Effects of Fluid Viscous Damper on Reinforced Concrete Tall Building under Lateral Loading in Lagos, Nigeria

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Received: 30-OCT-2023; Reviewed: 16-FEB-2024; Accepted: 13-MARCH-2024
https://dx.doi.org/10.4314/fuoyejet.v9i1.20

ORIGINAL RESEARCH

Abstract— The rapid construction of tall buildings in unconventional areas of Lagos, driven by high land cost necessitates meticulous analysis and design to withstand lateral loads such as wind and seismic forces. Typically, enhancing structural rigidity is the conventional approach to counteracting horizontal loads. This study examines the effectiveness of fluid viscous damping (FVD) in reducing gravity, wind and seismic loads in a 24 – story suspended floor frame structure. Using ETABS 2019 software, the building's modeling and analysis demonstrate that integrating FVDs at each floor level significantly reduces displacement, drift and overturning moments by 20%, 24%, and 29%, respectively, thus enhancing structural stability. Analyzing structural response in Nigeria, despite low seismic intensity, is crucial for risk management and resilience. It informs building practices, improves building codes, and prepares for potential seismic events, ensuring safer infrastructure. This research provides a computational framework for dampening vibrations in tall buildings through FVD technology.

Keywords— Fluid viscous dampers, Reinforced concrete, Seismic/Earthquake loads, Tall buildings, Wind loads.

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1 INTRODUCTION

In all human history we have reached 3.5 billion of urban settlers and in the next 30 years we are going to have 3 billion more (Lederer, 2013). So, to accommodate this large number of world's population in the urban areas, there is not enough space available on the horizontal ground. The only space to accommodate all this population is in vertical dimension (Angel, 2023). The University of Lagos is a perfect example of this. The need for land keeps rising due to the enormous population growth, which increases the responsibility of civil engineers. Earlier horizontal system of construction was in use but now a day's vertical system of construction is preferred more due to a lesser amount of ground existing. (Ali, and Moon, 2018). The trend in recent years has been to create taller, light structures, as indicated by the tall buildings that have already been built or are now being built. High-rise building structural design is frequently dictated by stiffness requirements rather than strength requirements (Lago, 2018). The influence of wind forces on the dynamics of tall building is a major factor that distinguish tall and low buildings. (Mittal *et al.*, 2014). In figure 1, in Nigeria, five major groups was categorized for design processes and economy, with the mean wind speed ranging from 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 m/s (Category IV) and 55 to 56 m/s (Category V), respectively (Onundi et al., 2009). These numbers relate to dynamic pressures in the following ranges: Category I: 941 to 1088 N/m^2; Category II: 1088 to 1283 N/m^2; Category III: 1283 to 1535 N/m^2; Category IV: 1535 to 1855N/m^2; and Category V: 1855 to 1925 N/m^2.

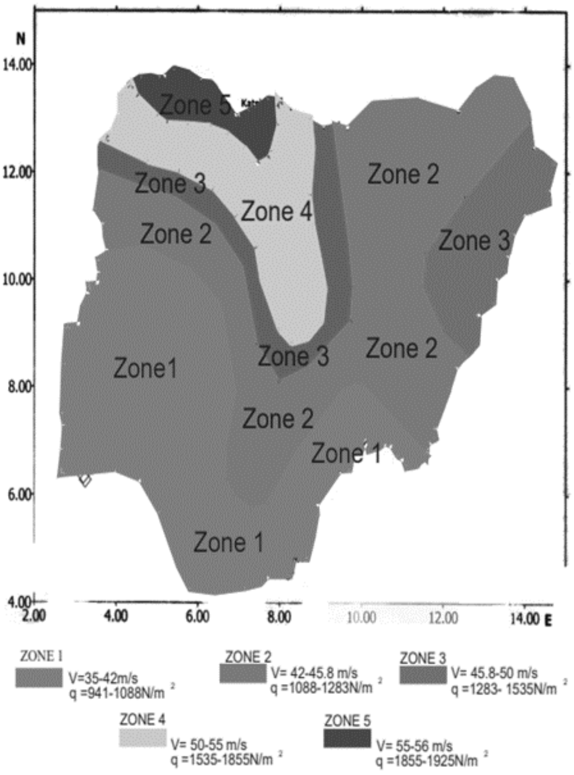

Fig. 1: Classification of Nigeria into Wind Speeds Isopleths Zones (Onundi et al., 2009).

