J. Mater. Environ. Sci. 7 (3) (2016) 781-789
ISSN : 2028-2508
CODEN: JMESC

Simulated Combined Earthquake and Dead Load Lateral Resistance Building Systems using Nigeria Seismic Data

P. O. Awoyera[1*], J. F. Ogundeji[1], P. A. Aderonmu[2]
[1]*Department of Civil Engineering, Covenant University, PMB 1023, Ota, Nigeria*
[2]*Department of Architecture, Covenant University, PMB 1023, Ota, Nigeria*

Received 30 Nov 2015, Revised 05 Jan 2016, Accepted 15 Jan 2016
**Corresponding author. E-mail: paul.awoyera@covenantuniversity.edu.ng*

Abstract

This study investigated the effects of combined earthquake and dead load on a simulated lateral load resistance building systems. An eight-floor level steel building was modelled in SAP2000, and analysed using seismic information obtained from an earthquake which occurred at Abeokuta, Ogun State, Nigeria. The study was based on a selected magnitude of earthquake by considering the highest magnitude ever experienced in Nigeria which was within 4 – 4.9 (light earthquake category).The building was analysed under bracing and shear wall systems, and it was checked for a maximum deflection and inter-storey drift not exceeding 500 mm and 2% respectively. From the analysis conducted, it was inferred that eccentric bracings are better than concentric bracings in dissipating energy under seismic conditions, short link eccentric bracings provide more stiffness than long link eccentric bracings hence in order to quickly achieve the requirements of a maximum deflection of 500 mm or below and a maximum inter-storey drift of two per cent or below, short links bracings were used which require lesser number of elements compared to long link bracing thus leading to a more economical solution.

Keywords: Earthquake, Shear wall, Bracing, Inter-storey drift, Dead load, SAP2000

1. Introduction

Earthquake is a major occurrence in regions of high seismicity. It occurs often along tectonic plate boundaries (interplate) or occasionally outside the plate margins (intraplate). Over the years, diverse earthquake occurrences have been recorded in Nigeria. Osagie [1] gave a succinct account of the occurrences of earthquakes and tremors in Nigeria. The first recorded earthquake occurred in Ibadan in 1949 while the first tremor took place in Warri in 1923. There have been other occurrences thereafter. A more recent one was the event that occurred precisely on the 11th September 2009 at about 03:10:30 am in Abeokuta, Nigeria; where earthquake of magnitude 4.8 and intensity 7 was recorded; since then, it has remained a real concern in the built environment. National Space Research and Development Agency (NARSDA) researchers corroborated the incident and thereafter articulated the tremor as a sign that Nigeria is not immune from earthquake occurrence. Figure1 shows the geological map of Nigeria and coastal parts of the area. According to Akpan et al [2], the location program for the area is on epicentral latitude of 6.611° and longitude 2.433°, and a focal depth 10.0 km.

This study is not focussed on the concept of epicentre or hypocentre but rather intends to provide precautions for consideration in building construction in the study area. Approach to building construction can lessen the extent of damage in the buildings during earthquake. It starts with the choice of materials; Duggal [3] suggested structural steel, due to its large ductility and high strength-to-weight ratio as an ideal material for earthquake resistance in buildings.

Steel buildings exhibit more flexibility, but display more lateral displacement than steel reinforced concrete cement (RCC) or steel fibre-reinforced concrete buildings [4]. However, the latter behaves in a highly nonlinear manner in uniaxial compression [5]. From an engineering point of view, available structural systems options for modifying building to provide the required stability include bracing, shear walls, moment resisting connections or a combination of any two or the three options [6, 7]. Bracing systems help buildings to resist lateral forces, but they are designed to yield first in shear or bending in localised ‘seismic links’ [8]. Similarly, shear walls provides lateral resistance to a structure, having a relatively high stiffness and strength [9]. It was deduced by Dudia [10] that shear wall with an opening has increased ductility compared to solid shear wall, which in turn makes it more efficient during seismic condition. United State Geological Survey (USGS) [11] reported the Japanese concrete shear-wall apartment buildings after the 1964 magnitude 7.2 Niigata earthquake. Though the foundations of the buildings failed due to liquefaction but the structures were unaffected, and subsequently the buildings were jacked back in position. Moment resisting connections are desirable for medium and tall buildings in order to resist earthquake forces and carry vertical gravity loads.

