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NUMERICAL INVESTIGATION OF WIND EFFECTS ON A HIGH-RISE RESIDENTIAL BUILDING (2 BASEMENT + 1 STILT + 10 FlOORS) USING STAAD.PRO

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***Abstract*— High-rise residential buildings are increasingly vulnerable to lateral forces caused by wind loads due to rapid urbanization and vertical development in metropolitan regions. Accurate assessment of wind-induced structural behavior is therefore essential to ensure safety, stability, and serviceability. This study presents a numerical investigation of wind effects on a reinforced concrete residential building consisting of two basement floors, one stilt floor, and ten upper floors using STAAD.Pro software. The building was modeled as a three-dimensional moment-resisting frame structure, and wind loads were evaluated according to the provisions of Indian Standard IS 875 (Part 3). Structural parameters including lateral displacement, storey drift, base shear, bending moments, and shear forces were analyzed under various loading combinations. The numerical analysis demonstrated that wind pressure increases with building height, resulting in larger displacements and drifts at upper storeys. The study also revealed that structural stiffness and floor configuration significantly influence the lateral response of the building. The results obtained confirmed that the structural responses remained within permissible limits specified by codal provisions. The proposed numerical methodology provides an efficient and reliable approach for evaluating wind effects in medium-rise residential buildings.**

Keywords: Wind Load Analysis, High-Rise Residential Building, STAAD.Pro, Storey Drift, Lateral Displacement, Numerical Modelling.

I. INTRODUCTION

The rapid growth of urbanization and population density has significantly increased the demand for high-rise residential buildings in metropolitan regions. Due to limited land availability, vertical development has become an effective solution for accommodating residential requirements. As building height increases, structures become more vulnerable to lateral forces such as wind and seismic loads. Among these forces, wind load plays a major role in the structural design of tall buildings because wind pressure increases with elevation and produces considerable lateral forces, bending moments, and storey drift. Therefore, accurate wind load analysis is essential for ensuring structural safety and stability.

Wind is a dynamic environmental force generated due to atmospheric pressure variations and temperature differences. When wind interacts with a building, positive pressure develops on the windward face while suction or negative pressure develops on the leeward face. These pressures generate horizontal forces that influence the structural behavior of the building. Excessive wind-induced displacement may affect structural stability and occupant comfort, while large storey drift can damage non-structural elements such as partitions, glazing systems, and cladding. Hence, controlling lateral displacement and storey drift is an important aspect of high-rise structural design.

Earlier methods of wind analysis mainly relied on simplified analytical procedures and wind tunnel testing. Although these methods provided valuable information regarding aerodynamic behavior and pressure distribution, they were often expensive and time-consuming. With the advancement of computational technology, numerical analysis methods have become widely adopted in structural engineering. Modern structural analysis techniques enable engineers to model complex buildings accurately and evaluate their behavior under different loading conditions with improved precision and efficiency.

The finite element method is one of the most commonly used numerical techniques for analyzing high-rise buildings. This method divides the structure into smaller elements connected through nodes, allowing detailed evaluation of stresses, displacement, bending moments, and shear forces. Structural analysis software based on finite element principles has greatly improved the accuracy and efficiency of building analysis. Among the available software tools, STAAD.Pro is widely used for structural modeling and analysis because it supports three-dimensional modeling, load combinations, and codal provisions for design and analysis.

In India, wind load calculations are generally performed according to IS 875 (Part 3), which provides standardized procedures for estimating wind pressure based on parameters such as basic wind speed, terrain category, building height, and topography. Proper implementation of these guidelines helps engineers evaluate wind effects accurately and maintain structural safety under extreme loading conditions. The use of numerical modeling software together with codal procedures provides reliable assessment of structural performance under wind loads.

The present study focuses on the numerical investigation of wind effects on a reinforced concrete residential building consisting of two basement floors, one stilt floor, and ten upper floors using STAAD.Pro software. The building is modeled as a three-dimensional moment-resisting frame structure, and wind loads are applied according to IS 875 (Part 3). Structural response parameters such as lateral displacement, storey drift, bending moments, shear forces, and base shear are evaluated to understand the overall performance of the structure under wind loading conditions.