In an area with frequent earthquakes and strong winds, tall buildings must be carefully built to attain the required balance, stiffness, and strength. A building is typically stiffened in order to decrease the dynamic response to wind loading. The seismic base shear that is attracted, however, is

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Section E-CIVIL AND ENVIRONMENTAL ENGINEERING

Can be cited as:
Giwa K.S., Oyelade A.O. (2024): Effects of Fluid Viscous Damper on Reinforced Concrete Tall Building under Lateral Loading in Lagos, Nigeria, FUOYE Journal of Engineering and Technology (FUOYE**JET), 9(1), 129-134.**
https://dx.doi.org/10.4314/fuoyejet.v9i1.20

increased as a result of this. Reducing the building's flexural stiffness to alleviate seismic base shear while simultaneously addressing wind response using structural dampers is a practical method (Longarini, et al., 2017).

Damping refer to the dissipation of energy in the response over time, involving factors like material properties and soil radiation. A thorough comprehension of damping is essential for integrating its effects into structural analysis. While damping does not alter the shape of the response curve, it diminishes the magnitudes of the response, highlighting the significance of considering damping in structural assessments (Patel and Agrawal, 2020). Dampers are categorized according to their friction, metal (flowing), viscous, viscoelastic, shape memory alloys (SMA), and mass damper performance (Makris, et al., 1994, Constantinou et al., 1993, Prabha and Mathew, 2014). The advantages of utilizing dampers include high energy absorption, ease of installation and replacement, and coordination with other structure parts (Heysami, 2015). Fluid viscous dampers (FVD), a type of dampers can be used as a strategy to increase the structure's stiffness and seismic response (Heysami, 2015).

According to the US Geological Survey, the 6.8-magnitude earthquake occurred at 11:11pm (22:11 GMT) on Friday 2023 in a hilly region 72 kilometers southwest of Marrakesh, Morrocco. The United Nations estimates that the death toll from the earthquake is approximately 2,800, and that at least 100,000 children have been affected. (Alsaafin, 2023). Following this incident, it was discovered that Africa is currently experiencing seismic activity. As a result, specialists have issued a four-year earthquake warning for Africa and the southwest of Nigeria (see figure 2). The people in the southwestern region will experience a 'damaging earthquake' in the coming years. (Adepelumi, 2016). Goki et al. (2020) studied the geological impact of September 2016 tremors in Nok and Chori villages near Kwoi. They analyzed crack patterns and intensity on structures and rocks. Results showed a significant displacement of 4 × 3 m diameter rock boulder, 1 km from Kwoi, moving 25 m and splitting in two, leaving a visible impact scar.

Oluwafemi et al. (2018) concluded that Nigeria faces the potential of encountering earthquakes with magnitudes reaching 6.0 by 2020, 6.5 between 2021 and 2022, 7.0 from 2025 to 2026, and 7.1 by 2028, with a likelihood of 36.79%. The chance of experiencing a magnitude 7.1 earthquake from 2019 to 2028 varies from 9% to 36.79%. Moreover, on the Earthquake Magnitude Scale: 5.5 to 6.0 cause slight damage, 6.1 to 6.9 may result in significant damage, 7.0 to 7.9 signifies a major event, and 8.0 or higher can devastate communities near the epicenter (Muanyana, 2021). Furthermore, despite Nigeria being classified as having low seismic activity, there exists a looming risk of a major earthquake in its southwestern region. Hence, it is imperative for the Nigerian government to prioritize earthquake preparedness and monitoring initiatives in the area to safeguard lives and property from potential seismic hazards (Oluwafemi et al., 2018). Therefore, the goal of this research is to examine the impact of wind and seismic forces on a 24-story suspended building using ETABS 2019. The study aims to simulate the structure under different conditions, analyzing its responses with and without FVDs integration. Through thorough analysis, the research seeks to assess structural resilience under dynamic loading scenarios, offering insights into potential mitigation strategies.