Seismic performance of moment-resisting concrete frames subjected to earthquake excitation has been evaluated [12–14]. Most studies have shown that base shear–drift relationship produced a higher demand in incremental dynamic analysis than in pushover analysis. Among other factors, the structural layout of a building in a seismic region is of substantial importance. In line with consideration of [15, 16], uniformity in the development of the structure along the height of the building is important, since it tends to eliminate the occurrence of sensitive zones where concentrations of stress or large ductility demands might prematurely cause collapse. It has been articulated that architectural designs with typical shapes like L, T, X or H, which allow for more windows, are preferable in earthquake prone region [17]. Lorant [18] reported that plan configurations produce re-entrant corners which lead to torsion and variations in rigidity under seismic loading. Currently, almost all buildings in the study area are not designed for seismic loadings, and there is need to evaluate the safety of buildings (at a near distance) from the earthquake source. Thus, this study simulates a proposed lateral load resistance system for a combined earthquake and dead load effect on a building, using SAP2000 software, which is an integrated software for structural analysis and design. The study was based on a selected magnitude of earthquake by considering the highest magnitude ever experienced in Nigeria which is within 4 – 4.9 (light earthquake category).

It also suggested precautions and some professional-ethical practices that may prevent such occurrences during building constructions.

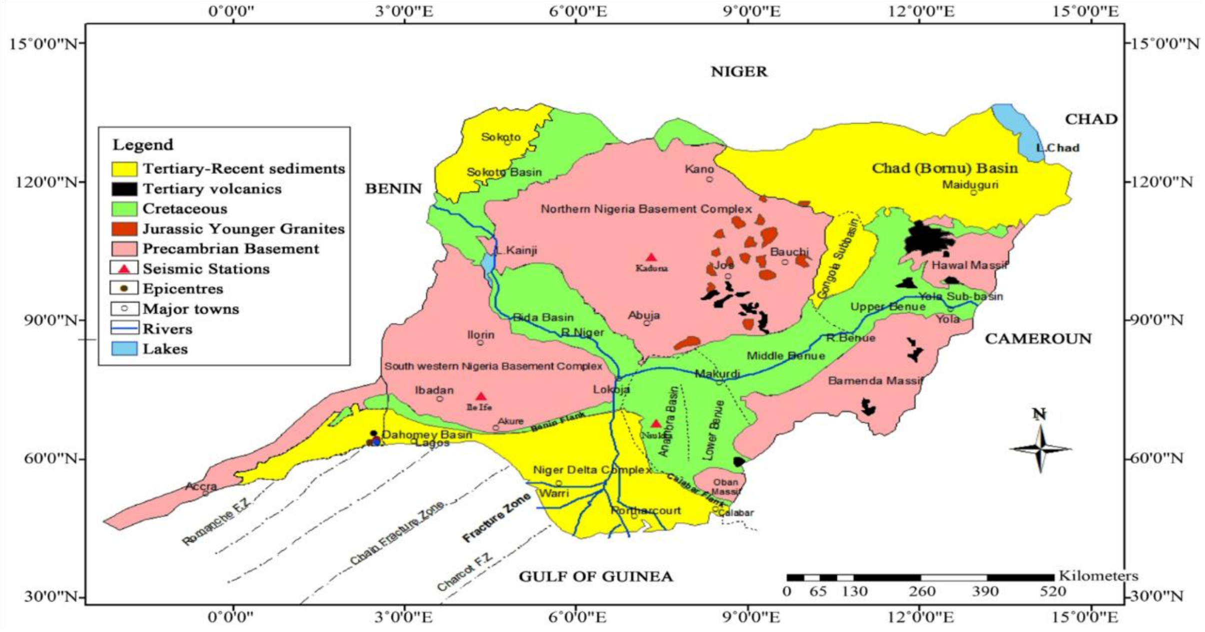


Figure 1: Geological map of Nigeria and coastal parts of the area showing the location of epicentre (west of Lagos) [19]

