NAU Journal of Civil Engineering (NAUJCVE) November/December 2025
Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)

Volume-4, Issue-3, pp-50-63
www.naujcve.com
Research Paper Open Access

# A Data-driven Approach to Predicting the Vibration Effects of Shear Walls under Wind and Seismic Loading.

**[1]Iaren T. Cornelius and [2]Bemshima, Raphael, T.,**

*[1]Department of Civil Engineering, Mudiame University, Irrua, Edo State, Nigeria)*

*[2]Department of Civil Engineering , Joseph Sarwuan Tarkaa University, Markurdi, Markurdi, Nigeria)*
*[2]bemshimatraphael@gmail.com*

***[1]Corresponding Author: cornelius.iaren@mudiameuniversity.edu.ng***

***ABSTRACT : This study explores how different shear wall placements affect the vibration response of a 26-story reinforced concrete building exposed to seismic and wind loading. Five structural models with the same geometry but different shear wall layouts were analysed using ETABS. To better understand the behaviour of each configuration, the displacement data were further processed in Python using tools such as Pandas for organizing the datasets, NumPy for computing displacement envelopes, and Matplotlib to visualize the results. The analysis showed clear differences among the five models. Shear walls placed around the building's core in x and/ or y axis provided much lower lateral displacements, as seen in the displacement results of Model 2 and 3. The displacement of model 2 been 340.21mm and that of model 3 is 332.95mm leading to better overall vibration control. It was also noticed that the displacement of model 3 (12m perimeter) was lowest though centralized only along X-axis this is due to the perimeter of the wall which is significantly greater than that of model 2 (8m perimeter) with the difference of 33.3%. In contrast, models where the walls were placed asymmetrically or only along the perimeter experienced noticeably higher displacements. These Include model 1,4 and 5. These findings show how strongly shear wall location influences the vibration behaviour of high-rise buildings and demonstrate the value of combining ETABS with data-driven (Python-based) processing in structural engineering research.***

***KEYWORDS: Data-driven computation, Shear wall optimization, High-rise structural vibration, Seismic and wind loading, Inter-storey drift control, Performance-based design.***

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Date of Submission: 10-12-2025 Date of acceptance: 16-12-2025

## I. INTRODUCTION

The rapid increase in the construction of high-rise buildings worldwide has intensified the need to understand and control structural vibrations induced by lateral loads. Among these, **wind and seismic actions** represent critical design considerations that govern the dynamic performance, stability, and safety of tall structures. The interaction between these dynamic loads often produces complex responses that can compromise both structural integrity and occupant comfort (Chopra, 2019; Smith & Coull, 2018). In high-rise buildings, where the height-to-base ratio is large, the lateral stiffness is relatively low, making them more susceptible to vibration effects. Consequently, the optimization of **lateral load-resisting systems**, such as shear walls, has become essential in performance-based structural design.

**Shear walls** are vertical reinforced concrete elements that enhance lateral stiffness and strength, acting as the primary defense against wind and earthquake-induced vibrations (Taranath, 2016). Their location and configuration significantly affect the building's global dynamic characteristics—particularly its **natural frequency, mode shapes, damping capacity, and inter-storey drift behavior** (Ali & Moon, 2017; Habibullah & Wilson, 2015). Strategic placement can minimize torsional irregularities and lateral displacements, while poor positioning can lead to concentration of stiffness, differential displacements, and resonance under dynamic loading. Thus, understanding how **shear wall placement influences vibration control** is fundamental to achieving efficient and resilient high-rise design.

**Wind-induced vibrations** result from fluctuating aerodynamic forces and vortex shedding effects that cause dynamic excitation of the structure (Holmes, 2018). As building height increases, these dynamic effects become dominant over static pressures, leading to increased amplitude of lateral motion and occupant discomfort. On the other hand, **seismic excitations** introduce transient ground motions that induce cyclic deformations, demanding sufficient stiffness and energy dissipation capacity from the structure (Clough & Penzien, 2015). The combined influence of these two dynamic forces necessitates a robust design approach grounded in internationally accepted codes.

The **Eurocode suite (EN 1990–1999)** provides comprehensive guidance for the structural design of buildings under multiple load conditions. Specifically, **EN 1991-1-4** addresses wind actions, while **EN 1998-1** focuses on seismic design principles, ensuring structures achieve adequate safety and serviceability under both static and dynamic loads (European Committee for Standardization [CEN], 2002, 2004). These standards integrate performance-based criteria, requiring designers to control displacements, accelerations, and vibration frequencies within allowable limits. However, determining an optimal shear wall arrangement that satisfies both seismic and wind performance remains a design challenge, particularly for irregular and slender high-rise geometries.

With the advancement of **finite element-based tools** such as ETABS, engineers can now perform precise dynamic analyses of tall buildings under multiple loading scenarios (Habibullah & Wilson, 2015). By simulating different shear wall configurations and evaluating key response parameters—such as fundamental time period, lateral drift, and base shear—engineers can identify configurations that minimize vibration and maximize stability. Previous studies have shown that optimized shear wall layouts can significantly reduce building sway and acceleration, improving both safety and comfort (Al-Chaar et al., 2013; Rahgozar & Sharifi, 2017).