II. LITERATURE SURVEY

Wind engineering has become an important area of research in structural engineering due to the increasing construction of high-rise buildings in urban regions. Several researchers have investigated the effects of wind loads on buildings, bridges, and other civil engineering structures using experimental, analytical, and numerical approaches. Earlier studies mainly focused on understanding wind pressure distribution and structural response under fluctuating wind conditions, while recent studies emphasize computational techniques and numerical simulations for accurate prediction of wind-induced behavior.

Davenport [1] introduced statistical concepts for evaluating wind loading on structures and explained the significance of gust effects in structural response prediction. His work established the foundation for modern wind engineering by relating wind fluctuations with dynamic structural behavior. Later, Davenport [2] further investigated the relationship between wind characteristics and structural loading, highlighting the importance of considering turbulence and gust effects in tall building design. Harris [3] also studied the response of structures subjected to wind gusts and demonstrated that fluctuating wind loads significantly influence structural vibrations and displacement.

Research on wind pressures acting on low-rise and medium-rise buildings was extensively carried out by Eaton and Mayne [4], who experimentally measured wind pressures on residential buildings and identified the influence of roof geometry on pressure distribution. Holmes [5] reviewed wind loads on low-rise buildings and emphasized the need for reliable wind pressure estimation methods to improve structural safety. Krishna [6] also presented a detailed review of wind effects on buildings and structures and discussed various analytical and experimental techniques used in wind engineering applications.

With advancements in computational technology, numerical modeling techniques gained significant attention in wind engineering research. Kareem [7] discussed numerical methods for analyzing wind effects on structures and explained the effectiveness of computational techniques in predicting aerodynamic behavior. Stathopoulos [8] highlighted the development of Computational Wind Engineering (CWE) and emphasized its importance in evaluating wind flow around buildings using numerical simulations. These studies demonstrated that computational methods could effectively replace expensive wind tunnel experiments for many practical engineering applications.

Several researchers also investigated Computational Fluid Dynamics (CFD) techniques for analyzing wind flow around structures. Murakami and Mochida [9] studied the past and future developments of computational wind engineering and demonstrated the capability of CFD methods in predicting wind-structure interaction. Tamura et al. [10] numerically investigated pressure fluctuations on rectangular cylinders subjected to aerodynamic oscillations and showed that numerical simulations provide accurate estimation of fluctuating wind pressures. Leitl et al. [11] analyzed flow distribution around U-shaped buildings using both wind tunnel and computational methods and concluded that numerical models can effectively predict complex airflow patterns around building geometries.

Studies related to wind-induced structural response in high-rise buildings were further extended by Isyumov [12], who investigated aeroelastic modeling techniques for tall buildings. The study emphasized the importance of considering structural flexibility in evaluating wind response. Larsen [13] also examined aeroelastic analysis methods for suspension and cable-stayed bridges and demonstrated the influence of wind-induced vibration on long-span structures. These investigations contributed significantly to understanding the interaction between wind forces and flexible structural systems.

Experimental and numerical investigations on wind-induced pressures and structural response were also carried out by Levitan and Mehta [14], who performed field experiments for evaluating wind loads on buildings. Their study provided important information regarding real-time wind pressure measurement systems and structural response behavior. Tieleman et al. [15] investigated wind tunnel simulation requirements for assessing wind loads on low-rise buildings and emphasized the importance of accurate boundary layer simulation for realistic wind load prediction.

Although several studies have been conducted on wind effects and aerodynamic behavior of structures, limited research is available on medium-rise residential buildings with basement and stilt floor configurations using STAAD.Pro analysis. Most existing studies mainly focus on low-rise buildings, tall skyscrapers, or aerodynamic investigations through wind tunnel analysis. Therefore, the present study aims to perform a detailed numerical investigation of wind effects on a reinforced concrete residential building consisting of two basements, one stilt floor, and ten upper floors using STAAD.Pro software. The study focuses on evaluating structural response parameters such as lateral displacement, storey drift, bending moments, and base shear under codal wind loading conditions.