2. **Experimental**

A multi-storey steel frame building was modelled in SAP2000 (Figure 2), and it was subjected to a simulated combined earthquake and dead loads. Standard British steel sections were utilised for beams and columns; which is the adopted system in Nigeria, and they are pinned, such that the design is sufficient to resist the lateral wind loads. For the modelling of the building, a square hollow section brace member of size 250 x 250 x 12.5 was adopted, based on the smallest column size of 254 x 254 x 73 UC and beams of 203 x 133 x 25 UB. A 200 mm thick concrete floor slab exists at every level. The building was assumed not too close to the seismic source, however if a large magnitude event is produced at the source, then the building can be affected by the earthquake. Any high rate of seismic activity from the source also means that there is a very high tendency that the building, when completed (or during construction), will not take too long before experiencing a seismic activity. Thus a proper modification of buildings in such area, to withstand seismic activities is substantially important.

Necessary information about the building location and the soil condition at the site as obtainable at the study area are presented as follows: stiff soil with a shear wave velocity of 250 m/sec nearest seismic source is 22.5 km from the site, and the fault is capable of producing a large magnitude event and has a high rate of seismic activity.

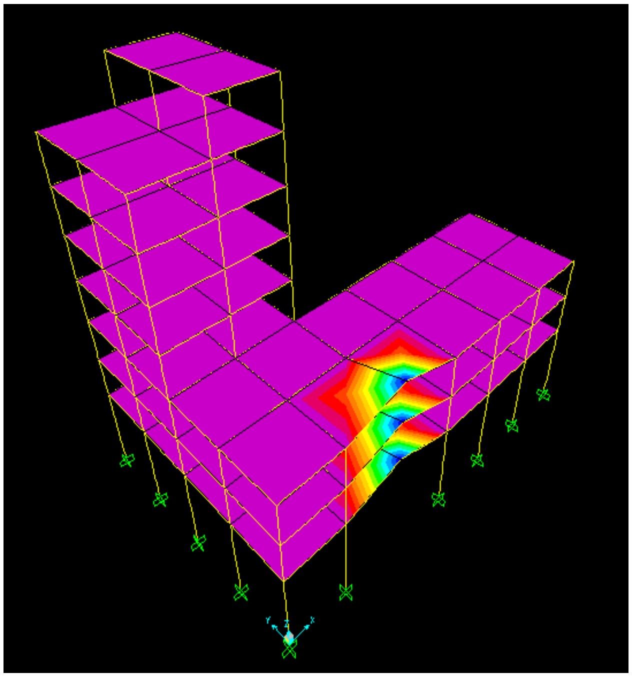


Figure 2: Model of the Building in Sap2000

The glazed part of the front elevation of the building (Fig. 2) is 12 meters wide. It is a soft spot in the building, which can easily undergo excessive deflection when there is seismic action. Hence, this part of the building requires modification (using a lateral load resisting structure); such that structural stability will be ascertained under seismic loading.

Two alternative structural solutions (brace and shear wall systems) were employed for the structure, such that a maximum roof deflection is equal to or below 500 mm and a maximum inter-storey drift is equal to or below two per cent (2%) under combined dead and seismic loading.

