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SIMULATED RESPONSE OF BUILDINGS TO EARTHQUAKE IN THE SOUTH-WESTERN REGION OF NIGERIA

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ABSTRACT

Recent seismic alerts and warnings from researchers and agencies in Nigeria as regards earthquakes in the south-western part of Nigeria has led to earthquake forecast by few researchers. A team of researchers among other researchers forecasted an earthquake of magnitude 7.2 for the south-western region of Nigeria in the year 2028 while another team of researchers also forecasted an earthquake of ≥ 5.0 magnitude for the year 2028 in the same south-western region. In a bid to prepare towards these forecasted events, it necessary to design subsequent upcoming buildings around the lines of fault in the south west to resist the forecasted earthquake magnitudes. Hence this research carried out simulated response spectrum analysis on a typical modeled 3-story reinforced concrete building. The analysis was carried out using Etabs 2016 based on the specification of EURO Code 2004. The building demonstrated the highest drift of 0.010695 in the x-direction at story 2, highest deflection of 90mm in the x-direction at story 4, highest overturning moment of 36859.9947 KNm at the base and the highest stiffness of 190378.969 KN/m at story 1. To this end, the results of this response analysis should guide the designs and construction of buildings around the lines of fault in the south-western part of Nigeria in order to ensure safety of lives and properties in response to quakes in this region.

Key words: Buildings, Earthquakes, Peak Ground Acceleration, Response Spectrum, South-West.

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1. INTRODUCTION

According to the seismic record of Nigeria, seismic activities have been occurring for more than eight decades. Recent developments have also established that devastating earthquake is likely going to be experienced in Nigeria in years to come [1]. The southwest region of Nigeria has been experiencing more earthquakes among other geo-political zones in Nigeria. These quakes are not just in number but are also in sizes. This is a pointer to the fact that this zone is prone to earthquake among other zones in Nigeria [2] & [3]. According to [4], an earthquake of ≥ 5 may be experienced in the South-West between the year 2008 and 2028 with a probability that ranges between 6% and 91.1%. In a bid to ascertain the extent of future earthquake in the south western part of Nigeria, [5] further forecasted that based on the seismic data of the south-west region of Nigeria between the period of 1939 and 2016, an earthquake magnitude that is as high as 7.2 Ml is likely going to be witnessed in the South-Western part of Nigeria between 2019 and 2028 with a probability of 36.78% in 2028. If such occurs in Nigeria, a nation known for sudden building collapse [6], [7] & [8], it will portend a great disaster. If earthquake induced building collapse is joined to the current spate of structural failures provoked by numerous other causes such as material variability, inconsistency and property flaws [9], [10], [11] & [12], the damage to the South-Western part of Nigeria will be unimaginable. To this end, this research looks into the possible response of buildings in the South-West to the forecast of [5], should the quake occur so as to help designers on the extent of forces to consider in the design of future structures for the south-west and most especially around the active lines of faults. This will ultimately mitigate the aftermaths of such occurrence in the region.

1.1. Peak Ground Acceleration

A vital parameter of an earthquake is the peak ground acceleration. When an earthquake occurs, it occurs with a level of vibration or induced ground motion which can affect the erected structures depending on the resisting capacity of the structures [13]. According to [13], PGAs are always considered in relation to the generated ground shakings at the occurrence of an earthquake. The Damages done to buildings during the occurrence of an earthquake is always related to the ground motion.

1.2. Response Spectrum

When it comes to analyzing and making solutions available to several dynamic issues in structures, response spectrum remains a very effective tool and a good approach in making vital contributions to structural problems. The method uses a very simple approach as proposed by Biot in 1932 and it has been employed for analysis in many works. Several changes have evolved in the use of the method ever since the time of its proposal. Over the years, the adoption of the response spectrum method has focused more on application in the horizontal motion direction [14].

Response spectrum is very handy in helping engineers to quantify the demands of building to adequately resist earthquakes [15]. Response spectrum results generally guides designers in the design of buildings for earthquake resistance.

2. METHODS

Outlined in the section are the approaches followed to realize the aim of this research.

2.1. Estimation of Peak Ground Acceleration

The 7.2 Ml earthquake forecasted by [5] for the South-West was converted to earthquake intensity through the adoption of the equation 1 as obtained from Murty (2004).

$M_L = 1 + 0.667 I_o$ (1)

The peak ground acceleration adopted for this research is 0.55g and it was obtained from the Table 1 and is thus the ground acceleration that corresponds to the 7.2Ml forecast.

