Wind Analysis of High-Rise Building Resting on Sloping (Hilly) Grounds of Federal Capital Territory, Abuja, Nigeria

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Authors’ contributions

This work was carried out in collaboration with all authors. Author KCO designed the study. Author FOE wrote the protocol. Authors ROO and FOE wrote the first draft of the manuscript and managed the analyses of the study and managed the literature searches. Authors KCO, FOE and SCU are supervisors for this manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The importance of wind induced vibration is a key factor in the analysis, design and construction of high-rise building structures. Owing to scarce land resources, urbanization and ever-growing demand for accommodation is leading developers into sloping (hilly) grounds which in turn requires researches on the structural equilibrium of these structures. This study draws to mind the requirements of a fast-growing city of the Federal Capital Territory, FCT, Abuja considering her vast undulating planes and plateaus, high altitudes and windspeeds (50 m/s). Here therein, lies a comparative study of different types of building configurations and responses for sloping grounds using approaches form seismic analyses as a background to achieving set objectives. The study therefore, attempts the application of a commonly used method (Static Wind Analysis, SWA) for analysis of wind loads on structures and also understudying the outcomes of applying the same.

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loads using dynamic method (Response Spectrum Analysis, RSA). STAAD Pro V8i software was used to synthesize both analyses using the ASCE 705 code (wind speed-up over Hills) on 40 models for each analysis method for a 3x5 planar building configurations (G+6, G+8, G+12 and G+18) on grounds (0°, 6°, 10°, 14°, 18°, and 27°). The findings confirmed the complexities of sloping ground buildings with a greater chance of vibration and sway for SWA than in RSA. It was concluded, that the Stepback-setback (STPB-SETB) frames were better configured to combat wind loads on sloping grounds for both analyses. Recommendations includes, prioritizing the construction industry, collaboration with international bodies on High-rise development, developing a data base and wind testing facilities.

Keywords: Building configurations; high-rise; wind loads; response spectrum analysis; setback; Stepback; Stepback-setback; slope angles; static wind analysis.

1. INTRODUCTION

Wind affects buildings with two distinct effects, buffeting and vortex shedding causing drifts and oscillations [1]. Wind load may be taken as a critical loading, and complicated dynamic wind load in effect controls the architectural/structural design of the structure. Structural Engineers/Construction Technologist are facing the challenges of striving for the most efficient and economical design in high rise building with accuracy in such a way that every component of the building structure must resist two types of loads, i.e. vertical load due to gravity, and lateral load due to earth movements and wind, while ensuring that the final design of the building must be serviceable for its intended use over its design lifespan. Geographical Information Systems (GIS) applications are rudimental in the calculations of different ground slope angles [2] required to establish how wind speed-up hills and the response of bluff bodies along-wind cross section. In understanding the mechanisms of wind-induced static and dynamic loads and reduce the risk of damage, wind tunnel testing has been carried out by many researchers and proven to be an effective tool to investigate wind loads acting on high-rise buildings [3].

Expert assessment on wind engineering have postulated that wind pressures for buildings exceeding 200 m shows can be disastrous on the overall strength of the building than a 9-point earthquake [4]. Wind loads may not necessarily be very high to cause damage. A very good example for modern day wind engineering lesson was the Tacoma Narrows bridge 1940 which failed under moderate wind speed (68 km/h) due to negative aerodynamic damping or self-excitation [5]. Hilly grounds provide the altitude for an intense wind load on structures as it further compresses its volume towards the peak of the hill, thus increasing its velocity along the slope of the hill. This has necessitated the study of wind applications in high-rise building delivery, considering the irregularities of building configurations and systems for hilly regions observed in the FCT, Abuja and Nigeria.

Researches conducted within the last 2 decades shows that the building responses in the across wind and torsional directions are at least substantial as compared with the response in along wind direction [6]. The along-wind response of a tall building is generally considered by applying the quasi-steady theory [7], which assumes that the fluctuating pressure on the windward face on the structure varies directly with the fluctuation of the longitudinal wind velocity upstream. There are two types of wind directionality factors. One defines a wind directionality factor that changes with direction, as shown in [8,9,10], except for the cyclone-prone regions. The other defines a constant reduction coefficient regardless of wind direction, as in the ASCE 7-98 standard.

