial steel building for performance-based wind design, with taking wind tunnel test for wind load pattern. Also, it is required to find out difference in response of building between conventional code-based design and performance-based design. The purpose of the project was to study the performance-based wind analysis of steel structure This method primary goal is to maintain the structural system linearly elastic, hence allowing controlled inelasticity in structural components may provide for a more effective section. In that dissertation work consider some parameters for performance-based wind analysis of industrial steel structure as we going at height wind effect will be changes for that study consider 10m,20m,30m height of building. Also, wind speed is varying as per locations. Wind velocity is getting increases as we go above. This study assessed how structure behaves in nonlinear dynamic response of wind at various locations, height, roof angle by creating 3D finite element model and using a time-history wind analysis approach. The wind loading of structure was acquired using wind simulation test in Autodesk Robot Structural Analysis Software. An approach for evaluating wind performance has built using those findings and the available wind performance criteria, expressing the estimated performance levels as a function of the fundamental wind speed.

Keywords: *Performance-based design; wind simulation; nonlinear dynamic response; time history analysis.*

1. Introduction

Steel construction is growing very rapidly all over the world. An industrial building is any structure that is used to store or manufacturing process. These buildings are used for workshops, warehouses, service stations etc. Steel is extensively used in the construction of industrial building of larger span where concrete construction is not feasible or when construction time is critical. The important elements of industrial buildings are purlins, rafter's, roof truss, wind bracings and columns. Now days, steel construction is growing very rapidly all over the world. An industrial building is any structure that is used to store or manufacturing process. Steel is extensively used in the construction of industrial building of larger span where concrete construction is not feasible or when construction time is critical. However, the change in climate introduces more natural disasters it makes challenging to structural engineer that building must be stable for those natural hazards. Due to their complex nature, the industrial building construction process is unique over others.

India lies in the region of north easterly winds. It blows from the north east in winter and rainy season as well as It flows south west in summer season.in some areas wind velocity is more than the seismic effects for that condition when designing buildings, structures and their components wind forces and their effects needs to be considered. Wind flows very randomly both in time and space therefore assessment of wind loads and response prediction are very important in the design. There are various types of structure or their components such as industrial steel building, long span beams, lattice towers etc., which require investigation of wind induced oscillations.

When the wind flows opposite to the building, the resulting force acting on the elevations is called the ‘ wind load’ . The building’s structural design must resist wind forces safely and efficiently and transfer them to the foundations in order to avoid structural collapse.

The structural response of typical, roof pitch, gable-end, industrial buildings, in a wind storm is dependent on the wind loads used in the design of cladding and the frame structure. Building codes and guidelines generally define the required performance via the specification of minimum structural performance requirements under wind load. Since this approach primarily intends to keep the structural system essentially elastic, the more efficient design may be achievable by allowing controlled inelasticity in structural components. However, recent studies in earthquake and wind engineering highlighted the conceptual and practical limitations of the Code oriented design methods. All these facts put a great emphasis on using are liable wind design and assessment approach evidently describing the performance of building to wind loads beyond the current design wind loads. Therefore, philosophically logical extension of the current wind design approaches is performance-based wind design. Cyclones are a major natural hazard in the tropics and are responsible for large-scale death and destruction. Extremely violent wind, heavy rains causing floods and storm tides are the destructive factors associate with tropical cyclones. Severe thunderstorms over northeast India are normally very severe and this is the natural phenomenon, which causes considerable damage to life and property every year in India.

1.1 Current wind design approach

The instructions in the code documents are transparent and clear. The prescriptive nature of the instructions allows the smooth implementation of the design steps in computer programs, which makes the design process quick. The present wind design methodology described in standard code, the structural members designed for the strength limit states that consider equivalent static wind loading for a certain risk category and hazard level.

Factored design wind loads are calculated by using either static, dynamic, or wind tunnel techniques. For designs that require wind tunnel testing, initial structural properties are usually determined based on the gravity and wind loads from the building codes. Based on the factored loads, the building lateral stiffness checked through drift requirements.

1.2 Performance-based wind design approach (PBWD)

Performance-based engineering is a modern engineering process through which a new structure is designed, or an existing building is evaluated and retrofitted more efficiently and economically by requiring the structure to meet certain performance requirements at various levels of demand. Comparing to the current perspective approach, utilizing the performance-based approach results in more informative and transparent output to stakeholders. The performance-based engineering concept was first developed and implemented in the seismic engineering field and is now well accepted in professional practice for seismic design and devaluation. To perform PBWD of wind-excited tall buildings, it is first necessary to have a clear understanding of structural responses in the nonlinear inelastic range. Performance-based wind design requires performance-objectives, analysis methods such as nonlinear static pushover and nonlinear time history analysis under wind loads, and mechanisms to reduce and, if possible, to eliminate damage accumulation.

ASCE released a pre-standard for PBWD in 2019 to satisfy the demand for PBWD. There are three types of performance objective: occupant comfort, operational and continuous occupancy defined in ASCE pre-standard with acceptance criteria for different wind mean recurrence interval (MRI). For occupant comfort and operational performance, objective structure should be in elastic behavior. However, when we go for continuous occupancy, it allows non-elastic behavior of a structure with allowable acceptance criteria of peak displacement as shown in figure 1.1. ASCE pre-standard gives the following steps for PBWD as:

Identify the risk category, the performance goals, and the acceptability standards.
Conceptual design
Develop an analysis model
Evaluate building envelope acceptance criteria
Refine and design

The Pre-standard recognizes that a detailed evaluation of building requires a detailed evaluation of building response requires a detailed understanding of the relevant wind environment. Therefore, the building analysis and design predicted by conducting wind tunnel testing to establish structural loads. One of three techniques for linear or nonlinear response history analysis used to assess these structural loads. In this work, a similar type of concept used to analyze and design the tall building for performance-based wind design using nonlinear response history analysis.

2. Objective of the Study

The following are the objectives of this study.

1. To analyze the wind load pattern by performing wind tunnel test in Robotics Software for various parameters like height of building, bay spacing /wall opening, wind angle, location etc.
2. To design the models in STAAD Pro. Software with the help of performance-based engineering procedure.

3 To compare performance of structure based on the parameters with the help of obtained results and give the best structural solution.

4 To develop the guidelines for the design of structure which will provide better performance against wind.

3. Methodology

3.1.1 Details of structure

To check wind performance level of Steel structure using non-linear dynamic analysis (Time-history analysis).

