RESEARCH ARTICLE OPEN ACCESS

Assessment of Residential Building Safety in Makurdi Metropolis Against Earth Tremor using Drain 2DX Software

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Abstract:

This project assesses the safety of residential buildings in Makurdimetropolis against ground tremors. Non-destructive strength tests were carried out on structural elements of six selected residential buildings in six areas of the metropolis to obtain strength values.These values were used as data source to prepare appropriate structural models tested under simulated earth tremors using drain 2dx software. The buildings were model as equivalent reinforced concrete frames designed according to the requirements of Eurocode 8. The result of the analysis shows that for conventional structural analysis and design, the materials are truly elastic to the magnitude of applied static forces since the elastic limit of the structural elements are not exceeded. However, for a dynamic load such as earthquake ground vibration, the response of the structure imposes excessive force on the material and the elastic limit is exceeded. It therefore becomes necessary to consider and appropriately idealize this post elastic behavior.

Keywords **— Buildings, Eurocode 8, Earth tremors, Drain 2DX, Earthquake**

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1.0 Introduction

Most structures especially residential buildings in Nigeria are vulnerable to the threatening desolation resulting from earth tremors.Earth tremoris an element of earthquake and has been a major phenomenon experienced in most part of Nigeria (Ebele, 2017). Though, no record in the history of Nigeria can show the occurrences of earthquakes, it is not a new phenomenon in the history of the world. The holy scripture established the validity of the latter statement by revealingthe existence of earthquakes which was dated back to the Old Testament where prophet Isaiah prophesied of the coming of the Lord unto his people in Isaiah chapter twenty nine and verse six states '*Thou shalt be visited of the Lord of Hosts with…earthquake'*. Also, in the gospel of Saint Matthew chapter twenty four and verse seven reiterates that *'…there shall be*

…earthquakes, in divers places'. Over the years, all these prophesy have been fulfilled in diverplaces of the world especially the in Asia which is the most susceptible areas.

In recent times, seismologists in Nigeria after studying from history the trend of earthquake occurrences in various part of the world have predicted that, there is real possibility of an earthquake occurring within the shores of Nigeria. Although, Abolarin and Adedeji(2016) in an attempt to weigh the possibility of earthquake occurrence in Nigeria, described Nigeria as geologically located in a stable Pre-Cambrain–Paleozoic era basement terrain asserted the country to be seismically safe. However, following, the series of earth tremors (minor earthquakes) occurrences in different parts of the country, an overview of these events would leave no other explanation than to question the previous believe that Nigeria is seismically safe (Ebele, 2017).Udo*et al.* (2016)in his study on '*Earthquake threat'* therefore strongly affirmed that, Nigeria is no longer aseismic as Figure 1 shows locations where earth tremor has occurred in Nigeria.In fact, from recent records of earth tremors in 1933, 1939, 1964, 1984, 1990, 1994, 1997, 2000 and 2009 in the country, there are indications that Nigeria may soon be faced with devastating earthquakes.

Despite considerable efforts in studying earthquake occurrences, the magnitude of loss of life and property during such events are still difficultto measure prior to its occurrence(Narasimha*et al.,* 2014), but there are opportunities to advance knowledge by studying what extent of properties especially buildings and structuresthat can be secured during occurrence.Therefore, as the tendency of earthquakes/tremors in Nigeria rises, seismic activities within the country will increase, response measures must be developed through adequate earthquake structural engineeringresearch;this will enhance the safety of buildings and structures, thus reducing injuries, loss of life, property damage, and the interruption of economic and social activities. Mustapha (2015) and Ebele (2017) both advocate that measurebe taken to plan towards such eventualities by providing structures engineered for earthquake resistance. This paper therefore aims at assessing residential buildings safety in Makurdi metropolis against ground tremor. This shall be achieved through non-destructive strength tests on structural elements of residential buildings and preparation of appropriate structural models under simulated earth tremors using DRAIN 2DX.