The aim of the study is to analyse the structural response and effectiveness of high rise RC buildings frames with different configurations resting on sloping (hilly) grounds of the FCT, Abuja, subjected to prevailing wind load with a view to determine critical response analyses of SWA and RSA, thus prescribing a suitable configuration for high-rise building construction and practice. Results are centred on maximum bending moments, maximum share force, displacement and resultants.

1.1 High-Rise Buildings on Sloping Grounds

According to the Council on Tall Buildings and Urban Habitat, factors that determine a building be classified as a "tall building", are hinged on displays high-rise qualities of height relative to
context, proportions and tall building technologies [11]. From the structural engineer's perspective, a tall building may be defined as one that because of its height, it is affected by lateral forces due to wind and earthquake actions to an extent that they play a critical role in the structural design [12].

A comparative study on the effect of different wind velocity on different sloping ground (0°, 5°, 10° & 15°) using STAAD. Pro software for modelling 2-D frame, observed maximum bending moment in beams for different building heights increases with increase in the wind velocity whereas minute change in moment on beam due to slope moments in column increases with increase in the wind velocity as well as ground slope [13].

A study of twenty-four (24) buildings of G +10, G+15, G+20 of setback, step back with setback on plain ground, sloped ground of 0°, 10°, 15°, 20° were analysed using Time history method and response spectrum method with the aid of STAAD Pro. and concluded from analysis, was the performance of set-step back building during seismic excitation as more vulnerable than other building configurations [14].

1.2 Wind Pattern in Nigeria, (Study Region)

Considerable amount of works has been carried out to investigate the characteristics and pattern of wind speed across Nigeria with accessibility to wind speed data information [15,16,17]. All studies draw the same conclusion as to the northern part of the country having highest wind speed. An improvement on the Soboyejo Isopleths [18] and the Nigerian Meteorological Agency (NIMET) wind map with considerations for structural/construction design processes led to the conclusion of subdividing the country into five main categories (Zones) with a yearly mean of 35 to 42 m/s (Category I), 42 to 45.8 m/s (Category II), 45.8 to 50 m/s (Category III), 50 to 55 (Category IV) and 55 to 56m/s (Category V) respectively [19].

The study area, Federal Capital Territory, FCT, Abuja falls within the category III and the upper limits of 50m/s was selected for this study.

![Map of Nigeria showing the FCT, Abuja](image_url)
Fig. 2. Map FCT, Abuja showing the Six Area Councils with focus on the Municipal Area Council

Fig. 3. Classification of Nigeria into Wind Speeds Isopleth Zones [19]
1.3 Code Provisions According to ASCE 7-05

According to chapter 6 of ASCE 7-05, there are three procedures in calculating wind loads for the design of buildings, Main Wind-Force-Resisting Systems (MWFRS), and Components and Cladding viz; Method 1: Simplified Method, Method 2: Analytical Procedure and Method 3: Wind-Tunnel Procedure. The emphasis as regards this study is based on Method 2, which applies to a majority of buildings. The steps of analytical procedure for method 2 are described in ASCE 7 Section 6.5.3 and it's basically built around two fundamental equations, the velocity equation, and the design wind pressure, p, equation:

\[ q_z = 0.613 K_z K_{zt} V^2 \text{ (N/m}^2; \text{V in m/s)} \]  
\[ p = qGC - q(GC_p) \text{ (N/m}^2) \]  

To determine the design wind load, F, on open buildings and other structure is given by the following formula:

\[ F = q_GC A_f \text{ (N)} \]  
\[ K_{zt} = (1+K_1K_2K_3)^2, \text{ the multipliers } K_1, K_2, K_3 \text{ (see Figs. 5-4 Chap.6, ASCE 705)} \]