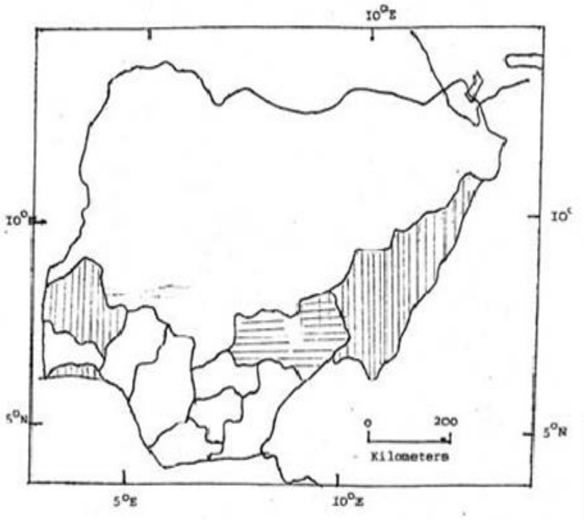

Fig. 2: Map of Nigeria areas with Seismic activity are shaded (Adepelumi, 2016).

2 METHODOLOGY

2.1 MODELLING

The 24 reinforced concrete suspended floors are modelled and the typical story height is 3 m with top elevation of 72 meters. The superimposed dead and live shell loads (on slabs) are 5 kN/m2 and 2k N/m2 respectively. The beams were subjected to homogenous frame dead loads of 10.5 kN/m. Using Eurocode 1-2005, the wind loads (wind-x and wind-y) are provided. Given that the case study's zoning region is Lagos State, the wind speed taken into account was 36 m/s (Figure 1). Additionally, using Eurocode 8-2004, the seismic loads EQ-x and EQ-y are provided in the load patterns directly. However, given that Nigeria is not located in seismically active fault zones, the evaluated seismic intensity was not severe.

Therefore, the ground acceleration (ag/g) was set at 0.15, the spectrum type was 1, the ground type was B, the soil factor (S) was 1.2, the spectrum period (Tb) was 0.15 seconds, the spectrum period (Tc) was 0.5 seconds, the spectrum period (Td) was 2 seconds, the lower bound factor was 0.2, the behavior factor was q - 2, and the correction factor was lambda was 1.

2.2 ANALYSIS

The ETABS software calculates the time frame automatically. It facilitates the automated generation of static lateral loads for seismic analysis. It is a specialized program designed for building systems, featuring an intuitive interface and comprehensive modeling, analytical, design and detailing capabilities. While suitable for simple structures, ETABS can handle complex models and nonlinear behaviors essential for performance-based design, making it the preferred tool for structural engineers.

https://dx.doi.org/10.4314/fuoyejet.v9i1.20

All of the building's slabs, beams, and columns are made out of C30/37 grade concrete and Fy 460 grade steel. These materials' elastic material qualities follow Eurocode 2-2004. For this work, after defining the link properties, FVD is added to the structure by adding a new Damper-Exponential in Link Property Data. FVD 250 (44 kg of mass 250 kN of weight) is utilized for direction U1 with fixed end attributes since it is linear. The viscous damper was produced by (Stefano et al., 2010) and installed in a three-story building structure for seismic control of the structure with additional viscous damper (see Figure 3).

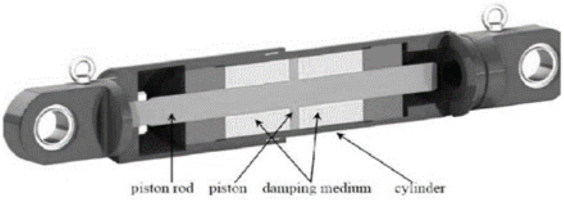

Fig. 3: Fluid Viscous Damper Cross-section. (Stefano et al., 2010).

The FVD are connected at every floor level at the corners of the building and at adjacent floor levels, respectively, as shown in Figures 4 and 5.