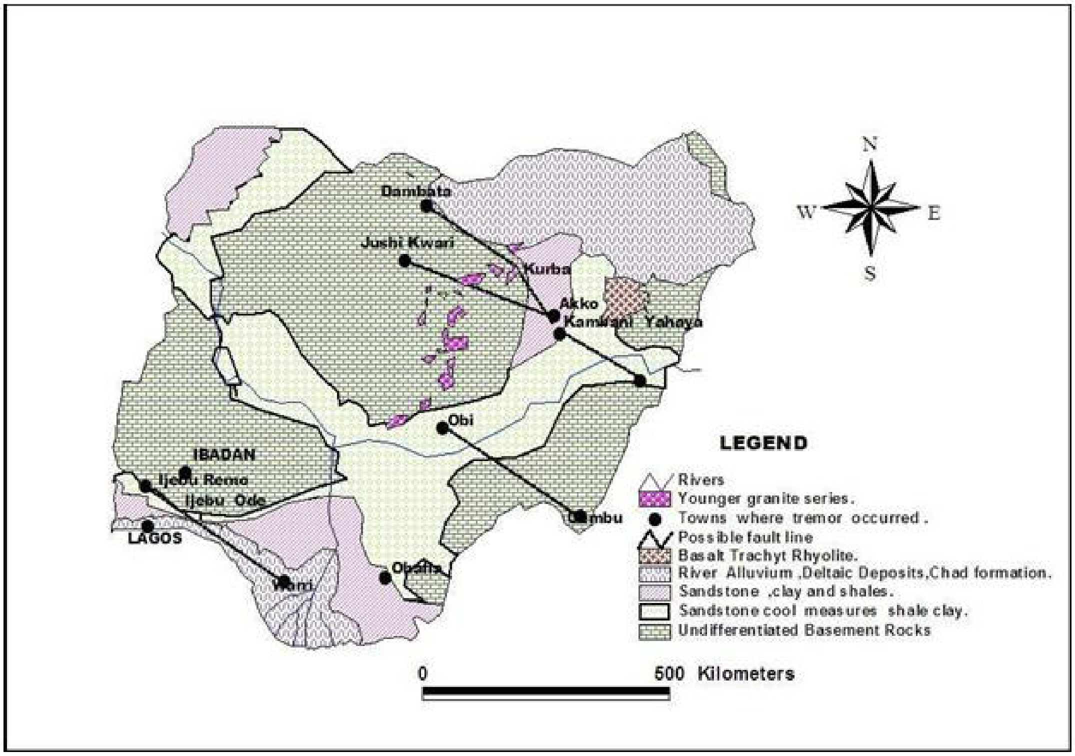

Figure 1: Map of Nigeria Showing Locations of Earth Tremor Occurrence between 2001 and 2009 (Source: Sunday and Eze, 2010).

2.0 Brief Description of the Area

Makurdi is the capital city of Benue State in Nigeria. The city is located in the Middle Belt along the Benue River. It lies between Latitude 7°43'50"N and Longitude 8°32'10"E.Established about 1927 when the railroad from Port Harcourt was extended to Jos and Kaduna, Makurdi rapidly developed into a transportation and market centre. In 1976, following the division of Benue-Plateau state into two states, Makurdi was selected as the capital of Benue State.Makurdi is located on the main highway network and has an airport. It is now a major transshipment point for cattle from Nigeria's northern states. From June to November, when the Niger River has high water, Makurdi serves as a port from which goods, including locally grown sesame seeds and cotton, are shipped to Lokoja and to the Niger River delta ports. The town is a local trade centre for the yams, sorghum, millet, rice, cassava, shea nuts, sesame oil, peanuts (groundnuts), soybeans, and cotton raised by the Tiv, Idoma, and Igede people of the surrounding area. It is also the site of a boatyard that builds medium-size rivercraft. In the late 1970s an oil pipeline was built from the refinery near Port Harcourt to Makurdi. There are extensive limestone and marble deposits in the area around Makurdi, and a cement plant has opened at Yandev, southeast of the town.Figure 2 shows the map depicting the studies areas in Makurdi Metropolis.