III. PROPOSED METHODOLOGY

The proposed methodology adopted in this study focuses on the numerical investigation of wind effects on a reinforced concrete high-rise residential building using STAAD.Pro software. The methodology involves systematic procedures including building modeling, material property assignment, wind load calculation, finite element analysis, and evaluation of structural response parameters. The overall objective of the proposed methodology is to accurately predict the structural behavior of the building under wind loading conditions and assess its safety and serviceability performance.

The building considered in this study consists of two basement floors, one stilt floor, and ten upper residential floors. The structure is modeled as a three-dimensional reinforced concrete moment-resisting frame system. Wind loads are calculated according to the provisions specified in IS 875 (Part 3), and numerical analysis is carried out using STAAD.Pro based on finite element principles.

A. Overall System Architecture

The proposed methodology follows the sequence shown below.

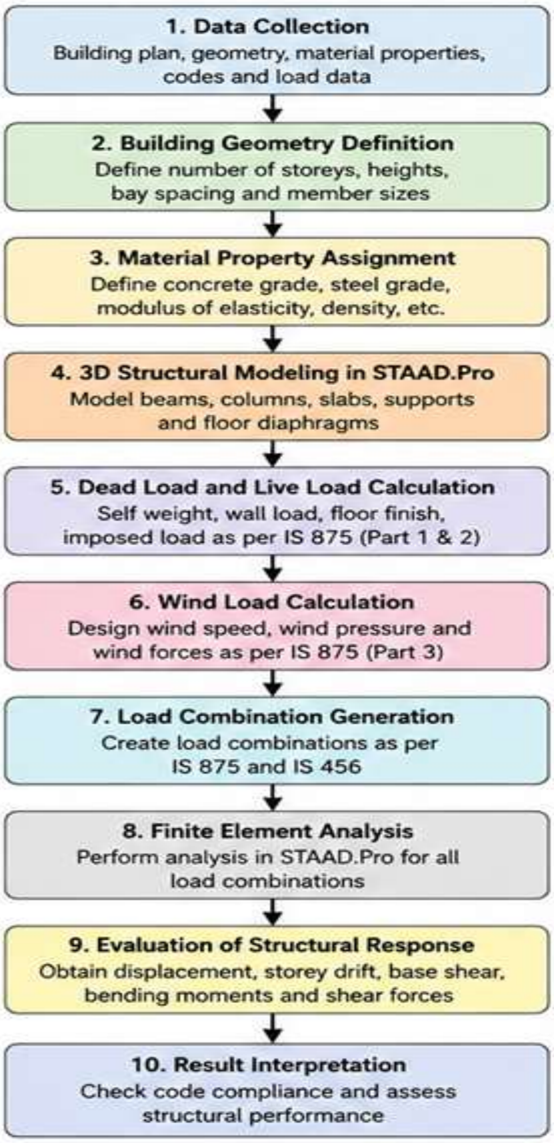

Fig. 1. Proposed Methodology Flowchart

B. Description of Building Model

The building selected for the present investigation is a reinforced concrete residential structure with two basement floors, one stilt floor, and ten upper floors. The basements are mainly used for parking and utility services, while the stilt floor is designed as an open parking level. The upper floors are typical residential floors consisting of beams, columns, and slabs forming the primary structural system.

The building is modeled as a moment-resisting frame structure capable of resisting both gravity and lateral loads. The overall geometry and dimensions are selected based on standard residential building practices commonly adopted in urban construction.

C. Structural Configuration

The structural configuration adopted for the study includes reinforced concrete beams, columns, slabs, and foundations. The major structural parameters considered in the modeling are listed in Table I.

TABLE I BUILDING PARAMETERS

Parameter	**Value**
Number of Basement Floors	2
Number of Stilt Floors	1
Number of Residential Floors	10
Basement Floor Height	3.5 m
Stilt Floor Height	4.0 m
Residential Floor Height	3.0 m
Total Building Height	40.5 m
Bay Spacing	4–5 m
Slab Thickness	150–200 mm
Concrete Grade	M25
Reinforcement Grade	Fe500