Geometrical Properties
[1] Height of structure = 10 m, 20m, 30m
[2] Length of the building = 72 m
[3] Width of the building = 35m, 30m, 25m
[4] bay spacing = 7m, 6m, 5m
[5] Support = fixed
[6] Location = Kolkata, Mumbai, Pune

3.1.1 Standard shape of the structure

Aesthetics, economy, and structural integrity of the entire system must all be considered while determining the design and arrangement of the structure.

3.1.2 Plan of a structure:

The floor plan view of the industrial steel building whose plan area 30 m X 72 m and all other geometrical parameters given above in section 3.1.1, studied in this research is shown in figure 3.1.

Table 1 Geometrical data of building

3.2.1. Dead Load:

Dead load will consist of the structure's own weight and all permanently borne weight. According to the IS 875 -1987 (Part-1) Code of Practice Design Loads (other than earthquake) for Buildings and Structure, dead load is calculated.

Self-Weight of Galvanized Sheet	=	0.2712	KN/m2
Weight of purlins + Fixtures and Fasteners	=	0.36	KN/m2
False ceiling load	=	0	KN/m2
Collateral load	=	2.625	KN/m
Total Dead Load	=	3.2562	KN/m

3.2.2. Live Load:

Live load on single floor = 4.5 KN/m^2

3.2.3. Wind Load:

The design wind velocity at any height (V_Z) for the chosen structure must be obtained by modifying the basic wind speed (Vb) for zone V, which is 50 m/sec, as specified in IS 875(Part 3-1987).

Wind Data:
Wind Zone: Zone V (Vb = 50m/s)
Terrain Category: Terrain category 2

Design Factors:

Risk Coefficient Factor k_1= 1.0
Terrain & Height factor k_2= 1.15 for Z=30m
Topography Factor k_3= 1.0
Importance Factor for cyclonic region k_4= 1.15

Design Wind Speed:

Vz = k_1 k_2 k_3 k_4*Vb..(i)

A) For 50m height

Vz = k_1 k_2 k_3 k_4*Vb
Vz = 1*1.15*1*1.15*50
= **66.125 m/s** @ height
Design wind speed(vz) =145.475
Wind pressure(pp.) =12.698 N/sq.m
Design wind pressure =8.89 KN/sq.m

B) For 44 m/s wind speed

Vz = k1 k2 k3 k4*Vb
Vz = 1*1.15*1*1.15*44
= 58.19 m/s @ height
Design wind speed(vz) =128.18
Wind pressure(pz) =7.726 N/sq.m
Design wind pressure =5.41 KN/sq.m

C) For 39 m/s wind speed

Vz = k1 k2 k3 k4*Vb
Vz = 1*1.15*1*1.15*39
= 51.57 m/s @ height
Design wind speed(vz) =113.4705
Wind pressure(pz) =7.726 N/sq.m
Design wind pressure =5.41 KN/sq.m

3.3 Wind profile

The wind speed given in the various code or standard in that basic wind speed consider for10m height from the ground surface. The velocity of wind goes on increasing with height due to surface friction and temperature change. When analyzing wind for taller structures, the impact of changing wind velocity with regard to height must be taken into account. The term "wind profile" refers to a change in wind speed with respect to building height. This is depended on the power law of wind given as,

$\frac{Vz}{Vb} = (\frac{Z}{Zb})^{\propto}$..(ii)

Here,

V_z = 66.125 m/s, V_b= 50 m/s, Z_b = 10 m, Z= 30 m
V_z = 58.19m/s, V_b= 44 m/s, Z_b = 10 m, Z= 30 m
V_z = 51.57 m/s, V_b= 39 m/s, Z_b = 10 m, Z= 30 m

3.4 Calculation of wind loads:

Wind load calculation on structure based on equivalent dynamic wind load method. For small building wind load calculation based on ESWL method is good but when we go for the taller building aerodynamic effect of wind must be consider. For tall buildings, most codes and researchers advise using pressurized data from wind tunnel tests for tall buildings. Wind tunnel test performed to evaluate wind pressure on building with multipoint pressure tabs introduced on the building model.

Performing wind tunnel test is highly expansive. There is some software for wind simulation based on ESWL method and it is very easy to analyze and design of structure on software for dynamic wind load. The programmer from Autodesk includes a potently new wind simulation tool that enables users to simulate wind tunnel testing to look at the performance of buildings.

3.5 Wind simulation in ARSA:

3.5.1 Autodesk robot structural analysis software (ARSA)

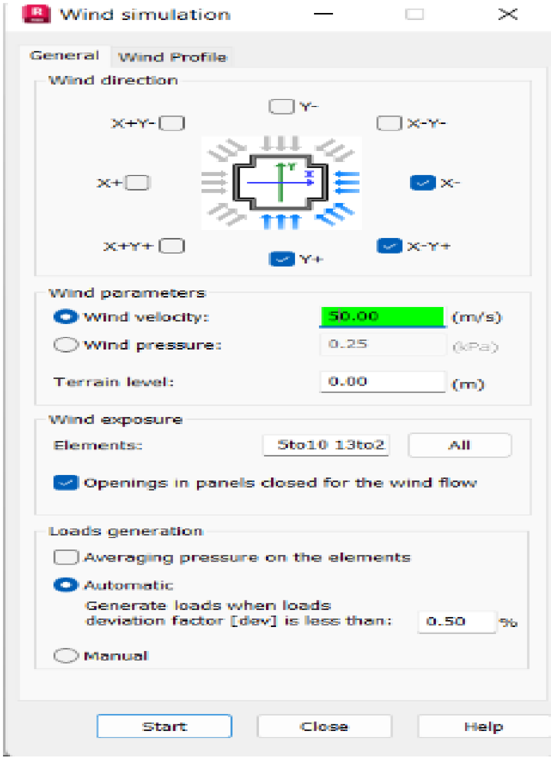
For engineers who need a structural analysis solution that enables them to model, analyze, and design steel and RCC structures, Autodesk Robot Structural Analysis Professional (ARSA) is a finite element analysis program. It hosts a range of powerful FEM solvers enabling structural engineers to conduct complex calculation such as model, harmonic, spectral, dynamic, non-linear, football, time-history analysis and many more. In addition, it is one of the software for the wind simulation based on CFD (computational fluid dynamic). In order to comprehend the impacts of wind even on complex buildings, we may view colorful pressure maps on our model using this wind simulation technology, which functions as a wind tunnel. The program uses the outcomes of the flow simulation to decide when to start the automatic load generation. It creates wind pressure on meshed surface of cladding. Wind theory in ARSA is as per below:

Dynamic fluid pressure,

$q = pv^2/2$..(iii)

Where, q = the dynamic pressure
p = the density of air
v = the velocity of air

It is necessary to input the wind direction, speed, elevation, topography, load generation needs, and wind profile along the building's height. Wind simulation for any direction or angle is possible at a time. This input dialog box with input of wind profile pattern from RSA is shown in figure 3.3 and 3.4.