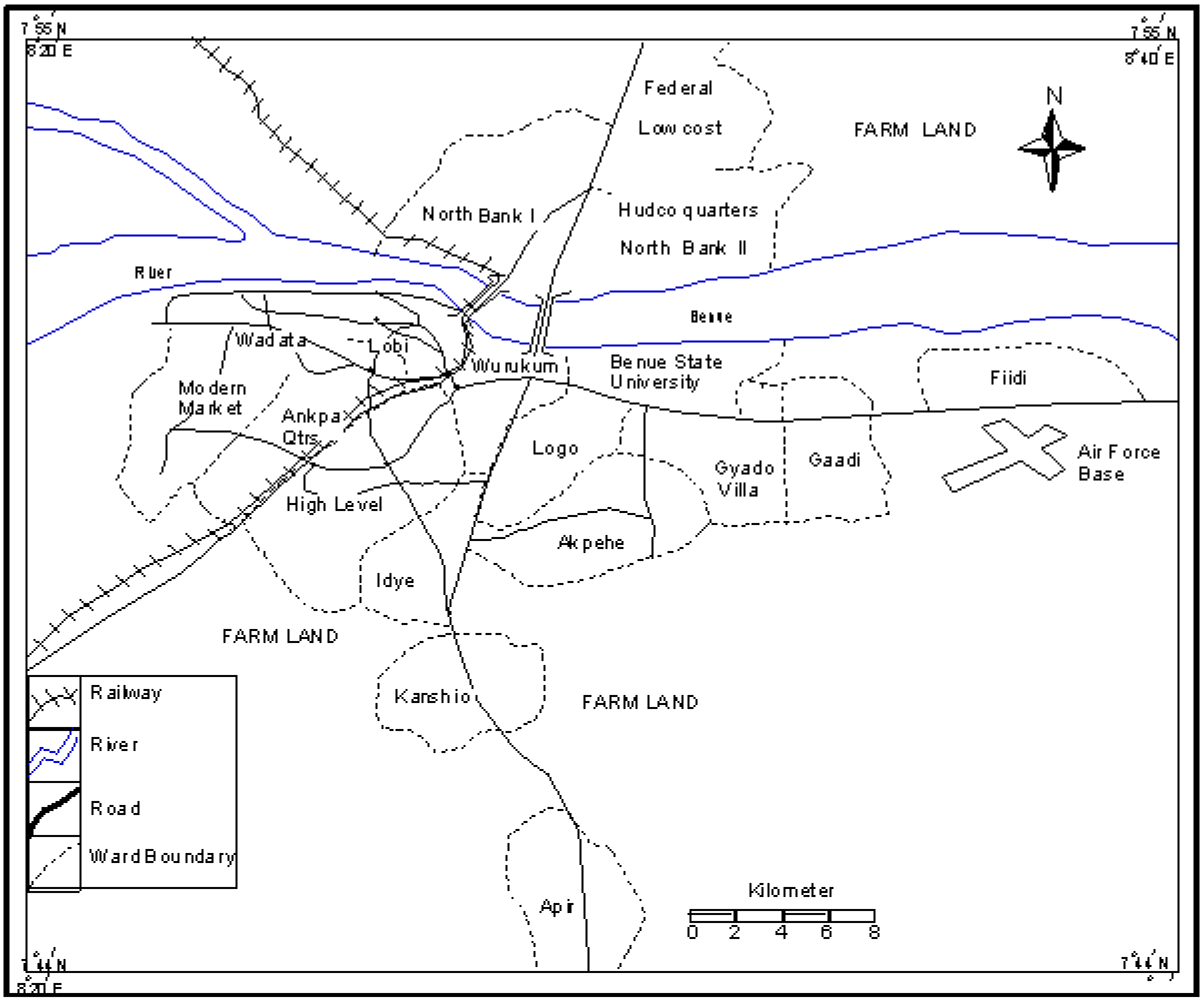

Figure 2: Map of Makurdi Metropolis in Benue State

3.0 Materials and Methods

For appropriate data collection in the study area, some group of buildings was selected for static and dynamic analysis of plane structures. Non-destructive data were collected by means of rebound hammer apparatusto determine the structural stability of the existing residential buildings at different locations. The data collected from the non-destructive test (Schmidt hammer test) was used in linear and nonlinear static and dynamic analyses which were then finally performed with DRAIN-2DX software package (computer program for static and dynamic analysis of plane structures).

The areas in the study area are classified into low, medium and high density based on the level of population and degree of urbanization (Table 1). For the non-destructive test measurement carried out in the study area, the selected groups of buildings include framed structures, bungalow, local built huts and wooden shades(Table 2).