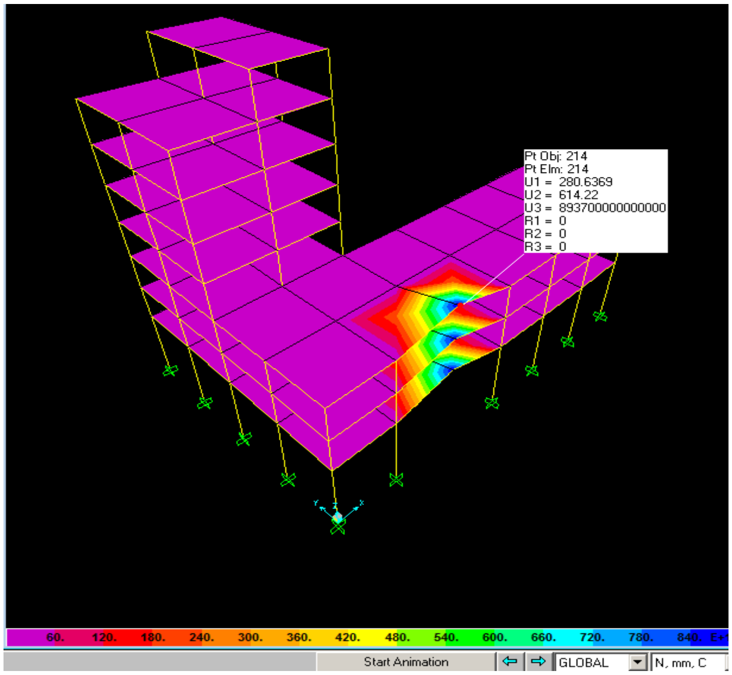
A sketch of UBC97 five percent (5%) damping elastic response spectrum was utilised to analyse the structure under both dead and seismic loads. The structure was modified consecutively until its conditions for roof deflection and inter-storey drift were achieved.

As can be seen in Fig. 2, there is no uniformity or regularity in both the elevation (height) and plan (L-shaped) of the proposed building; which is evident in the direction with the worst case. Consequently, the proposed building is at great risk in terms of structural stability as its seismic response is very poor. Moreover, the high irregularity in height means that there will be excessive sideways movement of the upper roof which is quite dangerous for nearby buildings. An economical structural modification (solution) of the building based on experience, expertise and research is therefore very necessary to ensure adequate structural stability, as well as satisfying the maximum 500 mm deflection and maximum two per cent inter-storey drift requirements. A fixed footing was selected for the building, so as to minimise the displacements at the supports (Figure 2). Such footing could be achieved in a Nigeria situation through the use of high strength insitu pocket foundation, where the columns are to be grouted.

3. **Results and discussion**

3.1. *Bracing System*

In order to reduce large displacements, the large open span and top part of the building were braced. An economical bracing was ascertained by placing bracings at only top part and open space of the structure; such that the minimum number of bracings that gave a deflection below 500 mm was achieved (Figure 3). Also, small torsional effect was induced at the right end (from plan or front elevation view) of the building as it had a displacement of over 500 mm. This could be attributed to the irregularity in the geometry. The resulting torsional behaviour was addressed by bracing some side bays on the right, the building was analysed until an overall maximum deflection below 500 mm was achieved.



```
Pt Obj: 214
Pt Elm: 214
U1 =  280.6369
U2 =  614.22
U3 =  893700000000000
R1 =  0
R2 =  0
R3 =  0
```

Figure 3: Displacement of the Structure using a fixed footing

As it can be seen on the bottom bar of the result window (Figure 3), the maximum deflection points/areas are shown in very deep blue colour and the minimum deflection points/areas are displayed in deep purple colour. Other colours are for intermediate deflections. The bottom bar is also calibrated on a scale of relative deflections on the structure analysed. Thus, the deep blue coloured points/areas are of interest and the most important. Figure 4 shows the lateral deflections at different levels of the building; Figures 5 and 6 present respectively the displacement result of the modified building using short link bracing and fixed bases, and a deformed shape view of the building with bracing systems after analysis.