This study investigates the **vibration effects of shear walls in high-rise buildings under seismic and wind loading**, focusing on a **26-storey reinforced concrete structure** modeled using ETABS. Five distinct shear wall placement configurations are analyzed to determine the most efficient and stable arrangement. The findings will contribute to the ongoing development of Eurocode-aligned vibration control strategies for tall buildings, providing data-driven insights for the design of resilient structural systems.

The primary aim of this study is to examine the influence of shear wall placement on the vibration behavior of high-rise buildings subjected to seismic and wind loads using Eurocode-based design principles.

This research is limited to the dynamic analysis of a **26-storey reinforced concrete high-rise structure** modeled in ETABS. The analysis focuses on **five different shear wall placement configurations**, evaluated under seismic and wind load conditions as prescribed in **EN 1991-1-4** and **EN 1998-1**. Material nonlinearities, soil–structure interaction, and foundation flexibility are excluded. The results will identify the optimal shear wall configurations that ensure vibration control and compliance with Eurocode performance criteria for serviceability and safety.

## II METHODOLOGY

### 2.1. Methods

A 26-story building with identical geometric and material properties was developed for all models. Only the shear wall configuration varied among the five alternatives, allowing direct comparison of vibration performance. Each model included the same floor height, structural frame system, and loading conditions so that displacement differences could be attributed solely to shear wall placement.

#### 2.1.1 Numerical Analysis Using ETABS

Dynamic analysis was carried out using ETABS, which provided modal characteristics and structural response under seismic and wind effects. The software generated joint displacements, story drifts, and joint drifts for each model. Seismic loading was defined according to standard code-based response spectrum parameters, while wind loads were applied using the directional method specified in the governing design standard.

#### 2.1.2. Data Extraction and Processing Workflow

To enable efficient handling of the large datasets produced by ETABS, all numerical outputs were exported into spreadsheet format and processed using Python. The post-processing workflow followed these steps:

#### 2.1.3. Data Cleaning and Structuring:

The exported spreadsheets were imported into Python using Pandas, which allowed systematic filtering, labeling of stories, and restructuring of displacement tables for analysis.

#### 2.1.4. Numerical Computation:

Key metrics such as maximum lateral displacement, comparative ratios between models, and displacement envelopes were computed with NumPy. This ensured consistent and accurate calculations across the five models.

#### 2.1.5. Visualization:

Graphical representations—including displacement profiles, drift distributions, and comparative charts—were generated using Matplotlib. These visualizations played a crucial role in interpreting the influence of shear wall positioning on the building's vibration behaviour.

#### 2.1.6. Comparative Evaluation

Each model's structural response was compared by examining: maximum joint displacement across all stories, displacement envelope patterns, drift concentrations indicating potential weak points, and qualitative vibration behaviour based on deformation shape and stiffness distribution.

This combined ETABS-Python workflow ensured a reproducible, transparent, and computationally rigorous approach for evaluating shear wall efficiency in tall buildings. The python code used for data processing is shown in appendix 1.

### 2.2 Materials

The materials and resources utilized in this research include design standards, analytical software, and reference materials for high-rise structural analysis. The methodological framework is guided by the principles and load combinations prescribed in Eurocode 0–9 (EN 1990–1999), ensuring international design compliance.

This study adopts the Eurocode series as the fundamental design framework:
- EN 1990 (Eurocode 0): Basis of structural design, defining limit states and safety principles.
- EN 1991-1-1 to 1-4 (Eurocode 1): Actions on structures—dead, live, and wind loads.
- EN 1992-1-1 (Eurocode 2): Design of concrete structures.
- EN 1998-1 (Eurocode 8): Design of structures for earthquake resistance.

1.The ETABS 22 structural analysis and design software was employed to model and simulate the dynamic behavior of the building under seismic and wind actions. ETABS provides advanced capabilities for 3D modeling of reinforced concrete and steel structures, dynamic analyses (modal, response spectrum, and time-history), and wind load simulation per EN 1991-1-4 and seismic load generation per EN 1998-1.

2. Python with its library (Matplotlib, Pandas and Numpy) used for data processing computation of mean absolute displacement, peak displacement, story displacement plotting of reference graphs for data visualization.

A systematic and computational approach was adopted, involving numerical modeling, dynamic load simulation, and parametric comparison. The research procedure comprised the following major phases:

1. Structural Modeling
2. Material and Section Definition
3. Shear Wall Placement Configurations
4. Dynamic Load Application (Seismic and Wind)
5. Structural Analysis
6. Result Evaluation with Python (Pandas, Matplotlib, Numpy Library)

**2.2.1 Structural Modeling**

A 26-storey reinforced concrete building was modeled in ETABS, representing a typical high-rise building form. Each storey has a height of 3.0 m, giving a total building height of 78 m. The base storey was modeled as a rigid foundation level with fixed supports. The floor system was designed as rigid diaphragms, ensuring in-plane stiffness and uniform load distribution across floors.

**2.2.2 Material and Section Properties**

Material properties were defined per EN 1992-1-1 (Eurocode 2) standards:

- Concrete: C20/25 grade (fck = 20 MPa), density = 25 kN/m³, E = 31,000 MPa, ν = 0.2.
- Reinforcement Steel: fyk = 500 MPa, E = 200,000 MPa, ν = 0.3., live load=2KN/m$^2$

The following section sizes were adopted: Beams (225×450 mm), Columns (450×450 mm), Slabs (150 mm), Shear walls (450 mm).