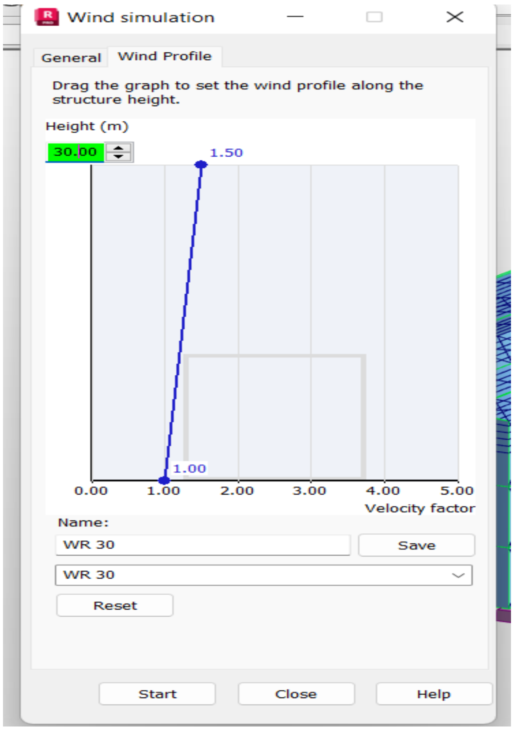


Wind direction
☐ Y-
☐ X+Y-
☐ X-Y-
☐ X+
☑ X-
☐ X+Y+
☑ X-Y+
☑ Y+

Wind parameters
● Wind velocity: 50.00 (m/s)
○ Wind pressure: 0.25 (kPa)
Terrain level: 0.00 (m)

Wind exposure
Elements: 5to10 13to2 All
☑ Openings in panels closed for the wind flow

Loads generation
☐ Averaging pressure on the elements
● Automatic
Generate loads when loads deviation factor [dev] is less than: 0.50 %
○ Manual



Drag the graph to set the wind profile along the structure height.
Height (m) 30.00
Name: WR 30
WR 30

Figure 3.3 Wind parameters in RSA

Figure 3.4 Wind profile input in RSA

3.6 Modelling of structure in ARSA:

After validation to get the wind loads on a structure due to wind events for different wind speed, different location, also for different height of building. wind simulation with CFD taken in ARSA software. The software gives the more accurately results for wind tunnel test as proved in above part of validation work. Model of industrial steel building for 10m 20m, 30m height with defined section size of structural element like frame section, bracing, Z purlin for gravity loads and cladding with finite meshing is developed. Three locations are chosen for parametric study Kolkata, Mumbai, Pune. For taking wind simulation, wind parameters shown above in chapter 3.3 defined for 50 years return wind event to get results in 0^0, 90^0 wind directions shown in figure 3.15. By using RSA software done the analysis of structure. then compare the result.

Analysis steps in RSA software

The model of the building provided with external cladding to get equal pressure on each finite element of cladding in simulation shown in figure 3.14. once model is generated then the dead load, live load, wind loads and lateral load are taken into consideration and the frame analysis is done in RSA software for getting wind effect done the wind simulation for different locations are follows.

1)Kolkata- wind speed is 50m/s.

2) Mumbai- wind speed 44m/s

3) Pune – wind speed 39m/s.

Consider the width of structure that 25m,30m,35m hence bay spacing will be changes because bay spacing is width / 5. Therefore, width is also changing that 7m, 6m, 5m. Also, for roof angle changes from 50, 60, 70 and observe the results. When opening in the walls are changes the external wind coefficient is also changes.