2. METHODOLOGY

2.1 Problem Formulation

Response Spectrum Analysis (RSA) and Static Wind Analysis (SWA) based on the ASCE 7-05 codebase provisions was performed using Finite Element Analysis model from STAAD Pro V8i software. Various structural outputs such as, base reactions, shear forces, bending moments, displacements/resultants will be computed. The maximum wind speed was adopted from zone 3 (45.8 - 50 m/s) boundary limits and calibrated due to wind speed-up hills effect. A four-group of Reinforced Concrete Building Frames types and configurations were considered, with all having a typical 3x5 bay system having a 9 mX9 m panel, in which first two (set as control reference) are on plane (0°) ground and the remaining two are resting on different degrees of sloping grounds (6°, 14°, 18°, and 27°). The average depth at footing below ground level was taken as 2.5 m where a hard stratum is available. A study of wind induced behaviour of a laterally unsymmetrical high-rise building resting on sloping ground was done considering different structural configurations. Building configurations were specified on basis of the following.

![Plan view of 3x5 bay system with 9 mX9 m planar configuration](image_url)
2.1.1 Type of frame

Normal Rectangular type of building frame structure (NREC-FRAME): STPB-FRAME (control). Setback type of building frame structure (SETB-FRAME): STPB-SETB-FRAME (control). Step-back type of building frame structure (STPB-FRAME) Step-back Setback type of building frame structure (STPB-SETB-FRAME).

2.1.2 Numbers of storeys

With the study centred on high-rise and its requirements [11], the proposal of between G+6 to G+18 storey R.C building frame was consideration. A ground floor, G, storey height of 5.1 m with subsequent floor storey height of 3.6 m was suggested. Numbers are as follows: G+6=26.7 m; G+8=33.9 m; G+12=48.3 m; and G+18=69.9 m.

2.2 Modelling and Analysis

STAAD Pro. was used for the analyses and pre-programed to adopt the ASCE 7/ACI. To understand the behaviour of each structure, 40 models each were generated for SWA and RSA respectively from AutoCAD software and exported into STAAD Pro V8i, where result verification was facilitated by tools contained in the program's graphical environment.

Table 1. Model/Configuration parametric representation for frame types

| Model No. | Frame type | Slope angle in ° | no. of Storeys |
|-----------|------------|-----------------|---------------|
| 1         | NREC       | 0               | G+6           |
| 2         | NREC       | 0               | G+8           |
| 3         | NREC       | 0               | G+12          |
| 4         | NREC       | 0               | G+18          |
| 5         | SETB       | 0               | G+6           |
| 6         | SETB       | 0               | G+8           |
| 7         | SETB       | 0               | G+12          |
| 8         | SETB       | 0               | G+18          |
| 9         | STPB 6     | 5.7 (6)         | G+6           |
| 10        | STPB 14    | 14              | G+6           |
| 11        | STPB 18    | 18.4 (18)       | G+6           |
| 12        | STPB 27    | 26.6 (27)       | G+6           |
| 13        | STPB 6     | 5.7             | G+8           |
| 14        | STPB 14    | 14              | G+8           |
| 15        | STPB 18    | 18.4            | G+8           |
| 16        | STPB 27    | 26.6            | G+8           |
| 17        | STPB 6     | 5.7             | G+12          |
| 18        | STPB 14    | 14              | G+12          |
| 19        | STPB 18    | 18.4            | G+12          |
| 20        | STPB 27    | 26.6            | G+12          |
| 21        | STPB 6     | 5.7             | G+18          |
| 22        | STPB 14    | 14              | G+18          |
| 23        | STPB 18    | 18.4            | G+18          |
| 24        | STPB 27    | 26.6            | G+18          |
| 25        | STPB-SETB 6| 5.7             | G+6           |
| 26        | STPB-SETB 14| 14             | G+6           |
| 27        | STPB-SETB 18| 18.4           | G+6           |
| 28        | STPB-SETB 27| 26.6           | G+6           |
| 29        | STPB-SETB 6| 5.7             | G+8           |
| 30        | STPB-SETB 14| 14             | G+8           |
| 31        | STPB-SETB 18| 18.4           | G+8           |
| 32        | STPB-SETB 27| 26.6           | G+8           |
| 33        | STPB-SETB 6| 5.7             | G+12          |
| 34        | STPB-SETB 14| 14             | G+12          |
| 35        | STPB-SETB 18| 18.4           | G+12          |
| 36        | STPB-SETB 27| 26.6           | G+12          |
| 37        | STPB-SETB 6| 5.7             | G+18          |
| 38        | STPB-SETB 14| 14             | G+18          |
| 39        | STPB-SETB 18| 18.4           | G+18          |
| 40        | STPB-SETB 26.6| 26.6     | G+18          |
Fig. 4a. 3D/2D view of NERC