Alternatively, an economical solution might have been obtained by bracing only the bays that moved beyond 500 mm in the model until all the critical bays were braced so that bracings are positioned in a scattered way. Such steps were however not taken because in seismic design, if any bay has to be braced, then all the bays in that vertical section of the building have to be braced in order to avoid what is known as discontinuity in stiffness along the height of the building. Bachmann [20] inferred that any modifications in the cross section of bracing systems over the height of a building or change in lateral resistance system along the height of a building leads to sudden variations in the stiffness and resistance of the building. This principle, Forth [21] also referred to it as in-plane discontinuity in nodes.

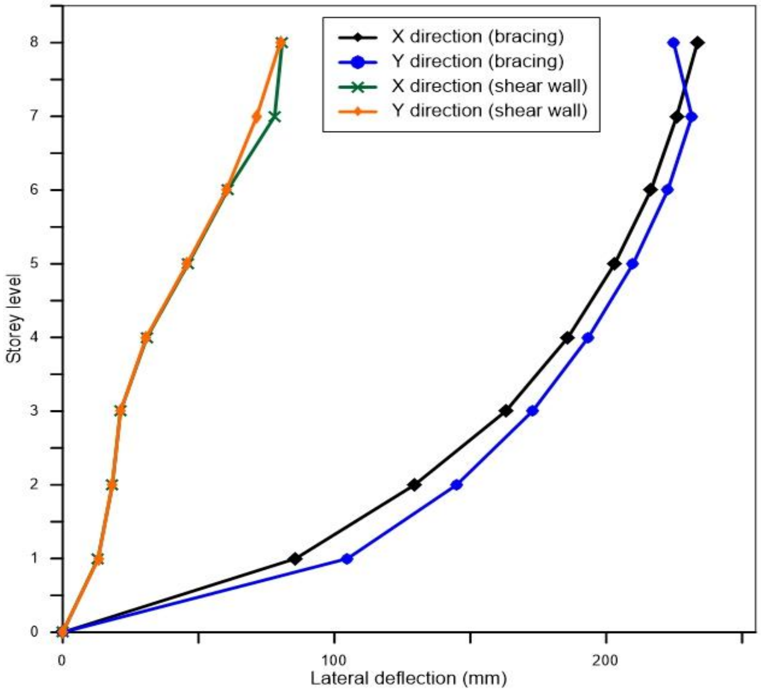
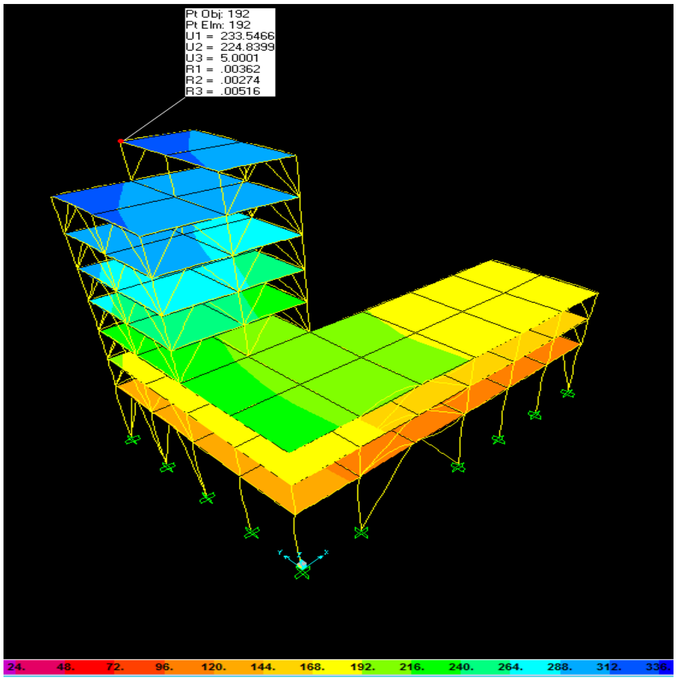