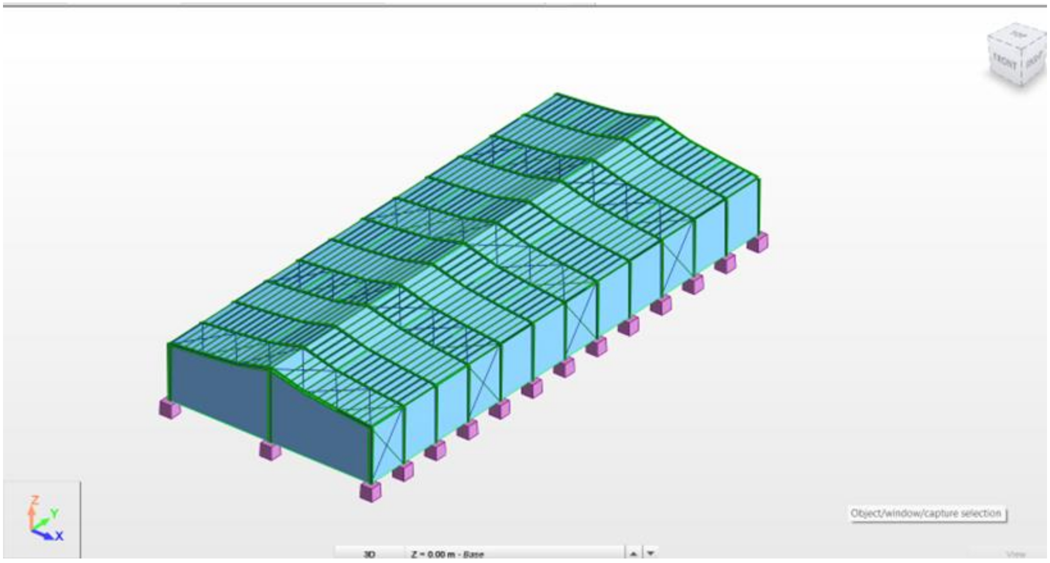


Figure 3.14 (c) modelling in RSA software for 10m height

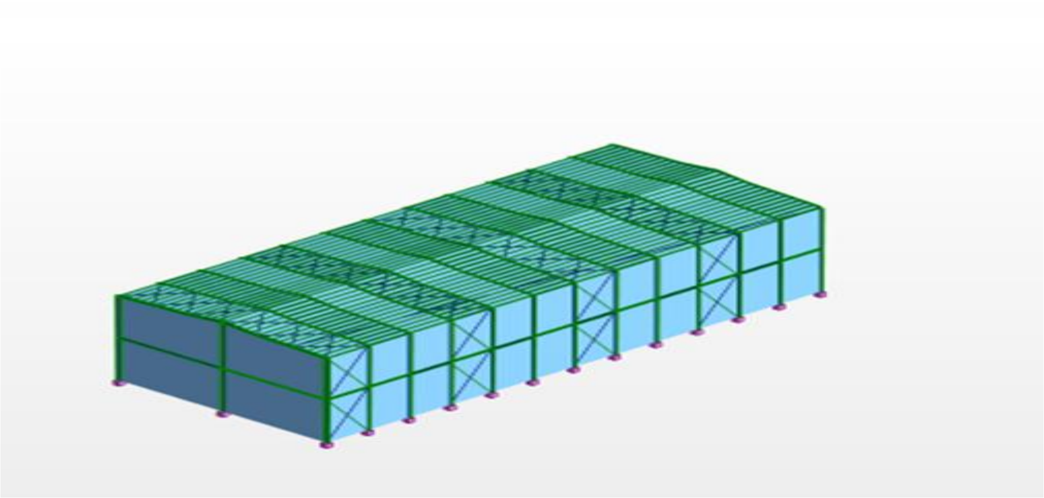


Figure 3.14 © modelling in RSA software for 20m height

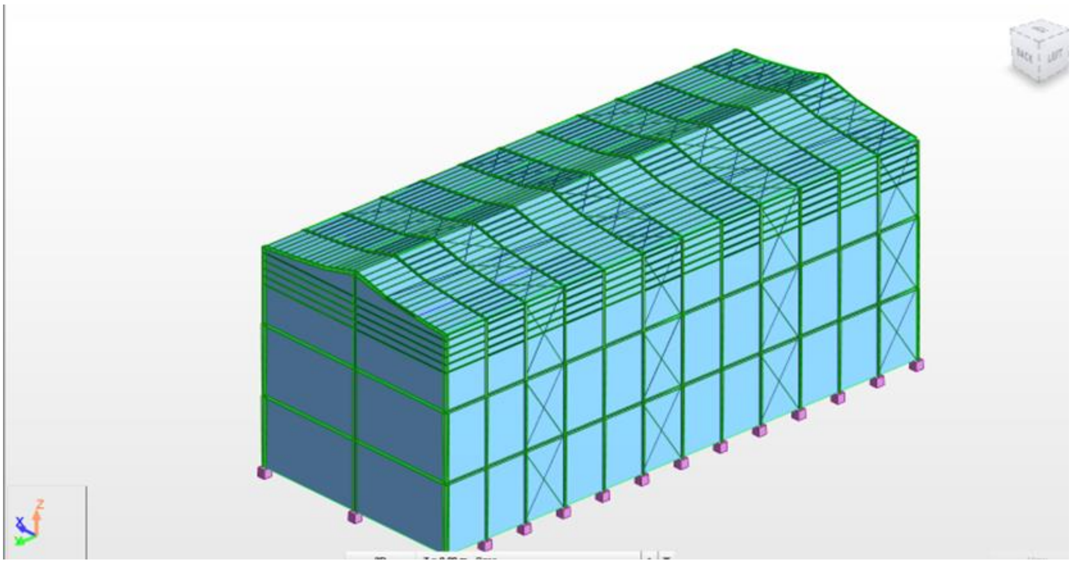


Figure 3.14 © modelling in RSA software for 30m height

Design the Portal frames

The dead load, live load, wind loads and lateral load are taken into consideration and the frame analysis is done in Stadd pro v8i. By taking number of trial and errors decide the most economical tapered section for the portal frame. The weight of frame and the weight of steel for all structural components are compared and find out economical one.

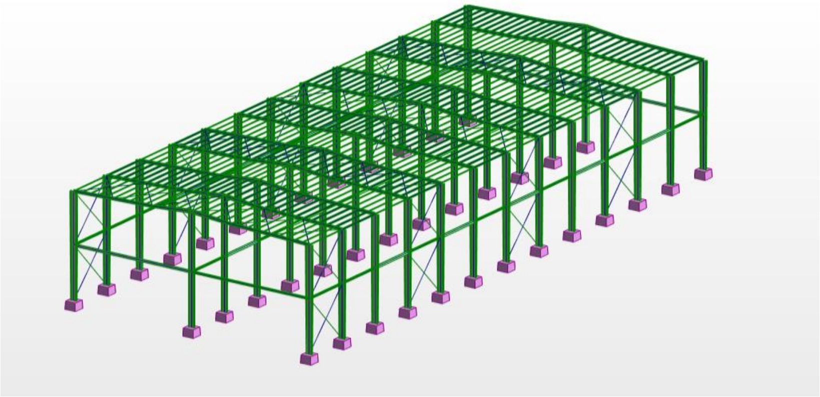


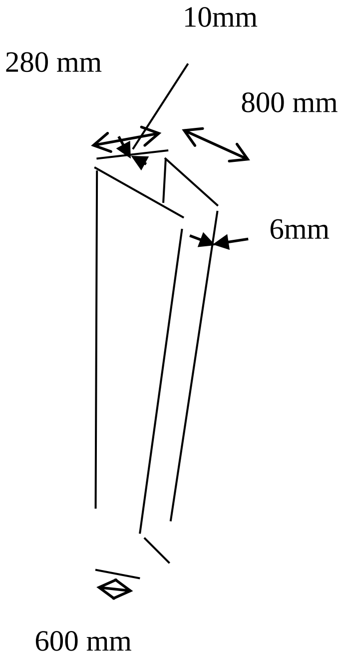
Figure 3.15 Structural model

3.6.3 Sections used for designing the structure are as follows.

Column sections
Tepper 280 X 600 X 800 X 6 X 10
Tepper 250X 400 X 600 X 6 X 10

Rafter sections
Tepper340 X 600 X 6 X 10
Tepper 225 X 600 X 5 X 6
Tepper 225 X 400 X 5 X 6

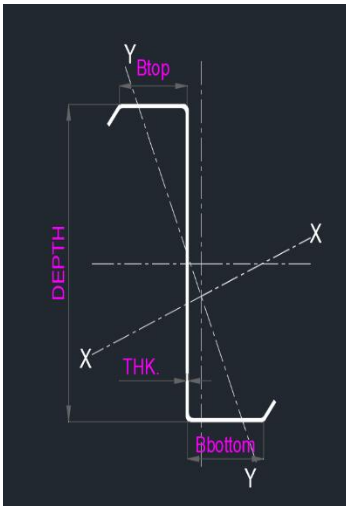
1Internal beam sections
Tepper 160 X 40 X 1 X 8
Tepper 225 X 600 X 6X 8



3.6.4 Purlin design

Building parameters

Building width = 30.0 m
Building length = 72.00 m
Building height = 30.0 m
Roof slope = 1.228:15
Roof angle = 7.01 o