**2.2.3 Shear Wall Configurations**

Five shear wall placement configurations were analyzed to evaluate the influence of location on vibration response as shown in Fig 1, 2,3,4 and 5.

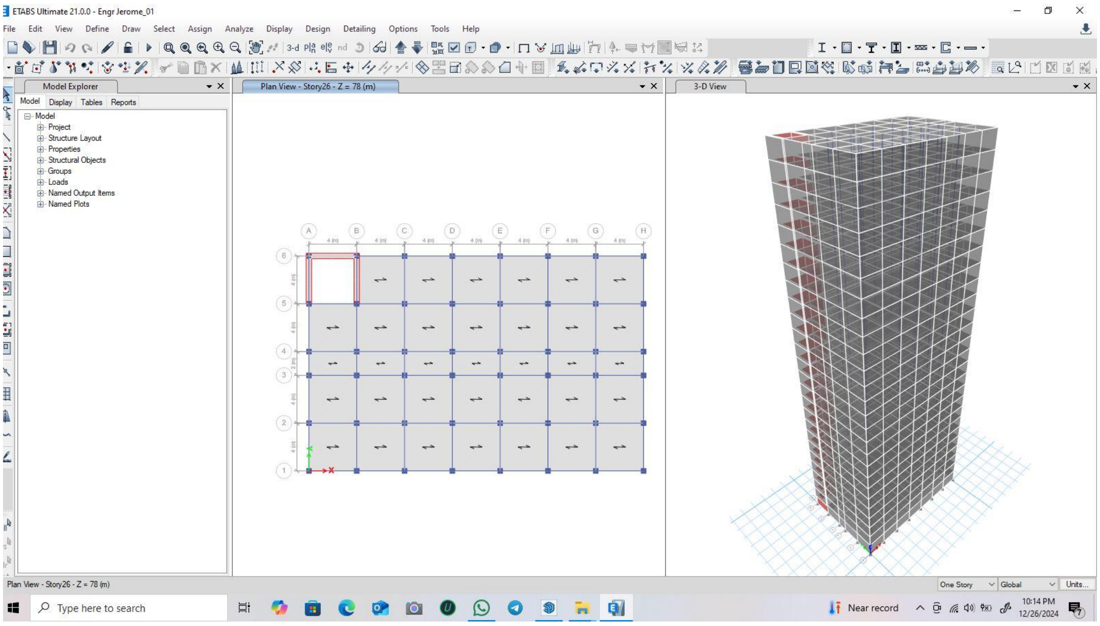


**Fig 1. Model 1 – Top Left Cornered shear walls-opening along Y axis**

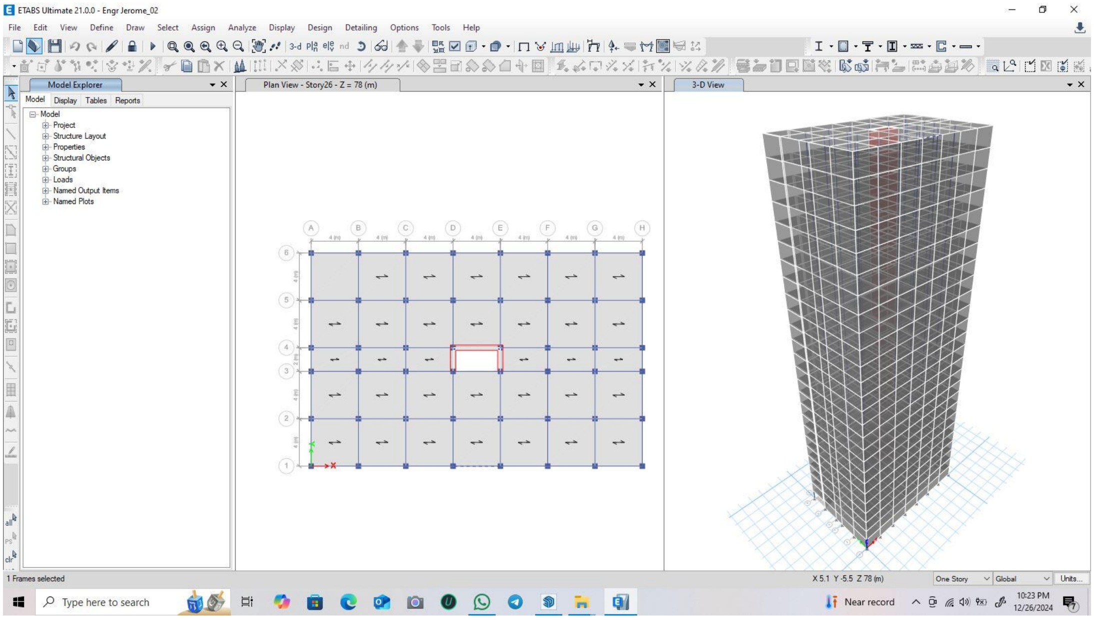


Fig 2. Model 2 – Core-centered shear walls.