Table 1 PGAs for different Intensities

MMI	V	VI	VII	VIII	IX	X
PGA (g)	0.03-0.04	0.06-0.07	0.10-.015	0.25-0.30	0.50-0.55	>0.6

Source: [16]

2.2. Modelling

The typical 3-storey reinforced concrete building of the Figure 1 was modelled using ETABS 2016 software. The usual properties considered in the design of buildings in the south-west, Nigeria were put into consideration in the modelling to suit the already built structures. The Table 2 presents the parameters and the dimensions considered in the modelling of the 3-storey RC

Table 2 Design Parameters for Building in South-West, Nigeria

Parameters	Value
Strength of Concrete (Fcu)	25 N/mm^2
Strength of Steel (Fy)	410 N/mm^2
Characteristic Concrete weight Ƴcu	24 KN/m^3
Slab Cover	25mm
Beam Cover	25mm
Column Cover	40mm
Slab depth	150mm
Beam Size	450mm x 230mm
Column Size	230mm x 230mm

The Figure 1 presents the modeled 3-storey building

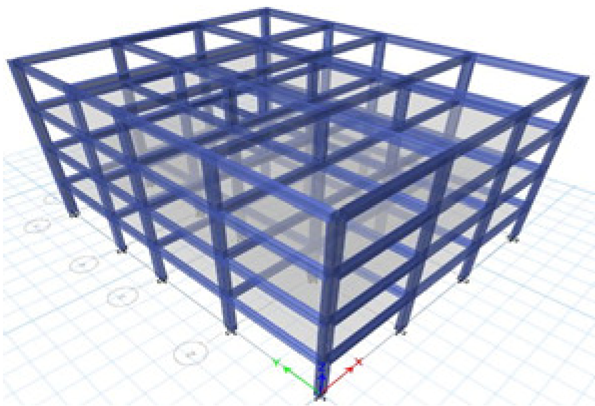

Fig. 1 Modeled 3-Storey Reinforced Concrete Building

2.3. Response Spectrum Analysis

The South-West region has adopted the British code of design in her buildings in the past years and has begun to embrace the adoption of the Eurocode of design in her designs in recent times. The British Code of design which has participated hugely in the designs of most of the built structures was found to come short in the demands of seismic analysis, hence the EURO Code 2004 was employed for the response spectrum analysis of the modeled structure. All the parameters adopted were selected from the code to suit the ground type in the south-west region of Nigeria as presented in the Figure 2.