Table 1: Area selected with their population densities

S/No	Location/Area	Population Density
1	UAM staff Quarters	Low
2	Judges Quarters	Low
3	Welfare Quarters	Medium
4	Federal Low-cost Estate	Medium
5	Wurukum Area	High
6	Wadata Area	High

Table 2: Group of buildings in Makurdi metropolis

S/No	Location/Area	A Framed structures	B Bungalows	C Huts	D Wooden shades
1	UAM staff Quarters	5	5	2	0
2	Judges Quarters	5	5	1	0
3	Welfare Quarters	3	5	2	2
5	Federal Low-cost Estate	3	5	3	4
5	Wurukum Area	2	4	5	5
6	Wadata Area	1	3	5	5

Non-Destructive Test

A study of concrete buildings over time has shown that they are susceptible to deterioration. Moreover, the effects of poor construction, environmental effects, and sudden damages resulting from natural disasters like earthquake, earth tremor, etc. all constitute a need for examination of existing structures. In addition, the need to adapt an existing structure for a different use requires adequate certainty and assurance that the structure in its present state will be able to function effectively without any threat to its stability and serviceability. However, testing of these structures has to be engaged in with care, considering that the structural integrity of the building should not be compromised. This is why non-destructive testing offers a viable alternative for the assessment of existing structures.Non-destructive test was carried out on the structural members of all the groups of structures.The average strength of the wall, columns and beams obtained were analyzed using Drain 2DX.

Drain-2dx Software Application

DRAIN-2DX was used to carry out linear response spectrum analyses and to compute mode shapes and periods of vibration.The buildings weremodeled as equivalent reinforced concrete frames designed according to the requirements of Eurocode 8. The Eurocode-8 method is used to analyze and design the structural system using elastic linear analysis for a reduced seismic force (design response spectrum). This implies that the structure will undergo post-elastic deformation when hit by the actual ground motion. The non-linear deformation of the structure is accounted for by this behaviour factor q, defined in the design code. The behaviour factor is often referred to as the q-factor and it is given by;

$$q = q_o k_w \quad (1)$$

Where:

q is the behaviour factor,

$q_o$is the basic value of the behaviour factor and

k_w is a factor that describes the predominating mode of failure of structural systems with walls.

Drain-2dX uses an input text file (*drain.inp*) which requires that the structure be discretized into elements joined at nodes with nodes and elements appropriately numbered (Allahabadi and Powell, 1988; Prakash*et al.,* 1993). For the purpose of consistency of units, quantities were defined in kilo-Newton and centimeters. Usually, at the start of design, a number of different element cross-sections commensurate with load demands are proposed to be used for robust and economic design. However for the purpose of simplicity, a single cross-section was defined for the column group and another cross-section for the beam group with their respective geometric properties included. Properties calculated and needed as inputs included, cross-sectional areas, moment of inertia and shear area of the elements. The elements were linked to the nodes and the respective properties of the elements were defined in the *drain.inp*file. Gravity loads were determined and converted to nodal loads to be used in gravity analysis. The loads at the nodes were then converted into nodal masses by dividing the load at each node by acceleration due to gravity of 981cm/s^2. While the nodal loads are required for gravity analysis, the nodal masses are used by the program for dynamic analysis. The loads and the masses were then assigned to the nodes in the file *drain.inp.* A design spectrum was generated with the aid of a matlab script. The inputs includes a file with T-S_d values, where T is the period in seconds and $S_d$is the corresponding design spectrum amplitude given as a proportion of *g*. All building categories were designed for medium ductility class according to the provisions of EN1998-1:2004. EN1998-1:2004 set limits to damage limitation for two classes of buildings. For buildings without non-structural elements or with non-structural elements attached to the structure in ways that prevents interference with the structural deformations;

$$d_r y \leq h/100; \quad (2)$$

Where;

$d_r$is the design interstorey drift,

h is the storey height and;

v is the reduction factor which takes into account the lower return period of the 'service level earthquake'.

As seismic ground motion moves in a back and forth manner, it is thus appropriate to represent the seismicdemands under two cases; Case 1 for left-to-rightaction, and Case 2 for right-to-left action.The adequate reinforcement areas were provided for the beam and column elements as required by the provisions of Eurocode 8. The reinforcement areas were automatically calculated by the SECT.EXE file of the software. After this, the capacities of the respective element groups were fed into the "drain-inp" file as the resistances of the beams and columns. Non-linear time-history dynamic analysis was then executed by subjecting the frame to the earthquake excitation. The non-linear response of the buildings were then assessed in terms of inter storey drift (where applicable) and plastic bridge formation.

4.0 Results and Discussion

The periods and effective modal masses of the frame modelare shown in Table 3. The period of vibration implies that the structure is pushed to the left side of the earthquake spectrum. The more to the left side of the spectrum the structure's period is pushed, the more the acceleration of the structure and consequently an increase of the force demand during excitation by the reference earthquake. This implies more structural damage.The respective periods and effective modal masses of the first 4modes of vibration of the Category A frame is also revealed in Table 3. The high effective modal mass in the first mode of vibration implies that the structure's ductility is poor.