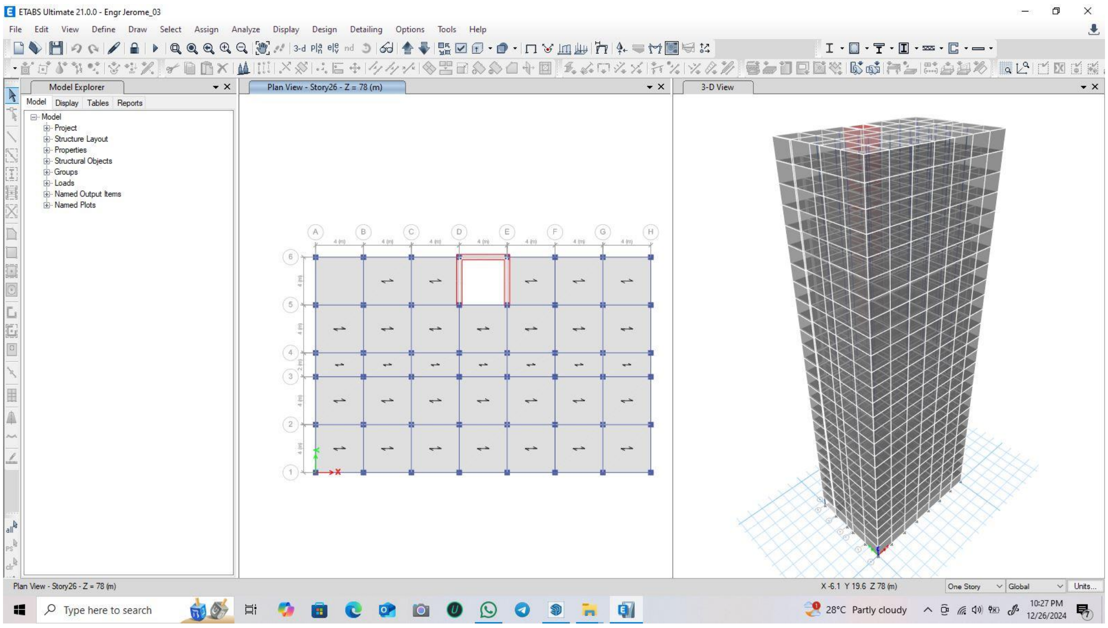


Fig 3. Model 3 – Core-centered along Y axis and X axis perimeter Shear wall

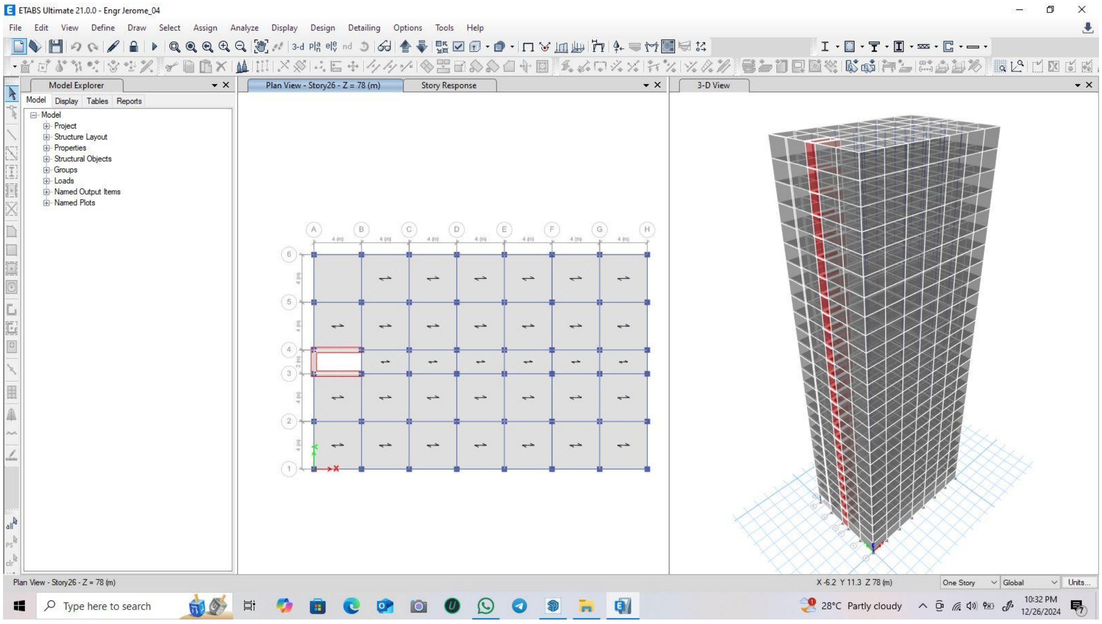

**Fig 4. Model 4 – Core-centered along X axis and Y axis perimeter Shear walls**

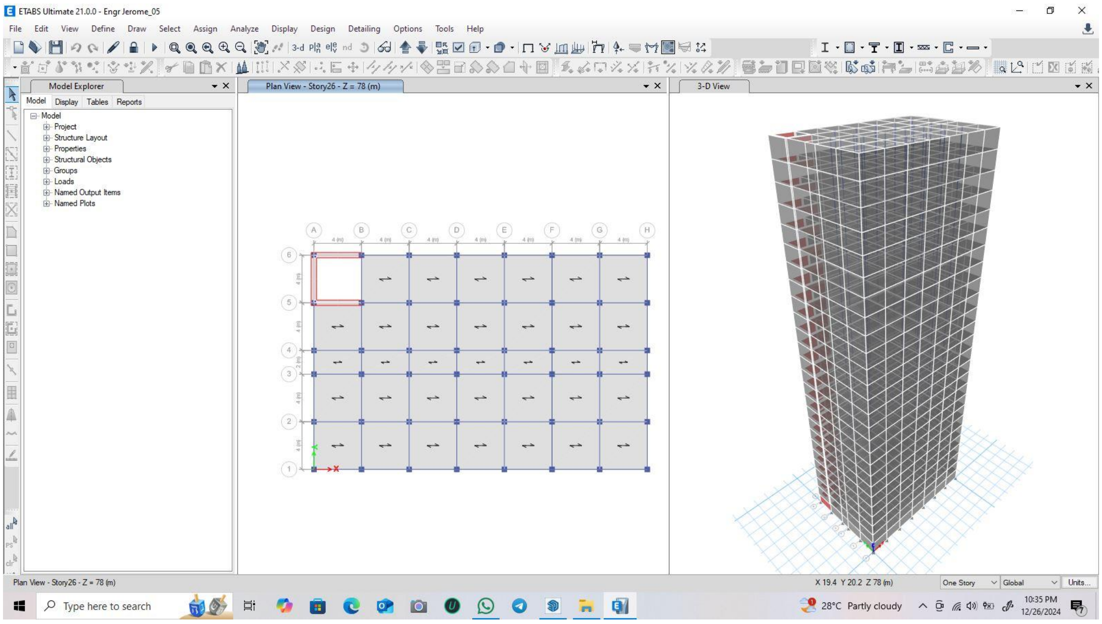

**Fig 5. Model 5 – Top Left Cornered shear walls-opening along X axis**

### 2.4 Load Applications

Dead and live loads were defined per EN 1991-1-1, accounting for self-weight, finishes (2.0 kN/m²), and imposed loads (2.0 kN/m²).

Wind loads were calculated per EN 1991-1-4 using:
$q_p = ½ \rho v_m^2 C_e C_d$

where:
$\rho$ = air density,