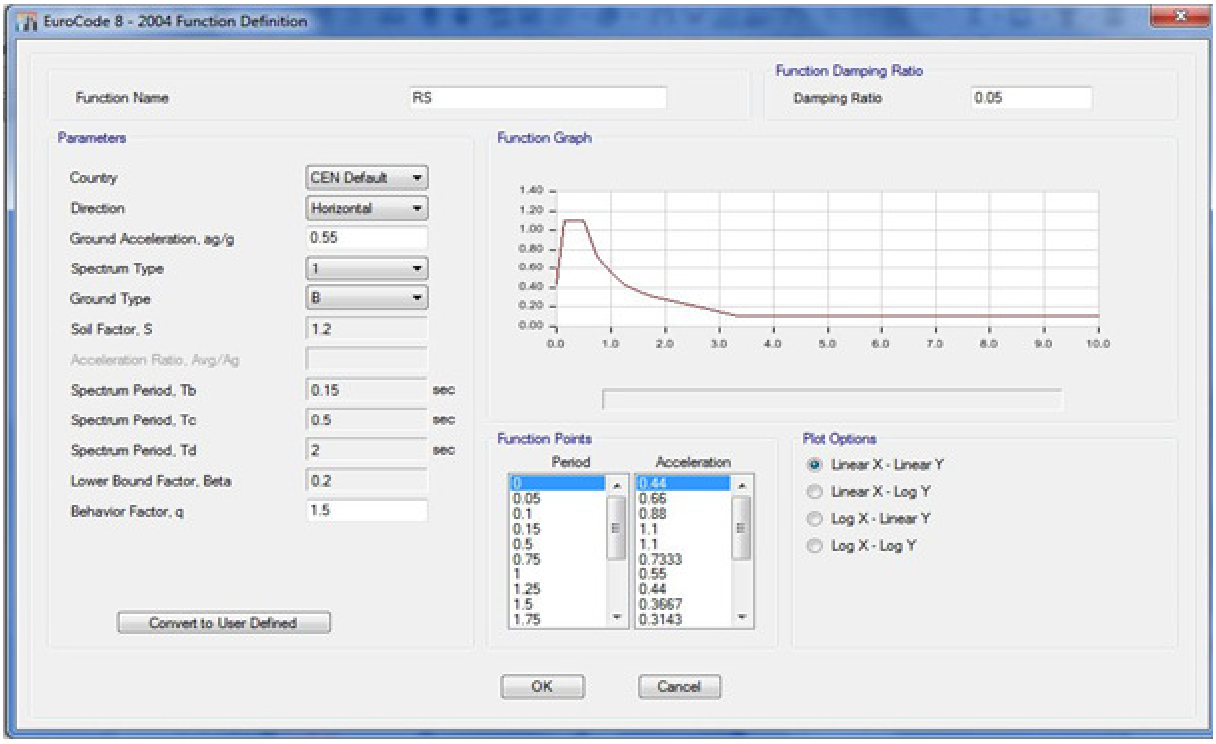

Fig. 2 Response Spectrum Definition

The modeled 3-storey RC building was subjected to response spectrum analysis according to the specifications outlined in [17]. Clause 3.2.2.2(1)P, gives the elastic response spectrum $S_e(T)$ of the horizontal components while the definition for the ground type and corresponding values for T_B, T_C , and T_D are used as defined by Clause 3.2.2.2(2)P for a damping ratio of 5%. 12 modes were used for the response spectrum analysis.

3. RESULTS AND DISCUSSIONS

3.1. Response Spectrum analysis

The results of the response spectrum analysis performed on the 3-storey reinforced concrete building are adequately presented in this section.

3.1.1. Storey Drifts

The drifts generated in the 3-storey reinforced concrete building due to the peak ground acceleration of 0.55g is related in the Figure 3.

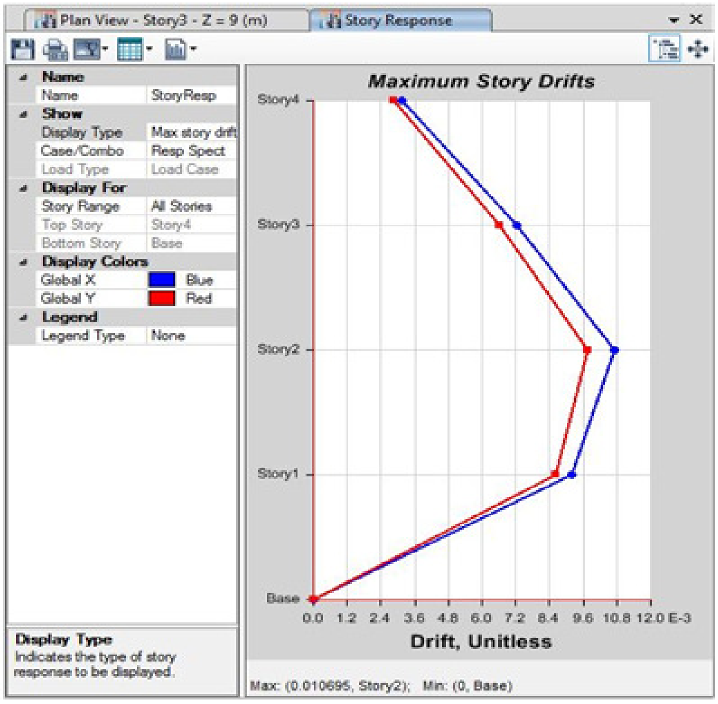

Fig. 3. Storey Drifts

The building demonstrated a drift of zero at the base and increased gradually till a maximum drift of 0.010695 and 0.009784 was reached for x and y axis respectively at the Storey 2 level. The drifts reduced back gradually and finally to 0.003146 and 0.002838 at the Storey 4 in the x and y axis respectively.

3.1.2. Storey Displacements

The resulting displacements/deflections generated in the modeled building due to the peak ground acceleration is shown in the Figure 4.