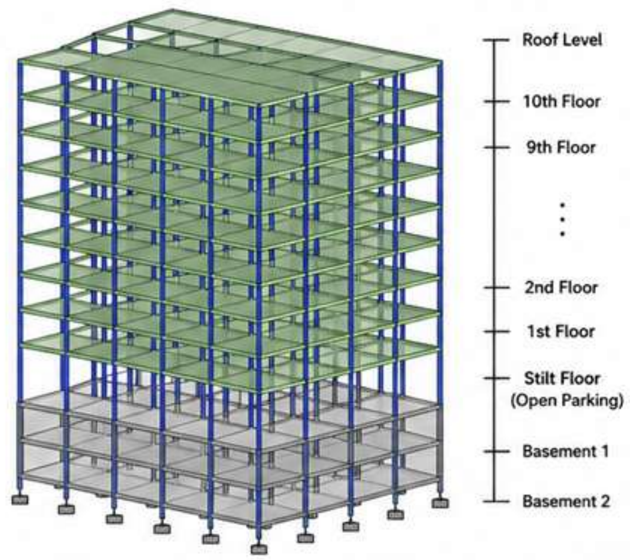

Fig. 2. Three-Dimensional Structural Model of the Building in STAAD.Pro

D. Material Properties

The material properties assigned in the numerical model are based on standard reinforced concrete design provisions. Concrete grade M25 and reinforcement steel Fe500 are considered for structural analysis.
The modulus of elasticity of concrete is calculated using:

$$E_c = 5000\sqrt{f_{ck}} \tag{1}$$

Where:

- E_c= Modulus of elasticity of concrete (MPa)
- f_{ck}= Characteristic compressive strength of concrete (MPa)

For M25 concrete:

$$E_c = 5000\sqrt{25} \tag{2}$$

$$E_c = 25000 \text{ MPa} \tag{3}$$

The density of reinforced concrete is taken as:

$$\gamma_c = 25 \text{ kN/m}^3 \tag{4}$$

The modulus of elasticity of reinforcement steel is:

$$E_s = 200000 \text{ MPa} \qquad (5)$$

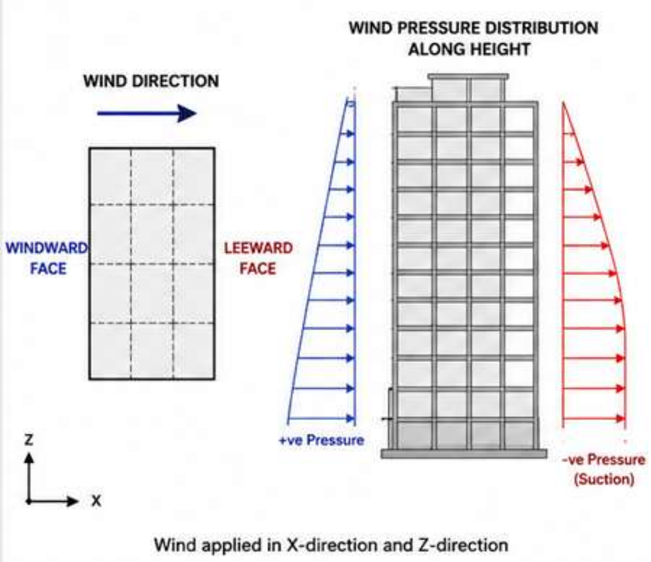

Fig. 3. Wind Load Acting on the Building Faces

E. Load Calculations

The structural model includes the following loads:

1) Dead Load

Dead load includes the self-weight of structural components such as slabs, beams, columns, and walls.

The dead load due to slab is calculated as:

$$W_d = \gamma_c \times t \qquad (8)$$

Where:

- W_d= Dead load per unit area
- γ_c= Density of concrete
- t= Thickness of slab

2) Live Load

Live load is considered according to IS 875 (Part 2) recommendations for residential buildings.

$$LL = 2 \text{ kN/m}^2 \qquad (9)$$

F. Structural Modeling in STAAD.Pro

The structural model is developed in STAAD.Pro software using finite element principles. Nodes are created at beam-column intersections, and structural members are connected to form the three-dimensional frame model.