$v_m$ = mean wind velocity,
$C_e$ = exposure factor,
$C_d$ = direction factor.

Seismic actions were determined using the Response Spectrum Method in line with EN 1998-1, with:
$T_1 = C_t h^{(3/4)}$

where:

$C_t$ = 0.05 for RC frames,
h = total height of the building.

Wind Velocity (v)=56.5 m/s (zone 5 wind for Northen Nigeria which is the highest for Nigeria)

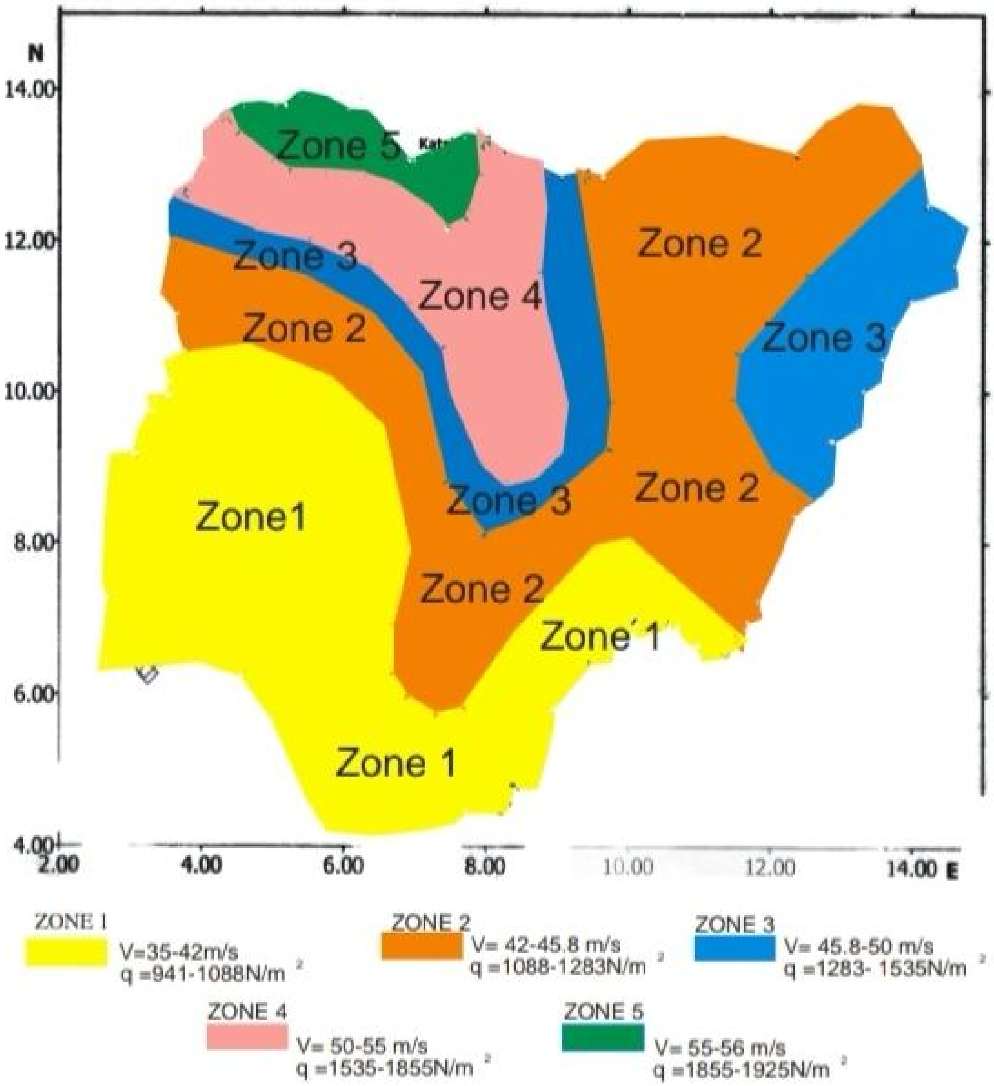


**Fig 6:** Classification of Nigeria into Wind Speeds Isopleths Zones (Onundi *et al.*, 2009)

The Fig 6 has been useful in estimating the wind velocity that was used in the loading computation for wind loading.