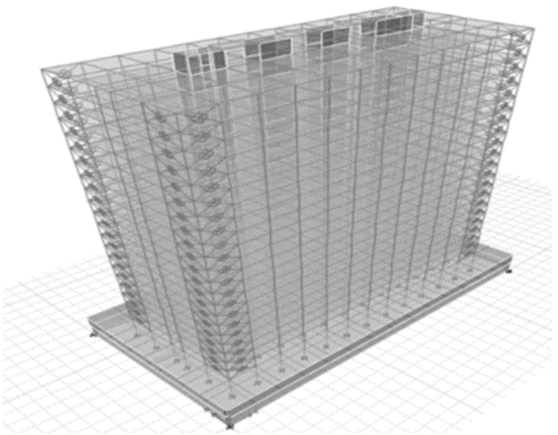

Fig. 4: Model with FVD for all storeys at Exterior Corners Isometric View.

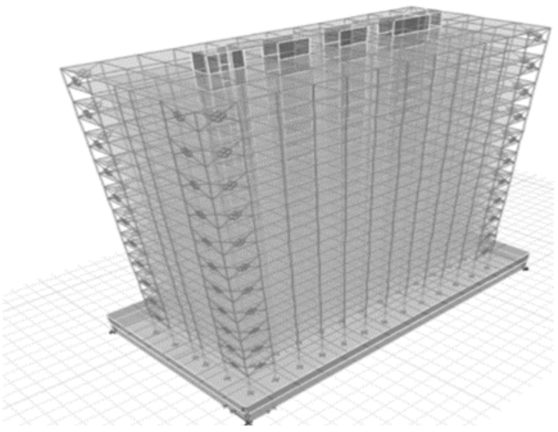

Fig. 5: Model with FVD alternate for all storeys at Exterior Corners Isometric View.

In order to compare the outcomes of models with and without FVD, Figure 6 depicts a model without FVD. Four models are considered in this present study, they are as follows: Case 1: building subjected to gravity loads only, Case 2: building subjected lateral loads (wind and seismic), Case 3: building subjected lateral loads (wind and seismic) with fluid viscous damping for all stories, Case 4: building subjected lateral loads (wind and seismic) with fluid viscous damping for alternate stories.

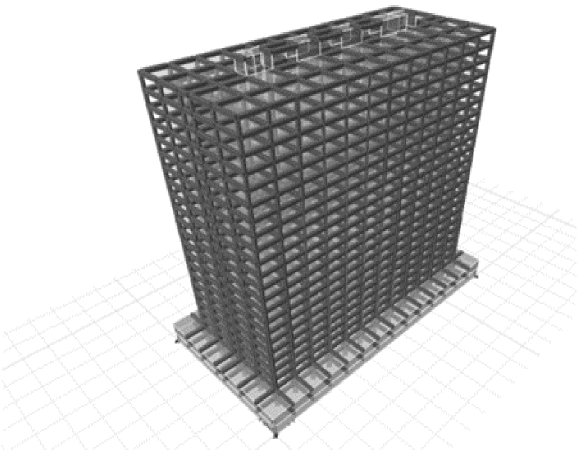

Fig. 6: Model without FVD.

3 RESULTS AND DISCUSSION

After the analysis is initiated, the output is calculated. Each load case is analyzed simultaneously by ETABS Software. The civil engineering structures are today designed with respect to the limit state of serviceability and limit states of the strength and stability. These complex problems of a different nature are possible to solve by finite element modelling (FEM) methods. A finite element analysis closely matches the real body or area. Grading the mesh makes it simple to increase the approximation.

3.1 BASE REACTIONS

The maximum projected lateral force that will result from seismic ground motion at the base of a structure is estimated as base shear. From the findings in Table 1, it is clear that the base shear when subjected to gravity and lateral loads decreased dramatically from Case 2 without FVD to Case 3 with FVD as a result of the inclusion of FVD in the model.