The following steps are adopted during modeling:

1. Geometry generation
2. Node creation
3. Beam and column definition
4. Plate element assignment
5. Support specification
6. Material property assignment
7. Load application
8. Load combination generation
9. Structural analysis

The foundation is modeled as a fixed support system to simulate realistic boundary conditions

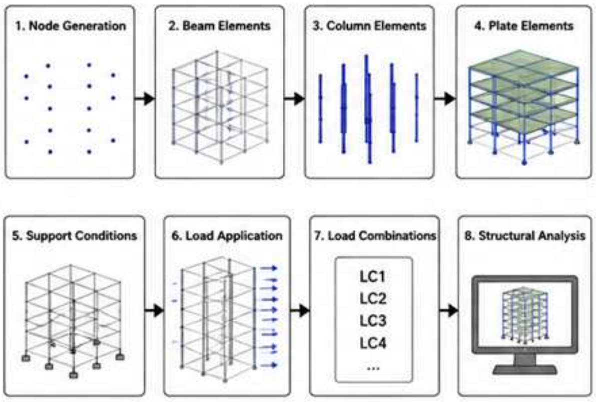

Fig. 4. Finite Element Modeling Procedure in STAAD.Pro

G. Load Combinations

The load combinations considered in the present study are generated according to IS 875 and IS 456 provisions.

TABLE II:LOAD COMBINATIONS USED FOR ANALYSIS.

Load Combination ID	Combination
LC1	DL + LL
LC2	DL + LL + WLX
LC3	DL + LL – WLX
LC4	DL + LL + WLZ
LC5	DL + LL – WLZ
LC6	1.5(DL + LL)
LC7	1.2(DL + LL + WL)

Where:

- DL = Dead Load
- LL = Live Load
- WL = Wind Load

H. Finite Element Analysis

The finite element method is used to evaluate the structural response under applied loading conditions. STAAD.Pro performs numerical computations to determine displacement, storey drift, bending moments, shear forces, and axial forces in structural members.

The governing equation used in finite element analysis is:

$$[K][D] = [F] \qquad (10)$$

Where:

- $[K]$= Global stiffness matrix
- $[D]$= Displacement vector
- $[F]$= Applied force vector

The structural response is obtained after solving the stiffness equations for all load combinations.

IV. STRUCTURAL MODELING AND ANALYSIS

The structural modeling and analysis of the proposed high-rise residential building were carried out using STAAD.Pro software based on finite element principles. The building consists of two basement floors, one stilt floor, and ten upper residential floors. A three-dimensional reinforced concrete moment-resisting frame model was developed to evaluate the structural behavior under gravity and wind loading conditions. The numerical model was created by defining nodes at beam-column junctions and connecting them through beam and column elements. Floor slabs were modeled using plate elements to simulate diaphragm action and load distribution.

The structural geometry was generated according to standard residential building dimensions. The basement floors were modeled with comparatively larger column sections to resist higher axial forces and soil pressure effects. The stilt floor was modeled as an open frame system with reduced wall stiffness, representing realistic parking floor conditions. The upper floors were modeled with typical beam-column framing systems commonly used in reinforced concrete residential structures.

Material properties assigned to the structural model include M25 grade concrete and Fe500 reinforcement steel. The modulus of elasticity, density, and strength parameters were specified according to Indian Standard code provisions. The foundation system was assumed as fixed support conditions to provide stability against lateral and vertical loads. The rigid diaphragm behavior of floor slabs was considered to ensure uniform distribution of lateral loads to the structural members.

Dead load, live load, and wind load were applied to the structural model according to IS 875 code provisions. Dead load included the self-weight of beams, columns, slabs, and walls, while live load was considered based on residential occupancy standards. Wind loads were calculated according to IS 875 (Part 3) considering terrain category, building height, and basic wind speed. Wind forces were applied along both principal directions of the building to evaluate structural response under critical loading conditions.

The structural analysis was performed using finite element analysis techniques available in STAAD.Pro. The software computed important structural response parameters including lateral displacement, storey drift, bending moments, shear forces, axial forces, and base shear. The obtained results were used to evaluate the overall structural performance and stability of the building under wind loading conditions.