Fig. 4b. 3D/2D view of SETB

Fig. 4c. 3D/2D view of STPB
2.2.1 Geometrical/material properties

The approach and accuracy of the analytical results depends on the idealization of the geometry and loading of the structure. The properties required for this study (adopted from ASCE 7-05) were as follows:

- Live load: $4.79 \text{ KN/m}^2$ (Table 4-1)
- Slab: $4.20 \text{ KN/m}^2$
- Floor finish: $1.20 \text{ KN/m}^2$ (sec.4.2.2)
- Partition: $1.00 \text{ KN/m}^2$
- Roof load: $3.02 \text{ KN/m}^2$ (equ.4-2)
vi. Wind load: calculated as per chap.6 ASCE 7-05

vii. Dynamic Pressure coefficient Cp: 3.2 for building category III (Table 5-1)

Loading combination based on occupancy category III

1.2D + 1.6W + L + 0.5L, (sec. 2.3.2)

2.2.1.2 Sizes of members

See Table 2.

2.2.2 Comparative analysis

The analyses were conducted using NREC FRAMES and SETB FRAMES as control configurations to establish a comparative study between STPB FRAMES and STPB-SETB FRAMES on the basis of SWA and RSA.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Results presentation for static wind analysis

See Table 3 - 9.

3.1.2 Results presentation for response spectrum analysis

See Table 10 - 15.

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 10170.229 | 10031.21 | 9459.133 | 8755.029 |
| 8      |             | 15598.854 | 12552.24 | 13345.29 | 11470.9 |
| 12     |             | 19722.42  | 17893.338| 19477.64 | 16926.39 |
| 18     |             | 25770.574 | 25417.861| 24116.95 | 23278.2 |

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 10159.12  | 8640.473| 6760.046| 6065.25 |
| 8      |             | 12369.397 | 11347.299| 9728.317| 9791.465|
| 12     |             | 17478.803 | 22057.426| 18653.9 | 13168.46 |
| 18     |             | 24064.912 | 23003.055| 20771.08| 18198.76 |

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 707.975  | 291.462 | 295.347 | 341.052 |
| 8      |             | 314.351  | 327.355 | 294.055 | 702.502 |
| 12     |             | 416.75   | 1304.59 | 1329.777| 990.908 |
| 18     |             | 627.436  | 686.199 | 822.782 | 866.753 |

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 199.789 | 190.096 | 182.917 | 172.469 |
| 8      |             | 287.50  | 227.829 | 295.683 | 221.988 |
| 12     |             | 358.641 | 346.507 | 332.747 | 344.127 |
| 18     |             | 462.559 | 453.119 | 440.655 | 417.077 |

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 215.747 | 178.594 | 157.806 | 145.308 |
| 8      |             | 227.62  | 221.592 | 187.383 | 224.672 |
| 12     |             | 335.767 | 257.28  | 240.199 | 207.751 |
| 18     |             | 424.052 | 409.426 | 388.363 | 348.482 |
### Table 6. Maximum displacement (mm)

| Floors | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|------|--------|---------|---------|---------|
| 6      | 39.146 | 27.053 | 74.305  | 79.3    | 8.783   |
| 8      | 266.227 | 154.254 | 199.799 | 113.122 | 118.158 |
| 12     | 211.636 | 120.98  | 96.741  | 145.499 | 153.389 |
| 18     | 288.106 | 249.204 | 207.845 | 185.676 | 141.592 |

| Floors | SETB | STPB-SETB 6 | STPB-SETB 14 | STPB-SETB 18 | STPB-SETB 27 |
|--------|------|-------------|--------------|--------------|--------------|
| 6      | 187.597 | 90.839      | 75.28        | 62.721       | 15.934       |
| 8      | 203.068 | 214.561     | 69.376       | 105.772      | 104.424      |
| 12     | 149.318 | 220.698     | 209.523      | 165.486      | 107.791      |
| 18     | 304.532 | 266.848     | 226.626      | 141.592      | 162.007      |