Load data

Dead load+collat. Load = 0.45 KN/m2
Live load = 0.57 KN/m2
Axial load = 1 KN
Wind load :-
Design wind pressure = 0.71 KN/m2
Internal press. Coefft. = 0.50
External press. Coefft. = 1.007
Local press. Coefft. = 1.00

Load calculations

Dead load + collateral Load

@ x-x axis = 0.45 x 6 x cos7.015 = 2.680 KN/m
@ y-y axis = 0.45 x 6 x sin7.015 = 0.330 KN/m

Live load
@ x-x axis = 0.57 x 6 x cos7.015 = 3.395 KN/m
@ y-y axis = 0.57 x 6 x sin7.015 = 0.418 KN/m

Wind load
@ x-x axis = 0.71 x (0.5 + 1.007) x 6 = 6.420 KN/m For end bay
= 0.71 x (0.5 + 1.007) x 6= 6.420 KN/m For intermediate bays

Load combinations

Dead load + live load
@ x-x axis = 2.68+3.395 = 6.075 KN/m
@ y-y axis = 0.33+0.418 = 0.748 KN/m

Dead load + wind load
@ x-x axis = -2.68+6.42 = 3.740 KN/m
@ y-y axis = -0.33+ 0 = 0.330 KN/m

3.7 Time-history wind data:

3.7.1 Introduction

It was study of dynamic wind loadings for the structural models in this study in order to carry out wind nonlinear dynamic studies. The dynamic wind loading for the 45-story building measured using wind simulation tests on RSA software as explained above. To take the time-history wind analysis, time-history wind data is required. There are different possible solutions available to get time history data like power spectral density, wind tunnel test and some online websites that provides wind data. TPU wind tunnel database and Nat Haz online wind simulator are two websites provides time-history wind data. For this research study we have choose Nat Haz online wind simulator to get wind data.

3.7.2 Nat Haz On-line wind simulator:

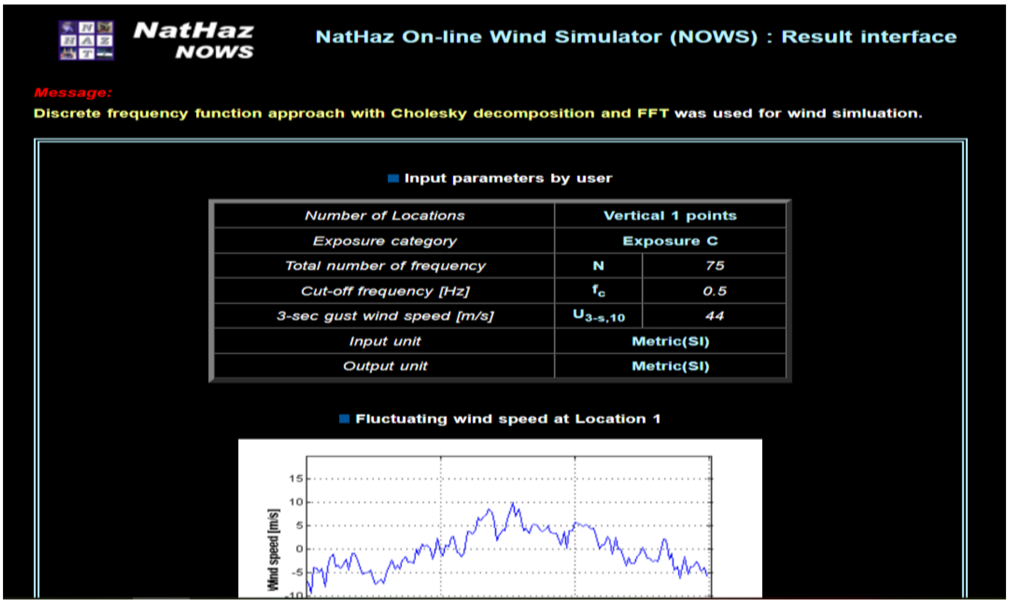
The Nat Haz on-line wind simulator (NOWS), which was first released in 2005, was created to give users access to real-time online simulation of stationary Gaussian multivariate wind fields for the longitudinal direction. A user can quickly input any parameters and check the outcomes of simulations, such as simulated wind histories and simulated power spectrum densities, using a simple and intuitive user interface shown in figure 3.19. This web framework features supporting both Metric (SI) and English units as input/output with on-line unit converter, location inputs for vertical, horizontal or arbitrary 2-D coordinates (Ahsan and Kwon, 2015). It provides the user with the option to download the simulation's results as a file for additional off-line analysis, such as time-history wind analysis, after entering the basic mean wind speed and terrain roughness category shown in figure 3.20. It gives graph and point data as wind data in wind speed (m/s) and time (sec) as shown in figure

Given Inputs:

Basic mean wind speed- 44 m/s @ 10m height

Height of building- 30m

Terrain category- C: open terrain with scattered obstructions that have heights generally less than 9.1m (IS 875 part III, 2015).



NatHaz On-line Wind Simulator (NOWS) : Result interface

Message:

Discrete frequency function approach with Cholesky decomposition and FFT was used for wind simluation.

Input parameters by user

Number of Locations	Vertical 1 points	
Exposure category	Exposure C	
Total number of frequency	N	75
Cut-off frequency [Hz]	f_c	0.5
3-sec gust wind speed [m/s]	$U_{3-s,10}$	44
Input unit	Metric(SI)	
Output unit	Metric(SI)	

Fluctuating wind speed at Location 1

Figure 3.20 User result interface of Nat Haz on-line wind simulator (http://windsim.ce.nd.edu/gew_init2.html)