TABLE III MATERIAL PROPERTIES USED IN ANALYSIS

Property	Value
Concrete Grade	M25
Reinforcement Steel	Fe500
Density of Concrete	25 kN/m³
Modulus of Elasticity of Concrete	25,000 MPa
Modulus of Elasticity of Steel	200,000 MPa

TABLE IV LOADS CONSIDERED FOR ANALYSIS

Load Type	Description
Dead Load	Self-weight of structural members
Live Load	Residential occupancy load
Wind Load	Lateral wind force based on IS 875 Part 3

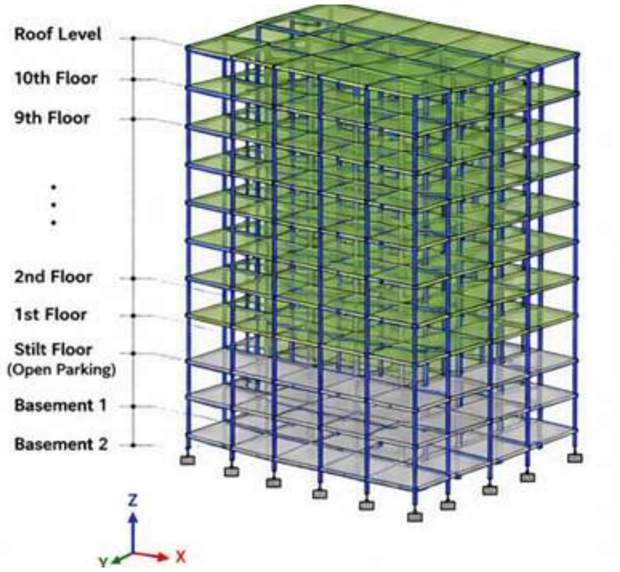

Fig. 5. Three-Dimensional Structural Model Developed in STAAD.Pro

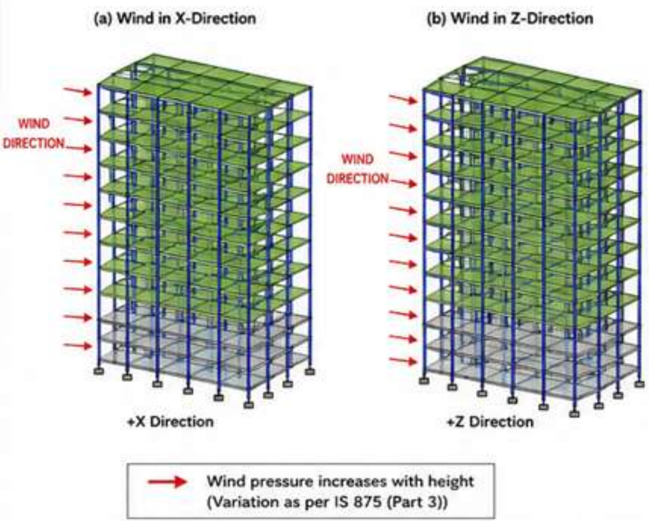

Fig. 6. Application of Wind Loads on the Building Model

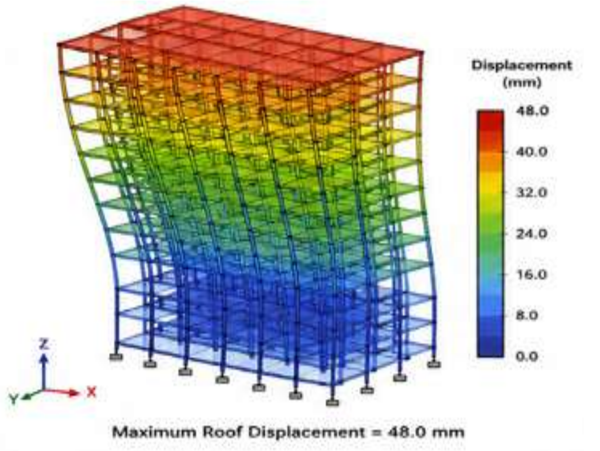

Fig. 8. Deflected Shape of the Building Under Wind Loading

V. EXPERIMENTAL RESULTS

The experimental results obtained from the numerical analysis provide an understanding of the structural response of the high-rise residential building under wind loading conditions. The analysis was performed using STAAD.Pro software by considering dead load, live load, and wind load combinations according to IS 875 (Part 3). The structural behavior was evaluated using important response parameters such as lateral displacement, storey drift, base shear, bending moments, and shear forces.