Figure 4: Lateral deflections at different storey levels



```
Pt Obj: 192
Pt Elm: 192
U1 =  233.5466
U2 =  224.8399
U3 =  5.0001
R1 =  .00362
R2 =  .00274
R3 =  .00516
```

Figure 5: The displacement result of the modified building using short link bracing and fixed bases

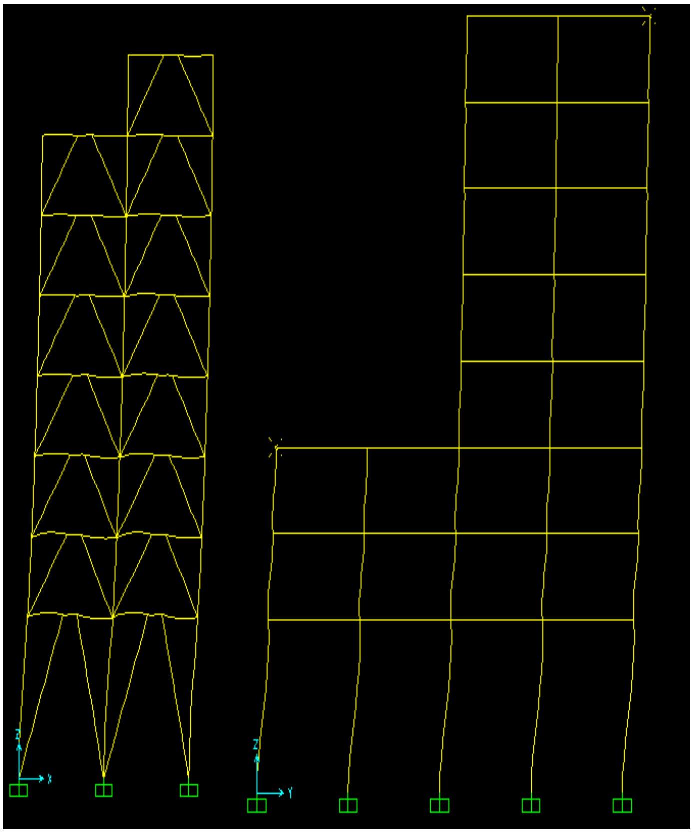


Figure 6: Deformed shape view of the building with bracing systems after analysis

3.2. *Shear Walls and Short Link Inverted V Bracing*

The shear walls were only used in the tall part of the building and in order not to block a large portion of possible view through the glazing, the short link inverted V-bracings were employed for the open space in front of the building**.** Connection between the shear wall and foundation is fixed thus the base in the model was fixed. Thus, in order to ensure uniform response of the building to seismic actions, the whole bases were fixed.

The right side that moved (with over 500 mm displacement) under bracing system as a result of torsion from modifying the tall part of the building initially did not need to be modified (braced) as displacement there was less than 500 mm. This was an indication that there is much higher stiffness in shear walls than in steel bracings.

The high stiffness of the concrete shear wall meant that a reduced number of bays needed to be provided with shear walls compared to the number of bays that had to be braced in the bracing systems. Despite this, a lesser maximum deflection value was still obtained compared to bracing. The inter-storey drifts were calculated and the maximum exceeded the required two per cent maximum. This led to adding the short link inverted V-bracings to the right side that moved (with over 500 mm displacement) due to torsion from modifying the tall part. Consequently, the addition of the short link inverted, V-bracings reduce the maximum inter-storey drift below two percent (as shown in Fig. 7). On the right side that moved, a minimum number of three vertical bays needed to be braced and since short link inverted V-bracings achieve the result with these minimum three bays, it was considered more economical to use them there rather than using shear walls there.

The deflections values of each floor along the point of maximum deflection at the topmost roof of the building are presented in Figure 4. Since the deflection on the right side of the third floor was a lot higher than the deflection on the third floor area along the maximum point of deflection (which is close to the centre). Figures 8 and 9 show the displacement of the long span beam of the modified building using combined shear wall and short link inverted V-bracings, and deformed shape view of the building with shear wall after analysis respectively.