Table 1: Base Reactions

Case	FZ (N)	MX (kN-m)	MY (kN-m)	MZ (kN-m)
1	849	13797081	-26700024	0.00002895
2	566	10074747	-19117814	-59193.5

3	650	11934230	-20440814	-925907.5
4	610	10976118	-19180814	-7163

3.2 STORY MAXIMUM DISPLACEMENTS, DRIFTS AND OVERTURNING MOMENTS

When lateral forces are applied to all three cases (case 2, 3, and 4) along X-X and Y-Y directions with case 1 only subjected to gravity loads as shown in figures 7 (a) and (b) respectively. The maximum displacement and most critical condition in all cases (case 1, 2, 3 and 4) on both are X-X and Y-Y directions are (6.786 mm, 8.293 mm), (7.013 mm, 129.299 mm), (2.875 mm, 122.708 mm) and (3.376 mm,128.129 mm) respectively. A higher displacement value is indicated on Case 2, which has been subjected to lateral and gravity loads. As a result of the FVD's installation on all stores, case 3 models' displacement value decreased from 129.299 mm to 122.708 mm, making it a better option compared to case 4's displacement value of 128.129 mm with FVD.

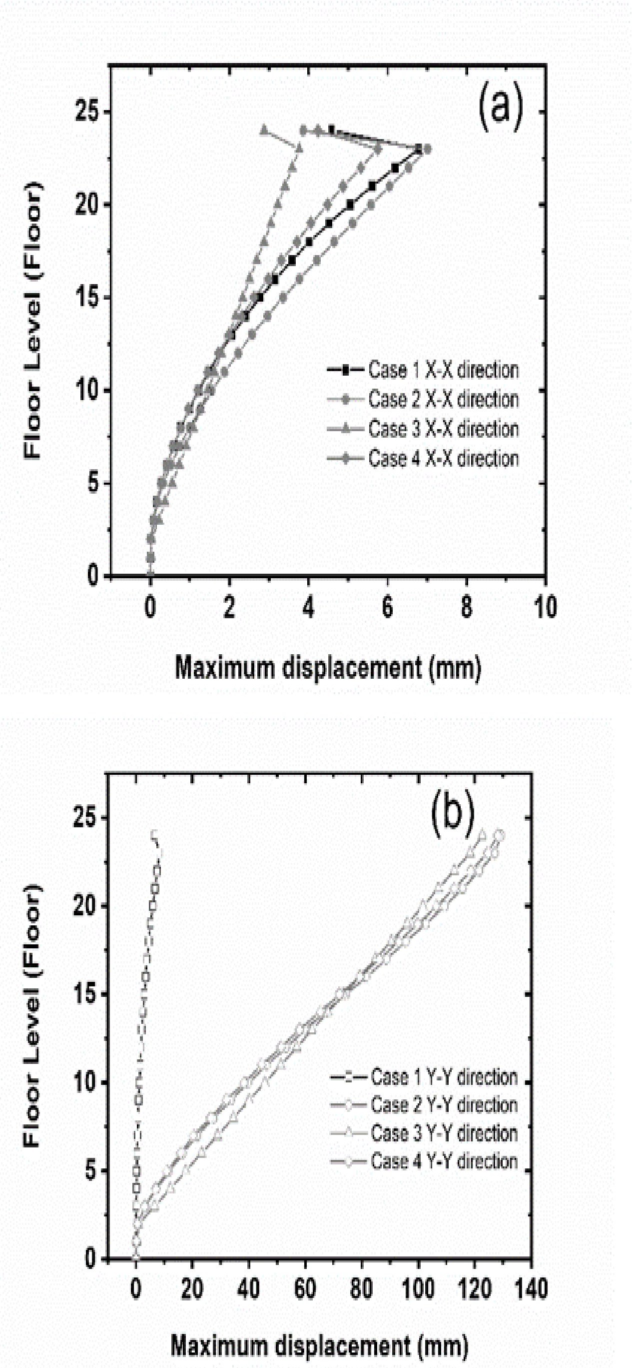

Fig. 7: Maximum displacement for all cases along (a) X-X direction and (b) Y-Y direction.

As illustrated in figures 8 (a) and (b), case 1 only experiences gravity loads when the other two examples (cases 2, 3, and 4) are all subjected to lateral loads and force along the X-X and Y-Y directions respectively. The maximum drifts and the most serious situation in each situation (cases 1, 2, 3, and 4) on both are X-X and Y-Y directions are (0.000199 mm, 0.000272 mm), (0.000161 mm, 0.002443 mm,) (0.000059 mm, 0.001864 mm) and (0.000123 mm, 0.002477 mm) respectively. A maximum drifts value is indicated on Case 2 and 4. As a result of the FVD's installation on all stores, case 3 models' drifts value decreased to 0.001864 mm, making it a better option compared to other cases.