### Table 7. Maximum bending moments in columns (KN.m)

| Floors | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|------|--------|---------|---------|---------|
| 6      | 391.549 | 373.588 | 359.851 | 354.132 | 339.694 |
| 8      | 566.608 | 445.793 | 577.343 | 491.508 | 461.799 |
| 12     | 753.339 | 727.188 | 698.539 | 764.804 | 693.255 |
| 18     | 968.068 | 948.688 | 922.822 | 910.164 | 873.905 |

| Floors | SETB | STPB-SETB 6 | STPB-SETB 14 | STPB-SETB 18 | STPB-SETB 27 |
|--------|------|-------------|--------------|--------------|--------------|
| 6      | 455.108 | 353.323     | 313.124      | 301.463      | 287.627      |
| 8      | 447.77  | 453.497     | 370.229      | 362.377      | 472.654      |
| 12     | 706.661 | 547.495     | 508.54      | 491.372      | 449.325      |
| 18     | 891.398 | 860.955     | 817.113      | 793.509      | 734.083      |

### Table 8. Maximum bending moments in beans (KN.m)

| Floors | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|------|--------|---------|---------|---------|
| 6      | 591.353 | 604.709 | 741.117 | 803.01  | 589.342 |
| 8      | 6350.309 | 993.343 | 6499.687 | 2791.342 | 4200.377 |
| 12     | 2912.772 | 1736.157 | 1845.833 | 5733.456 | 6787.107 |
| 18     | 2065.686 | 2537.825 | 2756.83  | 2198.801 | 2966.913 |

| Floors | SETB | STPB-SETB 6 | STPB-SETB 14 | STPB-SETB 18 | STPB-SETB 27 |
|--------|------|-------------|--------------|--------------|--------------|
| 6      | 2354.224 | 773.71     | 741.302      | 708.689      | 655.027      |
| 8      | 1006.351 | 1105.115   | 683.671      | 842.159      | 2413.162     |
| 12     | 1414.581 | 7018.07    | 7045.419     | 6876.004     | 3187.154     |
| 18     | 2068.571 | 2557.064   | 2770.928     | 2384.344     | 3054.221     |

### Table 9. Maximum resultants (mm)

| Floors | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|------|--------|---------|---------|---------|
| 6      | 57.613 | 47.78  | 82.45   | 86.356  | 30.261  |
| 8      | 786.82  | 165.191 | 813.203 | 259.138 | 681.124 |
| 12     | 275.244 | 132.239 | 109.073 | 689.041 | 687.558 |
| 18     | 308.173 | 270.154 | 229.509 | 208.305 | 167.58  |

| Floors | SETB | STPB-SETB 6 | STPB-SETB 14 | STPB-SETB 18 | STPB-SETB 27 |
|--------|------|-------------|--------------|--------------|--------------|
| 6      | 278.658 | 95.929     | 78.14        | 64.999       | 19.316       |
| 8      | 211.78  | 727.183    | 79.03        | 111.781      | 224.761      |
| 12     | 154.84  | 657.737    | 654.381      | 651.545      | 413.949      |
| 18     | 320.97  | 282.369    | 240.483      | 218.269      | 173.221      |
### Table 10. Maximum base reactions (KN)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 946.581 | 10382.48 | 9980.406 | 9940.492 | 9193.376 |
| 8      |             | 1598.724 | 13026.09 | 19487.16 | 14334.5 | 11879.28 |
| 12     |             | 20069.18 | 18337.79 | 17314.58 | 19570.76 | 17307.45 |
| 18     |             | 26138 | 26012.84 | 24570.71 | 24519.77 | 23742.09 |