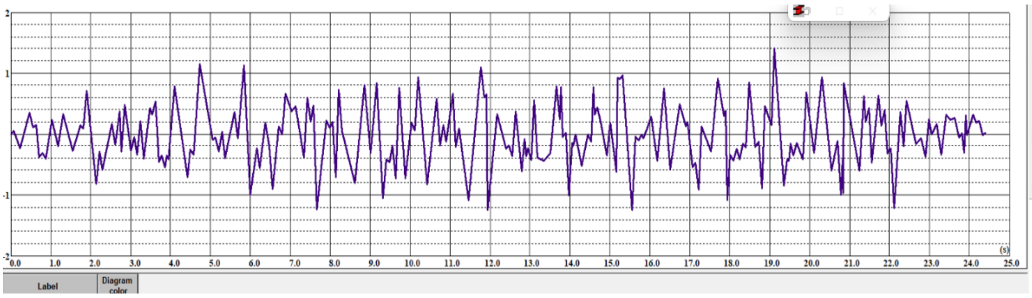


Figure 3.21-time history graph

Time history analysis in RSA

After getting time history data from Nat Haz Now' s put that Graph in the RSA

And give the parameters as shown in fig

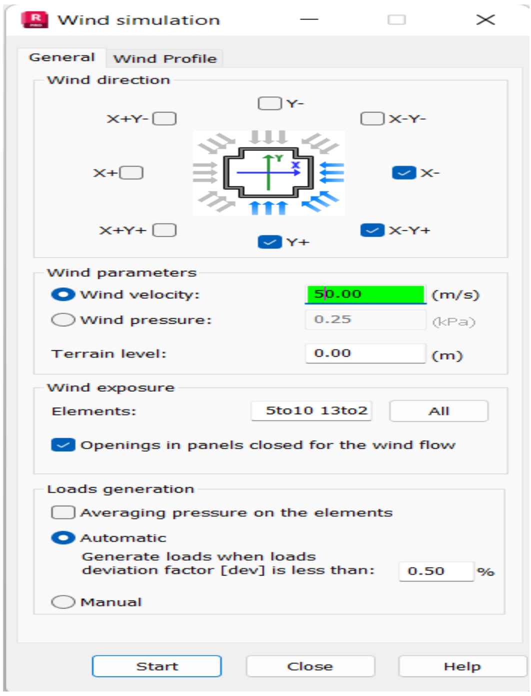
3.8 Nonlinear time-history analysis (NLTHA):

3.8.1 General:

Form the Nat Haz on-line simulator we get wind histories data for 150 second This time-history wind data is required for nonlinear time-history analysis of buildings. The time histories begin with a zero speed and gradually increase in speed over the course of the first few seconds. It was to avoid the dynamic impact effect influencing the dynamic response of the building to study the dynamic excitations like earthquakes and wind events, nonlinear response history analysis available. In that analysis including explicit structural component, nonlinear behaviour and lowering the uncertainty related to structure and load dynamics, this study enhances response prediction. it possible to offer the most realistic reaction and, as a result, the most accurate performance evaluation of a structure that has been subjected to dynamic excitations. Inelastic member response to cyclic wind loading is included in the nonlinear dynamic analysis. The nonlinear dynamic analysis ideally intends to simulate the full-range of structural response from the linear response to the onset of nonlinearity and corresponding induced damage and finally the collapse of the building

To evaluate the onset and distribution of nonlinearity throughout the entire structure, nonlinear time-history analyses aim to subject the building model to an incremental lateral load with a loading pattern that represents the distribution of wind loads on building surfaces during a wind event, as described in chapter 3. The model of building for NLTHA is same as explained above in linear time history analysis.

To approach the nonlinear time-history analysis in Autodesk robot structural analysis gives two methods: new mark method of acceleration and Hilber- Hughes- Taylor method shown in figure 4.10.



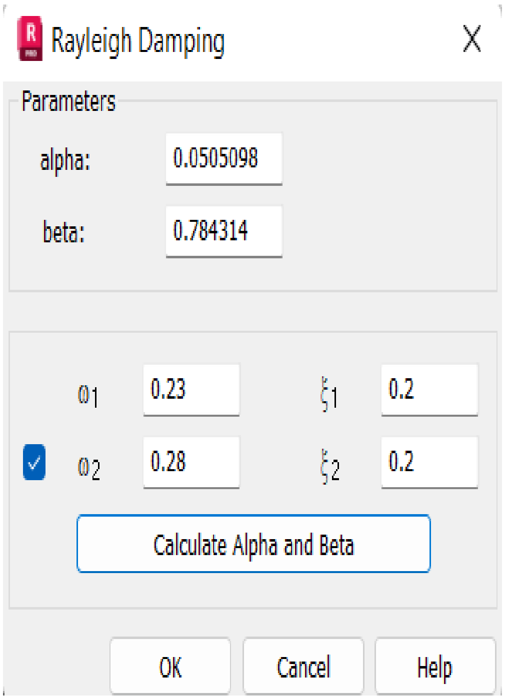
Wind direction
☐ Y-
X+Y- ☐
☐ X-Y-
X+ ☐
☑ X-
X+Y+ ☐
☑ X-Y+
☑ Y+

Wind parameters
● Wind velocity: 50.00 (m/s)
○ Wind pressure: 0.25 (kPa)
Terrain level: 0.00 (m)

Wind exposure
Elements: 5to10 13to2 All
☑ Openings in panels closed for the wind flow

Loads generation
☐ Averaging pressure on the elements
● Automatic
Generate loads when loads deviation factor [dev] is less than: 0.50 %
○ Manual

Fig. 4.10 Wind simulation Inputs



Parameters
alpha: 0.0505098
beta: 0.784314

☑ ω_1 0.23 ξ_1 0.2
ω_2 0.28 ξ_2 0.2

Fig. 4.10 Damping parameters

The initial equations benefited by the Newmark method of acceleration without any simplification. The accuracy of the numerical integration of temporal equations determines the precision of the outcome, and it are defined by value of time step for the selected parameters α, β as relying damping coefficient. The method used for the analysis is direct analysis method.

Geometric nonlinearity enforces nonlinear solution even for linearly elastic model. This is useful for large loads are applied to nodes with significant lateral displacement or when large displacement or rotations occur. Nonlinear time-history analysis consists geometric nonlinearity of p-delta and large displacement. P-delta effect considers second order effects like the variation in bending rigidity with longitudinal stresses and the impact of structural deformation on the ultimate equilibrium state. However, software that is based on massive displacement accounts for second- and third-order effects, such as the increased lateral rigidity brought on by deformation and the impact of bending on element elongation. Rayleigh damping coefficient are $\alpha= 0.006827$ and $\beta =0.34482$. By performing a series of nonlinear time-history analyses for wind.

4 Result and discussion

4.1 General:

The main goals of this research study are the development and practical use of a wind performance-based evaluation approach for tall buildings. Conducting a wind performance design typically necessitates a thorough understanding of the building's wind responses to various levels of wind hazard as well as an engineering framework introducing the various building performance types, performance levels, and accompanying acceptance criteria. The framework must take into account many performance types that represent various characteristics of the usability and resilience of tall buildings during wind events. A set of performance targets associated to various discrete hazard levels are necessary for a building framework, which is similar to the seismic performance-based evaluation technique such as 50 years.