**2.5 Load combination**

Four load combinations were considered to simulate the worst loading condition of the structure as shown in Figure 21. The notations used and their meanings are; DEAD LOAD (DL), LIVE LOAD (LL) and WIND LOAD (WL). The load combinations are:

a) 1.0DL + 1.0LL + 1.0WL
b) 1.0DL + 1.4LL
c) 1.2DL + 1.2LL + 1.2WL
d) 1.4DL + 1.6LL
e) Wind Loading

f) Seismic loading

Mean value of the peak loading was extracted for each story and model

A modal response spectrum analysis was conducted to capture the building's vibration characteristics. ETABS extracted modal frequencies, mode shapes, and mass participation ratios for all models. For wind loading, gust response factors and along-wind accelerations were computed to assess occupant comfort per EN 1991-1-4 Annex B.

Results were compared across the five shear wall configurations based on top displacement. The safest configuration was selected based on minimum displacement ($\Delta/h \leq 1/500$).

This methodology integrated Eurocode-compliant design principles with computational dynamic analysis using ETABS and Python. By examining five shear wall configurations in a 26-storey structure under both seismic and wind actions, the study identifies the configuration that minimizes vibration effects and maximizes safety.

## III RESULTS AND DISCIUSSION

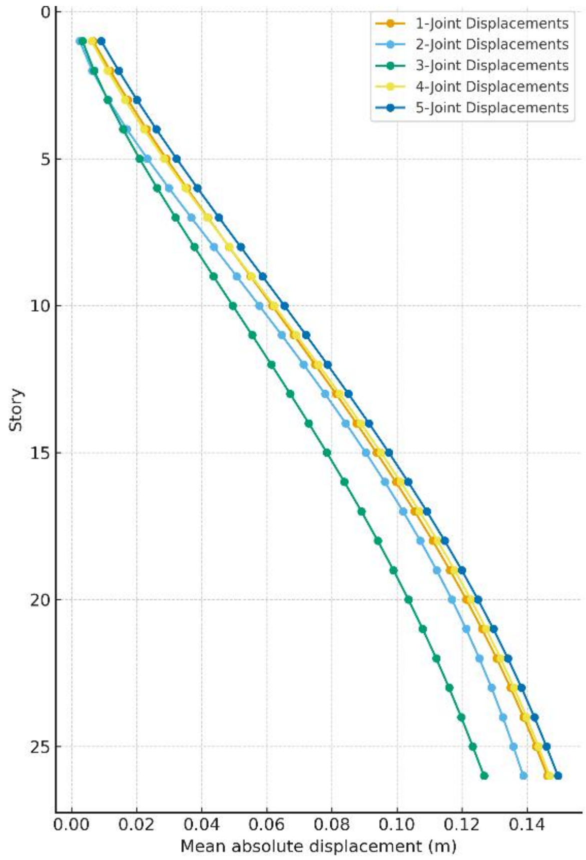


**Fig 7: Story Displacement Profile**

Fig 7 shows the story displacement for each story with all models represented in a curve respectively. From the curve plots in fig 7, it is observed that model 2 and 3 diplay lower mean absolute displacement (m) at the 26th floor. It is equally observed that there is a general increase in mean displacement from the base stories to the higher floors.

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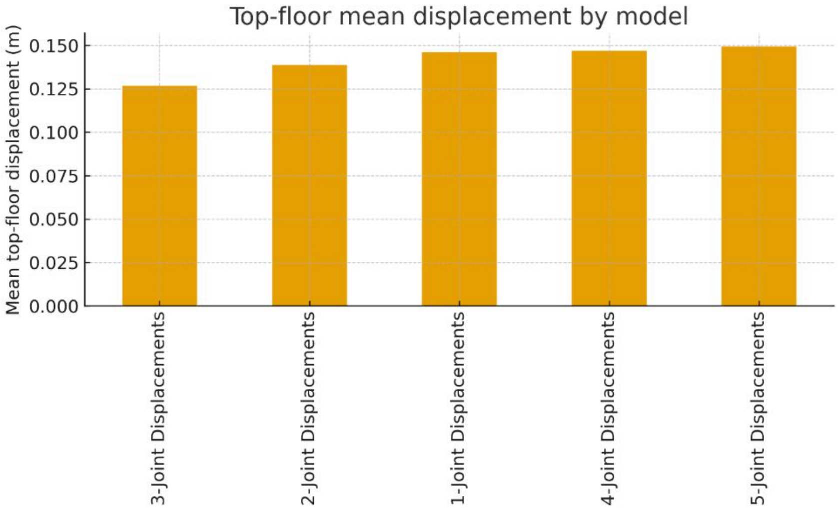


**Fig 8 : Mean Top floor Mean Displacement by model**

Fig 8 shows the Mean Top floor Mean Displacement by model for all models further showing with higher precision the maximum displacement for each model with model 3 and 2 been lowest ploted from the lowest diplacement value to the highest diplacement value.