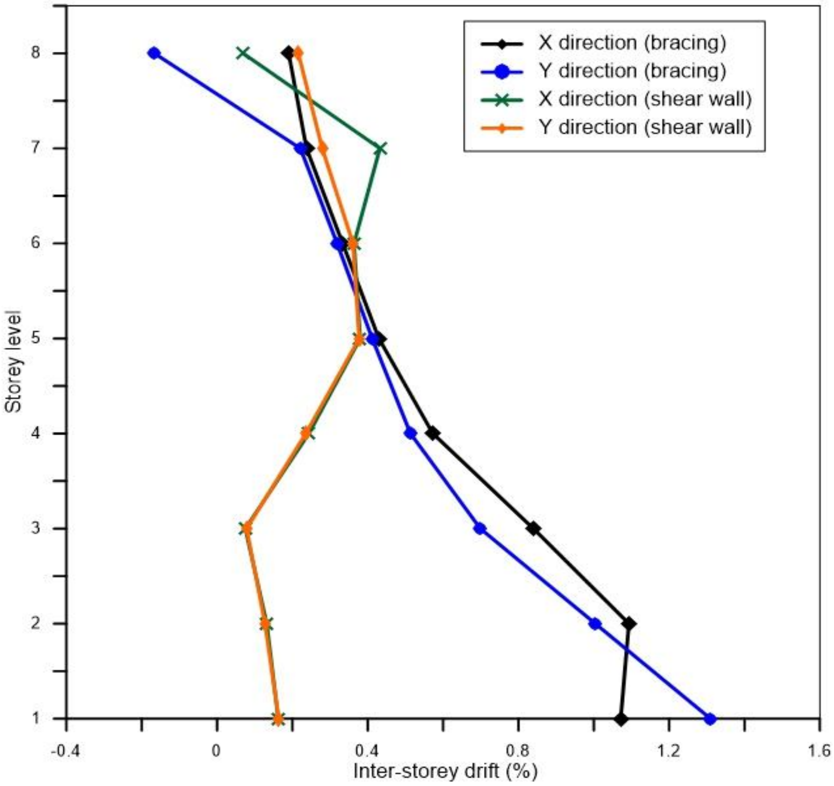


Figure 7: Inter-storey drift at different storey levels

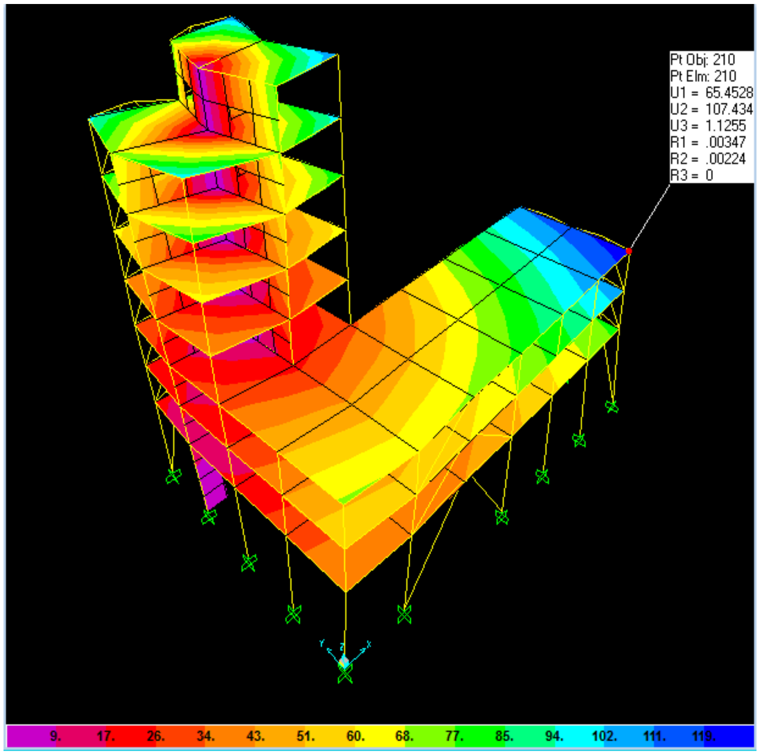


Figure 8: The displacement result of the long span beam of the modified building using combined shear wall and short link inverted V-bracings