4.2.1 Modal Analysis Result:

The modal analysis used to examine the steel building for 10m,20m,30m by using dynamic response properties. Table-4.1 displays the frequency, natural periods, and type (either translational or torsional) of the building's first ten modes for 30m, 20m & 10m height structure The first two modes match pure cantilever deformation modes in the building's two main directions, as would be predicted. The two first modes' comparatively low natural frequencies show the building's great flexibility, which leads to significant lateral displacement and lowers the lateral resistance of the structure.

Table 4.1 Modal analysis result for 30m

Mode	Frequency (Hz)	Period (sec)	Rel.mas.UX (%)	Rel.mas.UY (%)	Rel.mas.UZ (%)
1	0.23	4.29	86.87	0.00	0.03
2	0.28	3.63	87.19	0.00	0.03
3	0.34	2.98	91.80	0.00	0.03
4	0.40	2.52	92.84	0.00	0.03
5	0.47	2.15	94.34	0.00	0.03
6	0.55	1.81	94.34	0.02	0.03
7	0.59	1.69	94.48	0.02	0.03
8	0.61	1.64	94.49	0.02	0.03
9	0.69	1.45	94.89	0.04	0.03
10	0.89	1.13	94.89	59.68	0.03

Table 4.2 Modal analysis result for 20m

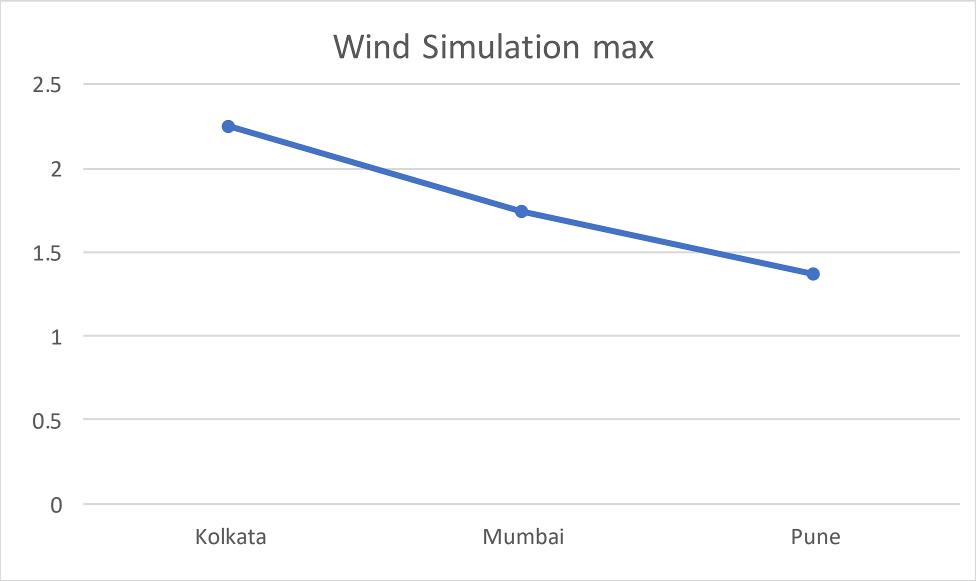
Mode	Frequency (Hz)	Period (sec)	Rel.mas.UX (%)	Rel.mas.UY (%)	Rel.mas.UZ (%)
1	1.62	0.62	65.26	2.33	0
2	1.65	0.61	75.15	15.26	0
3	1.72	0.58	75.29	15.87	0
4	1.83	0.55	81.88	16.06	0
5	1.94	0.51	82.03	16.13	0
6	2.17	0.46	84.03	16.13	0
7	2.51	0.4	84.04	16.14	0
8	2.6	0.38	84.16	16.14	0
9	2.66	0.38	84.24	16.14	0
10	2.84	0.35	84.65	16.16	0

Table 4.3 Modal analysis result for 10m

Mode	Frequency (Hz)	Period (sec)	Rel.mas.UX (%)	Rel.mas.UY (%)	Rel.mas.UZ (%)
1	0.84	1.19	78.76	0	0
2	0.86	1.16	78.98	0	0
3	0.88	1.13	83.96	0	0
4	0.91	1.1	84.14	0.33	0
5	0.94	1.07	84.83	0.33	0
6	0.96	1.04	84.92	0.37	0
7	0.98	1.02	85.34	0.37	0
8	1.05	0.95	91.39	1.01	0
9	1.1	0.91	91.42	91.09	0
10	1.21	0.83	93.97	91.1	0

4.2.2 Wind simulation graph

To get wind effects wind simulation need to done after wind simulation it shows wind pressure map. For Kolkata, Mumbai, Pune gives different pressure objects in KN



4.2.3 Roof angle

Providing room angle 5^0, 6^0, 7^0 and then check the wind effect on rafter wind forces on rafter at 0^0 90 wind flow direction

Table 4.3 external pressure coefficient of wind for roof angle 5^0

	Wind angle θ (0^o)		Wind angle θ (90^o)			
For roof angle	EF	GH	EG	FH	FOR	
5	-0.92529	-0.4	-0.8	-0.41686	H/W ≤ 0.5	
5	-0.91686	-0.6	-0.89157	-0.6	0.5 < H/W ≤ 1.5	
5	-0.65422	-0.6	-0.8	-0.8	1.5 < H/W ≤ 6	

Table 4.3 external pressure coefficient of wind for roof angle 6^0

	Wind angle θ (0^o)		Wind angle θ (90^o)			
For roof angle	EF	GH	EG	FH	FOR	
6	-0.99169	-0.4	-0.8	-0.46113	H/W ≤ 0.5	
6	-0.96113	-0.6	-0.86944	-0.6	0.5 < H/W ≤ 1.5	
6	-0.66528	-0.6	-0.8	-0.8	1.5 < H/W ≤ 6	

Table 4.3 external pressure coefficient of wind for roof angle 7^0

	WIND ANGLE θ (0^o)		WIND ANGLE θ (90^o)			
For roof angle	EF	GH	EG	FH	FOR	
7	-1.05792	-0.4	-0.8	-0.50528	H/W ≤ 0.5	
7	-1.00528	-0.6	-0.84736	-0.6	0.5 < H/W ≤ 1.5	
7	-0.67632	-0.6	-0.8	-0.8	1.5 < H/W ≤ 6	

4.3 Design of structure in STAAD Pro.

After design of structure in STAAD Pro. Software by using many trial and error methods for that for that considering structural safety taking following checks for representation purpose for 30m height structural building checks are shown in table