Table 1 shows the mean absolute displacement extracted from the etabs anysis and further processed with python and its library into the finished form for all models. The results is observed to be in continuous increasing order from story 1 to story 26 with model 3 having the lowest mean absolute dispacement of 126.73mm at 26 story and followed by story 2 with the mean absolute dispacement of 138.81mm.

**Table 1: Mean Absolute displacement**

| Story No | Model 1 MeanAbsDisp_mm | Model 2 MeanAbsDisp_mm | Model 3 MeanAbsDisp_mm | Model 4 MeanAbsDisp_mm | Model5 MeanAbsDisp_mm |
|---|---|---|---|---|---|
| 26 | 146.2405452 | 138.8072 | 126.737 | 146.896 | 149.4795 |
| 25 | 142.6609919 | 135.7625 | 123.3086 | 143.4583 | 145.9404 |
| 24 | 138.8906146 | 132.5253 | 119.7398 | 139.8277 | 142.2237 |
| 23 | 134.8850659 | 129.0532 | 115.9975 | 135.9597 | 138.2777 |
| 22 | 130.6245108 | 125.3028 | 112.0554 | 131.827 | 134.0801 |
| 21 | 126.1011895 | 121.2498 | 107.8993 | 127.4153 | 129.621 |
| 20 | 121.3139382 | 116.8815 | 103.5223 | 122.7177 | 124.8969 |
| 19 | 116.2666776 | 112.1941 | 98.92341 | 117.7336 | 119.9098 |
| 18 | 110.9675893 | 107.1907 | 94.10645 | 112.4679 | 114.6658 |
| 17 | 105.4286726 | 101.8798 | 89.07983 | 106.9301 | 109.1752 |
| 16 | 99.66543687 | 96.27461 | 83.85598 | 101.1341 | 103.4515 |

| | | | | | |
|---|---|---|---|---|---|
| 15 | 93.69671018 | 90.39211 | 78.45119 | 95.09795 | 97.51176 |
| 14 | 87.54453024 | 84.25317 | 72.8855 | 88.84325 | 91.37599 |
| 13 | 81.23410209 | 77.88235 | 67.18271 | 82.39572 | 85.06737 |
| 12 | 74.79381429 | 71.30828 | 61.37047 | 75.78507 | 78.61218 |
| 11 | 68.25530428 | 64.56409 | 55.48049 | 69.04547 | 72.04014 |
| 10 | 61.65356152 | 57.68833 | 49.54894 | 62.21562 | 65.38449 |
| 9 | 55.02704993 | 50.72628 | 43.61682 | 55.33973 | 58.67597 |
| 8 | 48.41782015 | 43.73201 | 37.73059 | 48.46486 | 51.96023 |
| 7 | 41.87156072 | 36.77124 | 31.94292 | 41.63621 | 45.28676 |
| 6 | 35.43499668 | 29.92563 | 26.31383 | 34.93839 | 38.70598 |
| 5 | 29.16015299 | 23.2993 | 20.90809 | 28.44855 | 32.26885 |
| 4 | 23.10198409 | 17.02804 | 15.80835 | 22.24468 | 26.04835 |
| 3 | 17.31908138 | 11.29308 | 11.10588 | 16.42808 | 20.10356 |
| 2 | 11.85161399 | 6.337953 | 6.919947 | 11.08823 | 14.46514 |
| 1 | 6.618332506 | 2.504976 | 3.37139 | 6.118872 | 9.125984 |

Table 2 shows the peak displacement plot generated from python code utilizing the analysis results from ETABS. It is observed that the displacement is peak at last floor (26th floor) for all models. Is is equally observed that the peak displacement values are lowest for model 3 been 332.95 and model 2 been 340.22. This observation is perfectly similar to that of mean absolute displacement and the story displacement plot. Showing that model 3 and 2 are the optimal models for shear wall placements. If both model are fused into one, the result would be very outstanding.

**Table 2: Peak Displacement**

| Model | PeakDisp_mm | JointAtPeak | StoryAtPeak |
|---|---|---|---|
| 1-Joint Displacements | 397.5585766 | 43 | 26 |
| 2-Joint Displacements | 340.2172452 | 43 | 26 |
| 3-Joint Displacements | 332.95388 | 43 | 26 |
| 4-Joint Displacements | 364.8858193 | 43 | 26 |
| 5-Joint Displacements | 364.183024 | 43 | 26 |

## IV CONCLUSION AND RECOMMENDATION

### CONCLUSION

The joint displacement results highlight how crucial shear wall placement is to the overall behaviour of tall buildings under dynamic loads. Among the five models examined, those with shear walls positioned around the central core or arranged symmetrically (Model 2 and 3) proved to be the most effective in reducing lateral movement. These configurations provided better stiffness distribution and limited vibration effects from both wind and seismic forces. On the other hand, models with perimeter-only or unbalanced shear wall layouts (model 1,4 and 5) showed higher displacement values, indicating a less efficient resistance to dynamic actions and a greater likelihood of torsional response.