The numerical analysis indicated that wind loads significantly influence the lateral behavior of the structure. As the building height increased, wind pressure also increased, resulting in higher displacement and drift values at upper floors. The roof level experienced the maximum lateral displacement, while the base level remained nearly fixed due to support restraints.

A. Lateral Displacement Analysis

Lateral displacement represents the horizontal movement of the building due to wind loading. The analysis results showed that displacement gradually increased from the base toward the roof level because of increasing wind pressure intensity along the height.

TABLE V MAXIMUM LATERAL DISPLACEMENT

Floor Level	Displacement (mm)
Roof Floor	32.8
8th Floor	25.7
6th Floor	20.3
4th Floor	14.6
2nd Floor	8.9
Base Level	0

The obtained displacement values were within permissible codal limits, indicating satisfactory structural performance.

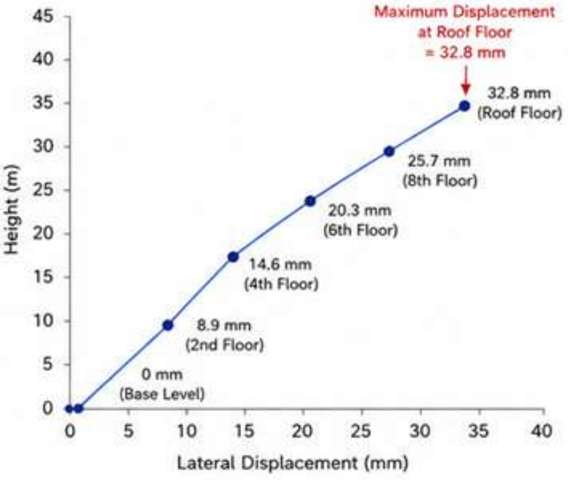

Fig. 12. Lateral Displacement Profile Along Building Height

B. Storey Drift Analysis

Storey drift refers to the relative displacement between two consecutive floors. Excessive drift may affect structural serviceability and damage non-structural components.

TABLE VI STOREY DRIFT VALUES

Storey Level	Storey Drift (mm)
Roof Floor	3.1
8th Floor	2.5
6th Floor	2.1
4th Floor	1.7
2nd Floor	1.2
Stilt Floor	0.8

The drift values remained within allowable limits specified in Indian Standard codes, confirming adequate stiffness of the building.

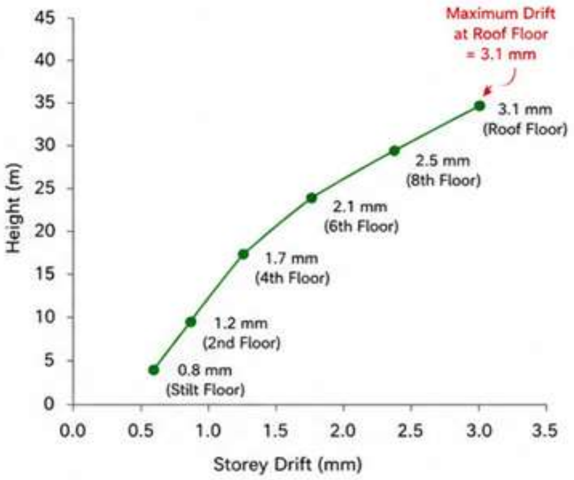

Fig. 13. Storey Drift Variation Along Building Height

C. Base Shear Analysis

Base shear represents the total horizontal force transferred to the foundation due to wind action. The analysis showed that wind acting along the longer face of the structure generated higher base shear values.

TABLE VII : BASE SHEAR VALUES

Wind Direction	Base Shear (kN)
X-Direction	865
Z-Direction	742

The obtained base shear values indicate that the structural system effectively resisted lateral wind forces.

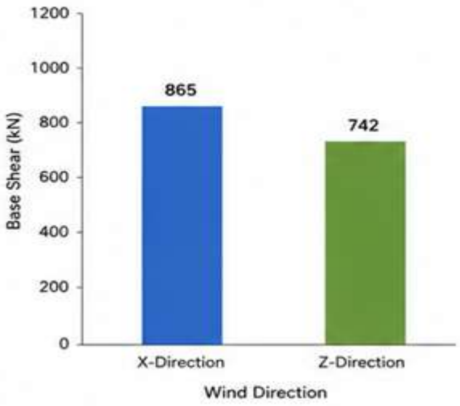

Fig. 14. Base Shear Comparison for Different Wind Directions

D. Bending Moment and Shear Force Analysis

Wind loads generated significant bending moments and shear forces in beams and columns. Maximum values were observed in lower columns because they resist cumulative lateral loads from upper floors.