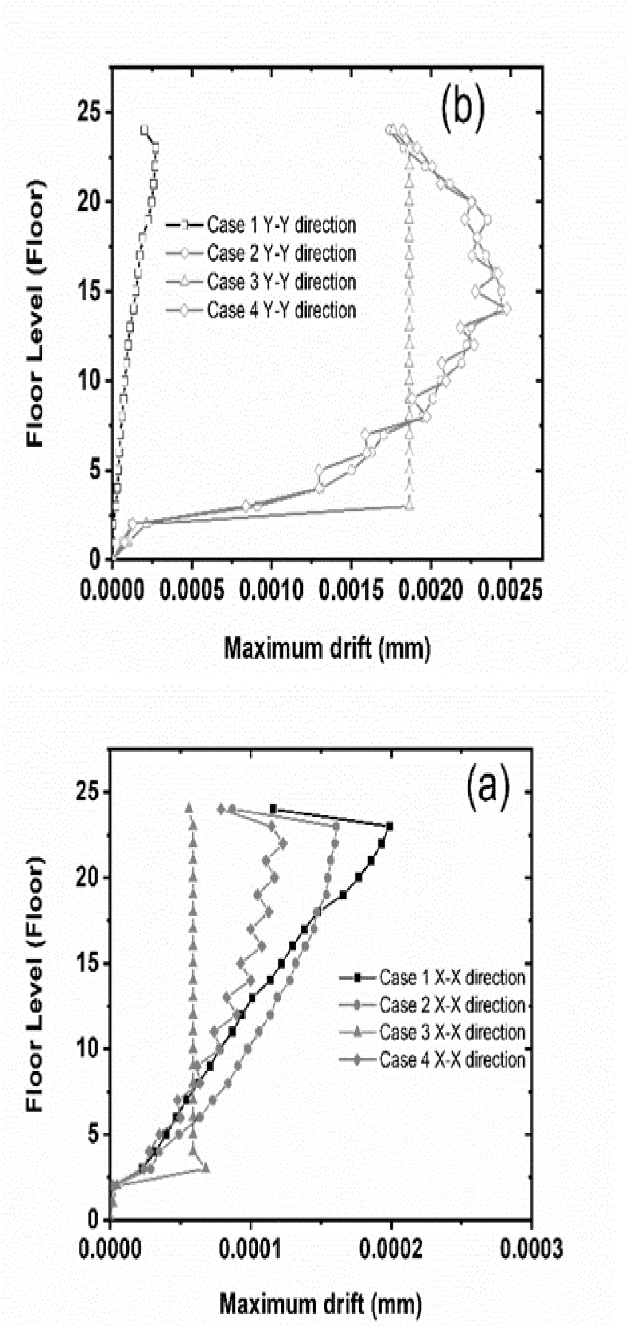

Fig. 8: Maximum drift for all cases along (a) X-X direction and (b) Y-Y direction.

Figures 9 (a) and (b) show that whereas cases 2, 3, and 4 are all exposed to lateral loads and force in the X-X and Y-Y directions, case 1 only experiences gravity loads. In cases 1, 2, 3, and 4, the maximum overturning moment and the most important factor on both are X-X and Y-Y directions are, respectively, (13797081 kNm, -26700024 kNm),(10074747 kNm,-17794814 kNm), (11934230 kNm, -20440814 kNm) and (10976118 kNm,-19180814 kNm). From the graphs it can noted that case 3 as the overall least overturning moment values compared to other cases as results of FVD been inserted at all story level of the model. The displacements, drifts, and overturning have been reduced as a result of the FVD being inserted in the structure.