Using Python in combination with ETABS played a major role in clarifying these patterns. With Pandas, the exported ETABS data were cleaned and structured; NumPy allowed fast numerical comparison across all models; and Matplotlib helped produce clear visual graphs that made differences between shear wall layouts easy to interpret. This combined workflow improved accuracy and ensured that the analysis remained transparent and reproducible.

Overall, the findings emphasize that even when material properties and geometry remain constant, **where** shear walls are placed has a major impact on how a tall building responds to vibration. Core-based or symmetrical arrangements remain the best options for controlling lateral movement and ensuring structural stability.

## RECOMMENDATIONS

**1. Prioritize central or symmetric shear wall positions**

These configurations consistently produced the lowest displacements and should be preferred in high-rise design.

**2. Avoid irregular or unbalanced wall layouts**

The results show higher drifts and a greater chance of torsional effects when walls are placed asymmetrically.

**3. Use Python to support structural decision-making**

Tools like Pandas, NumPy, and Matplotlib help engineers quickly process ETABS outputs and identify the best-performing configurations.

**4. Validate shear wall layouts early using displacement checks**

Even before running advanced dynamic analyses, joint displacement patterns can reveal whether a design is likely to experience excessive vibration.

**5. Maintain a reproducible digital workflow**

Combining ETABS with Python-based processing ensures data transparency and allows other researchers or engineers to verify or extend the study.

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**APPENDIX 1**

PYTHON Code used

```
# process_joint_drifts_local.py
import pandas as pd, numpy as np
from pathlib import Path
excel_path = Path("Joint Drifts.xlsx")
out = Path("jd_drift_outputs"); out.mkdir(exist_ok=True)
def find_header_row(df):
    for i in range(0, 20):
        row = " ".join([str(v).lower() for v in df.iloc[i].values])
        if ('disp x' in row and 'disp y' in row) or ('drift' in row and ('x' in row or 'y' in row)):
            return i
```

```
    return 0
xls = pd.ExcelFile(excel_path)
models = [s for s in xls.sheet_names if not s.lower().startswith('program control')]
summary = []
for sheet in models:
    raw = pd.read_excel(excel_path, sheet_name=sheet, header=None)
    hdr = find_header_row(raw)
    header = list(raw.iloc[hdr].fillna('').astype(str))
    df = raw.iloc[hdr+1:].copy().reset_index(drop=True)
    df.columns = [str(c).strip() for c in header]
    cols = {c.lower():c for c in df.columns}
    # map likely columns
    disp_x = next((v for k,v in cols.items() if 'disp' in k and 'x' in k), None)
    disp_y = next((v for k,v in cols.items() if 'disp' in k and 'y' in k), None)
    drift_x = next((v for k,v in cols.items() if 'drift' in k and 'x' in k), None)
    drift_y = next((v for k,v in cols.items() if 'drift' in k and 'y' in k), None)
    story = next((v for k,v in cols.items() if 'story' in k), None)
    joint = next((v for k,v in cols.items() if 'label' in k or 'unique name' in k or 'joint' in k), None)
    for c in [disp_x,disp_y,drift_x,drift_y]:
        if c and c in df.columns: df[c]=pd.to_numeric(df[c], errors='coerce')
    # parse story
    def parse_story(x):
        import re
        m=re.search(r'(\d+)', str(x)); return int(m.group(1)) if m else np.nan
    if story: df['StoryNo']=df[story].apply(parse_story)
    else: df['StoryNo']=np.nan
    # compute resultant drift (prefer drift columns else use disp as proxy)
    if drift_x and drift_y and drift_x in df.columns and drift_y in df.columns:
        df['DriftRes'] = (df[drift_x].fillna(0).astype(float)**2 + df[drift_y].fillna(0).astype(float)**2)**0.5
```

```
    elif disp_x and disp_y and disp_x in df.columns and disp_y in df.columns:
        df['DriftRes'] = (df[disp_x].fillna(0).astype(float)**2 + df[disp_y].fillna(0).astype(float)**2)**0.5
    else:
        df['DriftRes'] = pd.NA
    # group to get max per story/joint
    if joint and joint in df.columns:
        grp = df.groupby([joint,'StoryNo'], dropna=False)['DriftRes'].max().reset_index()
    else:
        grp = df.groupby(['StoryNo'], dropna=False)['DriftRes'].max().reset_index(); grp['Joint']=''
    # find global peak for sheet
    if grp['DriftRes'].notna().any():
        idx = grp['DriftRes'].idxmax()
        pk = float(grp.loc[idx,'DriftRes'])
        pk_story = int(grp.loc[idx,'StoryNo']) if not pd.isna(grp.loc[idx,'StoryNo']) else ''
        pk_joint = grp.loc[idx].get(joint,'')
    else:
        pk = pd.NA; pk_story=''; pk_joint=''
    summary.append({'Model': sheet, 'PeakDrift': pk, 'JointAtPeak': str(pk_joint), 'StoryAtPeak': pk_story})
    grp.to_csv(out / f"{sheet}_story_max_drift.csv", index=False)
    df.to_csv(out / f"{sheet}_cleaned.csv", index=False)

summary_df = pd.DataFrame(summary).set_index('Model')
summary_df.to_excel(out/"joint_drift_summary.xlsx")
print(summary_df)
print("Saved to", out/"joint_drift_summary.xlsx")
```