### Table 11. Maximum share forces in columns (KN)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 658.508 | 1062.947 | 1180.795 | 1114.631 | 4448.13 |
| 8      |             | 1314.662 | 1115.267 | 1429.333 | 1152.133 | 1555.356 |
| 12     |             | 1673.709 | 1782.739 | 2416.726 | 2149.788 | 3263.074 |
| 18     |             | 1497.402 | 1768.727 | 2461.312 | 1800.118 | 18513.21 |

### Table 12. Maximum share forces in beams (KN)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 684.313 | 932.177 | 987.615 | 1112.005 | 1739.203 |
| 8      |             | 794.58 | 1006.956 | 1041.964 | 1056.681 | 1426.138 |
| 12     |             | 1609.718 | 1714.282 | 1658.555 | 1426.806 | 1574.012 |
| 18     |             | 1552.387 | 1748.368 | 1687.756 | 1598.775 | 2059.516 |

### Table 13. Maximum bending moments in columns (KN.m)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 2164.481 | 2549.479 | 2525.919 | 2464.424 | 2128.108 |
| 8      |             | 2460.152 | 2753.121 | 2347.156 | 2341.064 | 1958.325 |
| 12     |             | 3623.648 | 3627.255 | 3437.262 | 5357.544 | 4140.753 |
| 18     |             | 3705.393 | 3691.119 | 3491.944 | 3848.193 | 3537.479 |

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      |             | 2605.128 | 2793.323 | 2274.774 | 2005.599 | 1788.173 |
| 8      |             | 2814.977 | 2312.643 | 2517.938 | 2222.113 | 2060.487 |
| 12     |             | 4182.231 | 3944.118 | 4786.799 | 4573.842 | 3210.776 |
| 18     |             | 4278.002 | 4798.971 | 4793.519 | 6614.162 | 5553.071 |
Table 14. Maximum bending moments in beams (KN.m)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      | NREC        | 2177.915 | 2740.994 | 3135.188 | 2470.173 | 5122.377 |
| 8      | STPB 6      | 6662.771 | 2884.571 | 6388.224 | 3566.538 | 4216.708 |
| 12     | STPB 14     | 4379.744 | 4560.059 | 5641.543 | 7168.077 | 8717.349 |
| 18     | STPB 18     | 3621.391 | 4496.137 | 5732.078 | 7650.722 | 7820.142 |
|       | STPB 27     | 5122.377 | 6662.771 | 2884.571 | 6388.224 | 3566.538 | 4216.708 |
| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
| 6      | NREC        | 2510.833 | 2795.786 | 2135.653 | 3827.600 |
| 8      | STPB 6      | 2626.775 | 3084.65  | 2276.900 | 3168.518 |
| 12     | STPB 14     | 3874.554 | 7612.837 | 7584.015 | 6900.348 |
| 18     | STPB 18     | 3965.101 | 3958.321 | 4680.969 | 6519.134 |
|       | STPB 27     | 379.136  | 910.954  | 910.954  | 6900.348 |

Table 15. Maximum resultants (mm)

| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
|--------|-------------|------|--------|---------|---------|---------|
| 6      | NREC        | 707.093 | 771.557 | 704.509 | 671.336 | 379.136 |
| 8      | STPB 6      | 3982.794 | 934.368 | 2766.449 | 1536.778 | 910.954 |
| 12     | STPB 14     | 848.525  | 873.270 | 868.097 | 1052.928 | 1000.643 |
| 18     | STPB 18     | 1152.902 | 2121.281 | 1254.358 | 1219.172 | 1162.328 |
|       | STPB 27     | 646.123  | 685.186 | 502.014 | 448.690 | 273.004 |
| Floors | Frame Types | NREC | STPB 6 | STPB 14 | STPB 18 | STPB 27 |
| 6      | NREC        | 665.186 | 502.014 | 448.690 | 273.004 |
| 8      | STPB 6      | 1013.563 | 1104.361 | 651.292 | 602.067 | 574.433 |
| 12     | STPB 14     | 922.838  | 914.533 | 821.643 | 758.016 | 1115.839 |
| 18     | STPB 18     | 1311.137 | 1244.039 | 1156.097 | 1081.771 | 927.394 |

3.2 Discussion

3.2.1 Maximum base reactions

Table 3 and 10 indicates an increase in base reactions with increase in numbers floor relative to frame type and decrease base reactions with increase in slope angle relative to number of floors respectively. In comparasion, STPB-SETB frames shows lower base reactions.