Table 3:Periods and Effective Modal Masses of the First Four Modes of Vibration

Category A	**Mode**			
	1	2	3	4
Period	0.4803	0.3002	0.2010	0.1903
Effective modal mass (%)	98.10	1.79	0.09	0.02

A summary of inter-storey drifts and overall roof drifts is presented in Table 4. A recommended value of 0.5 is given for buildings of important classes I and II. The National Earthquake Hazards Reduction Programme (NEHRP) defines an allowable maximum roof drift for its own defined Group II building as 1.5%H Where H is the overall height of the building (NEHRP FEMA 450:Part 1, 2003). Referring to Table (discretized frame), the total height of the control frame is 12m. This implies an NEHRP recommendation of 18cm maximum roof drift for the category 'A' buildings. These values are greater than the roof drifts specification. To minimize this drift, the stiffness can be mobilized by either increasing the column cross-sections or applying braces to the frame, whichever is most economical.

Table 4: Summary of Storey drifts and inter-storey drifts of the different categories of building

Structural System	**Floor**	**Input Node on Drain 2DX**	**Interstoreydrift(cm)**	**Damage limitation Requirement $d_r \leq h/100$**
A (reinforced Concrete Multi-storey)	Foundation	1010	0.00	Damage limitation exceeded at all floors
	Ground floor	2010	7.73	
	First floor	3010	6.56	
	Second floor	4010	6.34	

	Overall drift at roof		20.63	
B (Small 2 room houses)	Foundation	1010	0.00	Ok
	Roof	2010	10.56	
C (Bungalows)	Foundation	1010	0.00	Ok
	Roof	2010	12.98	
D (Duplex)	Foundation	1010	0.00	Ok
	Roof	2010	11.89	
E(Huts)	Foundation	1010	0.00	Ok
	Roof	2010	9.20	

From the Table 4, category A reflects that the structure is not safe against the earthquake as the damage limitation exceeded at all floors. Though, it seem that the only structure not safe against the earthquake is Category A buildings. That in fact, may not be true since the Schmidt hammer concrete strength for category B and E elements almost gives zero which implies that the slightest drifts would lead to the collapse of such buildings. The building categories studied showed poor seismic response due to a lack of continuity in the structural elements. Even where continuity was established as for framed structures, the connections at the joints were not strong enough to resist the cyclic loads caused by the excitation of the building foundation. The principle of seismicity however, requires that buildings should possess clearly defined load paths for the transmission of seismic forces incident on the structure. Other factors that contribute to the poor seismic behavior of the structure include lack of symmetry of the structure, low redundancy and poor concrete strength and inadequate reinforcement detailing.As regarding damages in structure, only category A shows plastic hinges on all column-beam joints, all the other categories of buildings collapsed. This was as the result of poor quality control in the erection of these buildings and weak-brittle materials used in construction. These observations are similar to the work of Sathiparan and Kimiro (2014).

5.0 Conclusion

From the study, it was observed that for conventional structural analysis and design, the materials are truly elastic to the magnitude of applied static forces. In other words, the elastic limits of the structural elements are not exceeded. However for a dynamic load such as earthquake ground vibration, the response of the structure imposes excessive force on the material and the elastic limit is exceeded. Some factors responsible for poor seismic response of the building categories studied include:

(i) Possessing clearly defined load paths for transmitting seismic forces incident on the structure. One benefit of this is that structural response can easily be predicted. The buildings studied lack continuity in the various elements. Even when continuity is established as for framed structures, the connections at the joints are not strong enough to resist the cyclic load caused by the excitation from the buildings foundation.

(ii) Symmetricity of the buildings. A structure which is symmetric in both geometry and lateral resistance performs better than one which is asymmetric in either or both characteristics. Asymmetry creates stress concentration and likelihood of parts of the structure being overloaded during seismic excitation. Some of the buildings, especially bungalows had assymetric plans.

(iii)Degree of redundancy.Structural systems with a higher degree of redundancy will perform better than a less redundant one. The consequence of increased redundancy is increase in energy dissipation and reduction of seismic demand on the structure.

(iv)Poor concrete strength and inadequate reinforcement detailing. These are the major factors as large category of the buildings had zero strengths from the Schmidt hammer test.

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