Figure 9: Deformed shape view of the building with shear wall after analysis

Conclusions

The following conclusions were drawn from the modifications of the building:

i. Moment connections possess lots of disadvantages when it comes to seismic design, moreover, since the total roof deflection has been set to 500 mm, the structure has been optimized to about 16% of the maximum deflection limit that was set for the structure.
ii. Eccentric bracings are better than concentric bracings in dissipating energy under seismic conditions, short link eccentric bracings provide more stiffness than long link eccentric bracings hence in order to quickly achieve the requirements of a maximum deflection of 500mm or below and a maximum inter-storey drift of two per cent or below, short links bracings were used which require lesser number of elements compared to long link bracing thus leading to a more economical solution.
iii. Shear walls have very high stiffness compared to other lateral load resisting systems, a fact which corroborated the findings of Arum and Akinloye [22].
iv. Steel shear walls are more ductile than concrete shear walls but possess many uncertainties; however concrete shear walls' ductility can be improved by creating openings in them.
v. Solution alternative two was achieved by combining concrete shear walls with wide door openings and short link eccentric bracings for the structure.

Acknowledgments - The authors hereby appreciate the Computers & Structures, Inc. for supplying the SAP2000 software used for this investigation.

References

1. Osagie E.O., *Pacific J. Sci. Technol*. 9 (2008) 546 – 551.
2. Akpan O.U., Isogun, M.A., Yakubu, T.A., Adepelumi, A.A., Okereke, C.S., Oniku, A.S., Oden M.I., *Open J. Geology* 4 (2014) 542-550.
3. Duggal S.K., *Technol. Eng*., 448 (2007).
4. Awoyera P.O., Ijalana G.K., Babalola O.E., *J. Mater. Environ. Sci*. 6 (2015) 3634 – 3642.
5. Awoyera P.O., J. Eng. Sci. Technol. (in press)
6. Ricles J., Sause R., Peng S., Lu L., *J. Struct. Eng*. 128 (2002) 850–859.
7. Christopoulos C., Filiatrault A., Uang C., Folz B., *J. struct. Eng*. 128 (2002) 1111–1120.
8. ArcelorMittalTechnical Brochure. Luxembourg: ArcelorMittal
9. Sabouri J., Ziyaeifar M., *Asian J. civ. Eng*. (building and housing) 10 (2009) 593-609.
10. DudiaC., Struct. Engineering digest Oct-Dec 2010/11.
11. US Geological Survey.Geological Survey Circular (2000) 1193.
12. Habibi A.R., Izadpanah M., *Scientia Iranica* 19 (2012) 234–241.
13. Habibi A.R.,Asadi K., *Inter. J. Civ. Eng*. 12 (2013) 41 – 54.
14. Nazri F.M., Yan P.S., *J. Eng. Sci. Technol*. 9 (2014) 717 – 727.
15. BS EN1998-1:2004: Eurocode 8: British Standards Institute, London.
16. Uniform Building Code. Whittier, CA (1997)
17. Guevara L.T., Alonso J.L. Fortoul E., *Earthquake Eng*., (1992).
18. Lorant G., http://www.wbdg.org/design/seismic_design.php, [Accessed 26 June 2015].
19. Obaje N. G., Springer-Verlag, Berlin (2009).
20. Bachmann H., Biel: BWG (2003).
21. Forth J., University of Leeds, 15 March (2011).
22. Arum C. Akinloye A., *Eng*. 3 (2011) 236-247.

(2016) ; http://www.jmaterenvironsci.com/