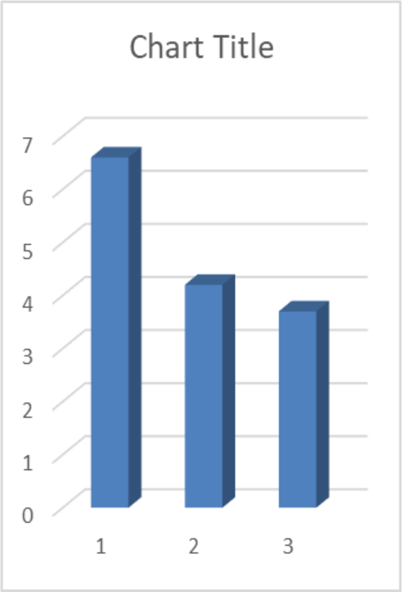
4.3.1 Deflection Check: -

From IS800-2007, pg. no. 32, table no.- 6

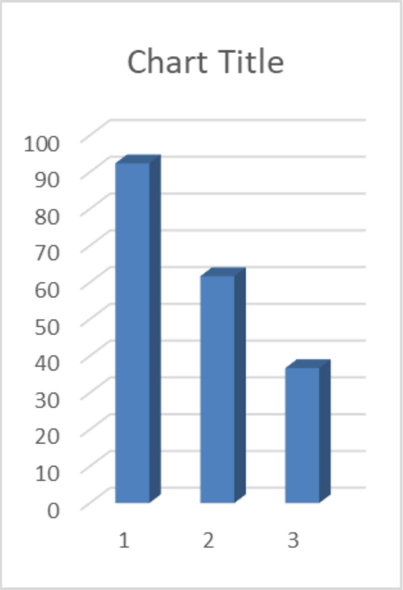
Maximum deflection for 35m span= $\frac{Span}{180} = \frac{35X1000}{180}$ =194.44

Maximum deflection for 30m span= $\frac{Span}{180} = \frac{30X1000}{180}$ =166.66

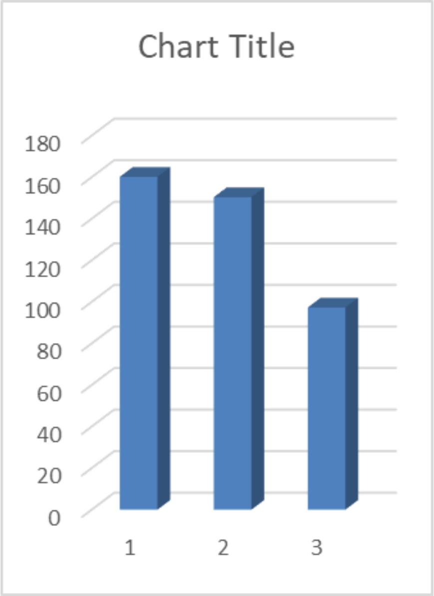
Maximum deflection for 25m span= $\frac{Span}{180} = \frac{25X1000}{180}$ =138.88



10m Height



20m Height



30m height

4.3.2 Utility Ratio: -

Analysis Property	Section (in mm)	Actual Ratio	Normalized Ratio (Actual/Allowable)	Allowable Ratio
Tepper	280 X 600 X 800 X 6 X 10	0.875	0.875	1
Tepper	340 X 600 X 6 X 10	0.906	0.906	1
Tepper	225 X 600 X 5 X 6	0.814	0.814	1
Tepper	225 X 400 X 5 X 6	0.875	0.875	1
Tepper	160 X 40 X 1 X 8	0.987	0.987	1
Tepper	250X 400 X 600 X 6 X 10	0.925	0.925	1
Tepper	225 X 600 X 6X 8	0.872	0.872	1

4.3.3 Total Weight of steel structure

Height	**Width**	**Bay Spacing**	**Location**	**Steel**
10m	35	35/5=7m	Mumbai	421.15
			Kolkata	
			Pune	
10m	30	30/5= 6m	Mumbai	343.15
			Kolkata	
			Pune	
10m	25	25/5=5	Mumbai	298.4
			Kolkata	
			Pune	
20m	35	35/5=7m	Mumbai	524.15
			Kolkata	
			Pune	
20m	30	30/5= 6m	Mumbai	423.15
			Kolkata	
			Pune	
20m	25	25/5=5	Mumbai	321.4
			Kolkata	
			Pune	
30m	35	35/5=7m	Mumbai	
			Kolkata	823.4
			Pune	
30m	30	30/5= 6m	Mumbai	693.15
			Kolkata	
			Pune	
30m	25	25/5=5	Mumbai	
			Kolkata	498.4
			Pune	

5 Conclusion

By considering results and discussion we can conclude that.

1)For Kolkata region wind pressure coefficient is more than 2 KN as compare to wind pressure coefficient for Mumbai and Pune region.

2) By considering different parameters such as height, location, roof Angle we have below conclusion.

A) By Height

- Wind velocity changed as height increased above 10 m. For 20m height of structure it increased by 0.8m/s and for 30m height it increased by 1.56 m/s.
- For 10m height frequency of structure is 1.21 Hz, 20m height it is 2.84 Hz and for 30m height it is 0.84Hz. Structural frequency is not more than 3Hz therefore it is accepted.

B) By location

- Wind direction and wind speed changed as per location. In Kolkata region wind speed is 50m/s. Wind speed at leeward side is 70% more than windward side. Structure is critical when it is designed parallel to the ridge.
- Wind direction and wind speed is changing as per location. In Mumbai region wind speed is 44m/s. Wind speed at windward side is 40% more than leeward side. Structure is critical when it is designed parallel to the ridge.
- Wind direction and wind speed is changing as per location. In Pune region wind speed is 39m/s. Wind speed at windward side is 37% more than leeward side. Structure is critical when it is designed parallel to the ridge.

C) By roof angle

- External wind pressure coefficient of wind flow for roof angle 5,6,7 at leeward side increased when structure designed perpendicular to the ridge. As roof angle increases external wind pressure coefficient remain same for structure designed perpendicular to ridge.
- External wind pressure coefficient of wind flow for roof angle 5,6,7 at leeward side increased when structure designed perpendicular to the ridge. As roof angle increases external wind pressure coefficient remain same for structure designed perpendicular to ridge.
- As angle of roof increases but it is same for structure designed at perpendicular to ridge for roof angle 5^0 , 6^0, 7^0 for $H/W \leq 0.5$condition.

3) As per the results the structure is safe in deflection criteria for span 35m,30m and 25m and for height 10m,20m and30m respectively.
4) For the tapered sections utility ratio is below 1 hence it is economical and safe.
5) Steel required for 30m height is more than that of the 10m and 20m height respectively in case of tapered section.
6) Section 280x600x800x6x10 is economical and safe column section
7) All tapered sections used for principal rafter, columns and internal beams are safe and economical for height 30m,20m,and 10m respectively.

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