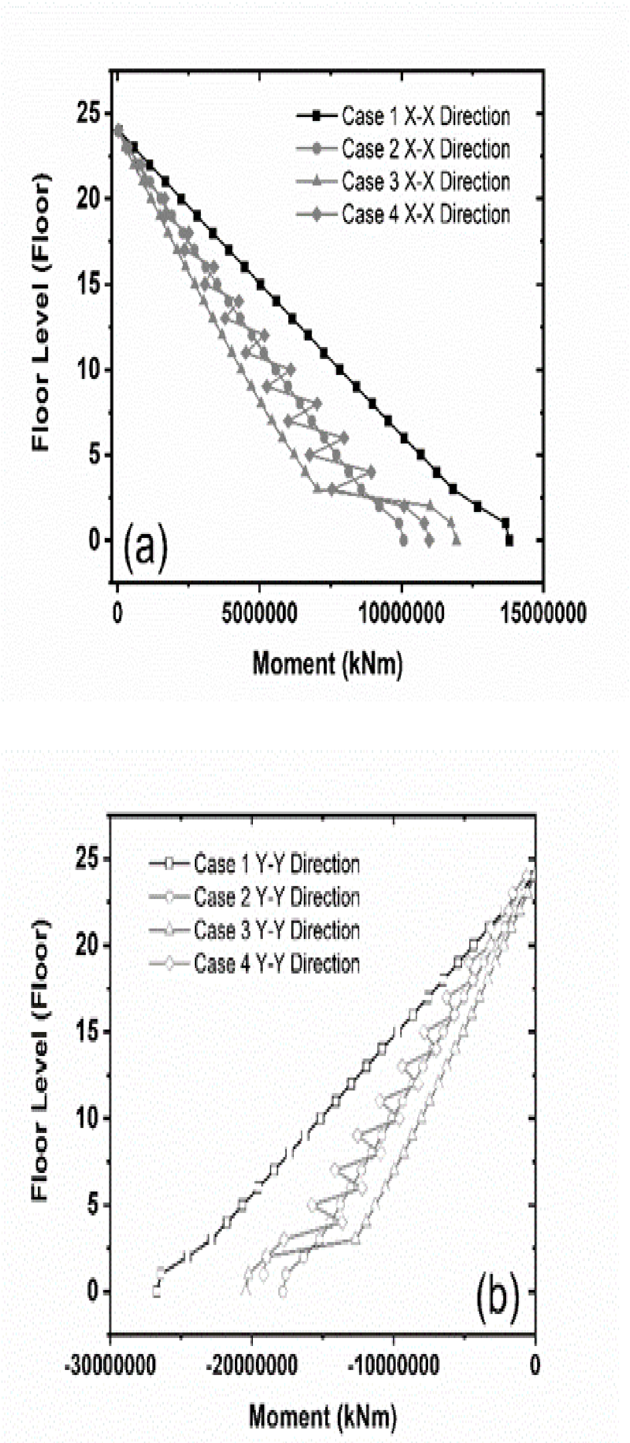

Fig. 9: Maximum moment for all cases along (a) X-X direction and (b) Y-Y direction.

4 CONCLUSION

The analysis of the impact of FVD on the lateral loads of high-rise buildings in Lagos reveals that:

- Case 2 has the maximum displacement and drifts values among the four cases taken in to consideration.
- The lateral loads from the ground floor to the fifth-floor level (at 15 m high) have no significant effect. Above the fifth-floor level, lateral loads were prominent.
- When compared to the other cases in the study,

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Case 3 has the lowest value for displacement, drift, and overturning by 20%, 24%, and 29% respectively which makes the structure more stable

- Based on the analysis, we can infer that case 3 is more appropriate and acceptable to high-rise buildings in Lagos state, Nigeria.
- Studying structural response in Nigeria, despite low seismic intensity, is crucial for risk management and resilience. It informs building practices, enhances codes, and prepares for potential seismic events, ensuring safer infrastructure.

5 RECOMMENDATION

Based on this study, it is recommended that:

- In order to reduce the impact of lateral loads, the introduction of FVD should be considered and applied to tall buildings above 15 m in Lagos, Nigeria and the applied at all floor levels.
- Regulations and rules, such as a seismic map, shape effect tables, and structural systems, should be put in place to improve the construction process of tall buildings in Lagos, Nigeria.

6 AREA FOR FURTHER RESEARCH

Further research should also look into:

- FVD500kN or higher weight can be added to the same structures, and it can also be employed in the exterior middle position.
- Determining the economic viability of implementing FVD on tall building in Lagos, Nigeria.
- The effects of FVD on steel tall structures.

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