TABLE X :MAXIMUM INTERNAL FORCE VALUES

Structural Parameter	**Maximum Value**
Column Bending Moment	425 kN-m
Beam Bending Moment	142 kN-m
Column Shear Force	286 kN
Beam Shear Force	96 kN

The results confirmed that the structural members possessed sufficient strength to resist wind-induced forces.

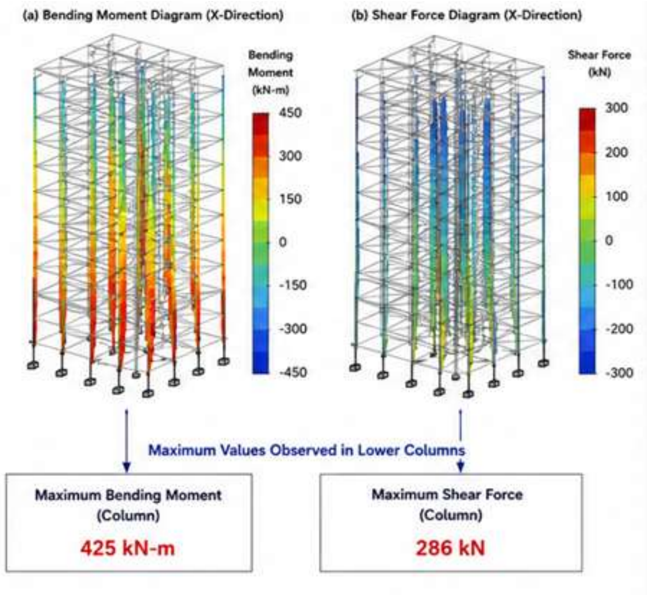

Fig. 15. Bending Moment and Shear Force Distribution

E. Discussion of Results

The numerical investigation demonstrated that wind loads significantly affect the structural response of high-rise residential buildings. Lateral displacement and storey drift increased progressively with building height due to increasing wind pressure. The maximum response occurred at upper floors, while lower floors experienced larger internal forces such as bending moments and shear forces.

The obtained results confirmed that the building satisfies the strength, stability, and serviceability requirements specified by Indian Standard provisions. The study also demonstrated that STAAD.Pro software provides accurate and reliable numerical analysis for evaluating wind effects on reinforced concrete high-rise structures.

V. CONCLUSION

The present study investigated the wind-induced structural behavior of a reinforced concrete high-rise residential building consisting of two basement floors, one stilt floor, and ten upper floors using STAAD.Pro software. Wind loads were calculated according to the provisions of IS 875 (Part 3), and detailed numerical analysis was carried out to evaluate important structural response parameters such as lateral displacement, storey drift, base shear, bending moments, and shear forces. The analysis results demonstrated that wind pressure increases significantly with building height, resulting in larger displacement and drift values at upper floors. Maximum internal forces were observed in lower structural members due to cumulative load transfer from upper storeys. The obtained results confirmed that the structural responses remained within permissible codal limits, indicating adequate strength, stiffness, and stability of the building under wind loading conditions. The study also proved that STAAD.Pro is an effective and reliable tool for evaluating the structural performance of medium-rise buildings subjected to lateral loads.

Future research may focus on advanced dynamic wind analysis considering fluctuating wind effects and time-history response of high-rise structures. The inclusion of soil-structure interaction, nonlinear material behavior, and aerodynamic effects can further improve the accuracy of structural prediction. Comparative studies using other analysis software such as ETABS and SAP2000 may also be carried out to validate the numerical results. In addition, optimization techniques can be applied to improve structural efficiency and reduce construction cost while maintaining safety requirements. Experimental validation using wind tunnel testing or Computational Fluid Dynamics analysis may further enhance understanding of wind behavior on complex residential building configurations.

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