3.2.2 Maximum share forces

Table 4 indicates an increase in share forces with increase in slope angle for individual frames with corresponding floors for STPB frames. It was also observed that share forces in STPB frames were lower compared to STPB-SETB frames. Share force in beams (Table 5) increases with increase in number of floors and decreases with increase in slope angle. STPB-SETB frames recorded lower share forces in beams. However, bending moments in beams (Table 8) showed high level of disparity due to redistribution of moments along increasing slope angles with a dip occurring after the 12 floors for all slope angles. Table 13 indicates increase bending moments in columns with in increase in number of floors applicable to STPB-SETB frames, while a dip was recorded at slope angles 18°/27° on 12 floors for STPB frames. Decreases in bending moments in columns were observed with increase in slope angle with an increase at 18° for 12 and 18 floors for STPB frames and increase at 18° for 18 floors for STPB-SETB frames. However, bending moments in beams (Table 14) showed increase in bending moments with increase in number of floors for...
STPB/STPB-SETB frames with a dip at 18 floors for all slope angle.

3.2.4 Maximum displacements

Table 6 indicates a decrease in displacement with increase in slope angle and increase in displacement with increase in number of floors. It was also observed that maximum displacements were higher in STPB-SETB frames.

3.2.5 Maximum Resultants

Table 9 indicates increase in resultant with increase in number of floors with a dip occurring between 12 and 18 floors for STPB frames. It was observed that resultant is lower overall in STPB-SETB frames compared to STPB frames at slope angle of 27°. Table 15 indicates a high resultant at 8 floors and a dip at 12 floors followed by a gradual rise. Also, only STPB 27 had a steady increase in resultant, while NREC, STPB 6, STPB 14, and STPB 18 showed similar pattern in resultant computations. It also indicates decrease in resultant with increase in slope angle. SETB and STPB-SETB frames shows similar pattern in resultant computation, while others indicate increase in resultant with increase in number of floors. STPB-SETB frames showed higher resultant.

4. CONCLUSION

The application of two analysis methods used in the comparative study of different configurations of high rise building resting on sloping grounds under the influence of wind loads has led to the conclusion;

Configuration of building frames were not adversely affected by wind load for frames of six and eight floors resting on 6° slope. However, as ground slope increases viz-a-viz number of floors, the Stepback-setback (STPB-SETB) configuration proved effective against wind loads. This was due to the reduction in vertical area and increase in horizontal area of load application. Stepback (STPB) configuration produces more vertical area spaces but will require complicated and advanced system of damping as number of floors increases. It was also concluded, that the windspeed in the study area is not a threat to high rise buildings of up to 18 floors for RSA than in SWA at 12 floors.

Taking a general view of results from analysis of different configuration viz-a-viz ground slopes, their applications in design may reveal complicated processes in construction. Using result from SWA, the introduction of diagonal braces or outriggers technology in combating displacement and sway (torsion) will be a design/construction requirement. Wind pressures influences SWA on all configuration due to noticeable displacement patterns. While, RSA showed negligible displacement owing to the fact that the wind pressure was not enough to trigger excitation, it however revealed high share, which would indicate the introduction of pre/post-tensioned (R.C members) technology in combating the share.

Configuration of building structure is key in presenting a preliminary approach to the challenges of high-rise structure under the action of wind. To this end, some recommendations proffered in this study includes, but not restricted to; engaging researchers in high-rise developments through professional workshops, prioritizing the construction industry, collaboration with international bodies on high-rise developments, example is the Council on Tall Buildings and Urban Habitat, CTBUH, and develop a national wind data base and testing facilities that can be readily accessible/assessible in the event of analyses, designs and referencing in all areas of construction.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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