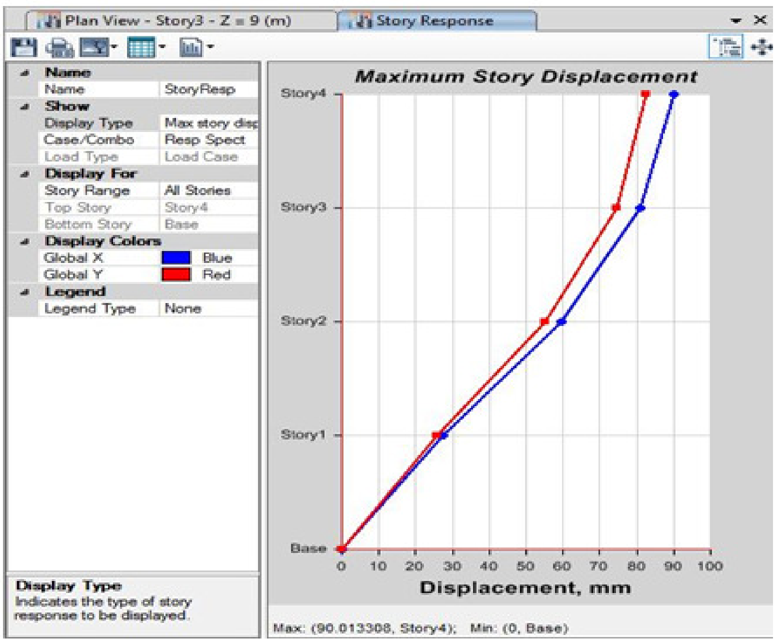

Fig. 4. Storey Displacements

The displacement at the base of the building remained at zero while it increased gradually till it reached the highest value of 90mm and 82.7mm in x and y direction respectively at the last floor level.

3.1.3. Storey Stiffness

The stiffness in the building as shown in the Figure 5 has zero value at the base and increased to a maximum value of 183345.131 KN/m and 190378.969 KN/m in the x and y direction respectively at the level 1. The stiffness demonstrated continuous reduction from the level 2 to the level 4 at a value of 95888.625 KN/m and 101636.726 KN/m in the x and y direction respectively.

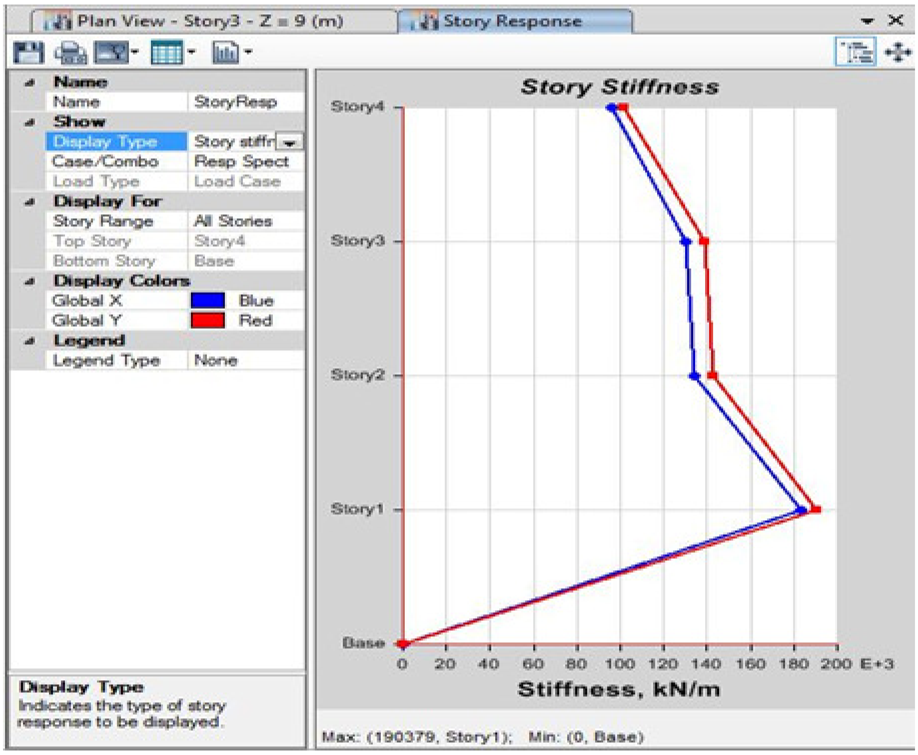

Fig 5 Response Spectrum Storey Stiffness

3.1.4. Overturning Moment

The moment generated in the building due to the peak ground acceleration is presented in the Table 3. These results relate the overturning moment both in x and y direction.

Table 3 Overturning Moment

Story	Elevation	Location	X-Dir	Y-Dir
	m		kN-m	kN-m
Story4	12	Top	0	0
Story3	9	Top	2177.8638	2183.2771
Story2	6	Top	10289.2321	10281.1482
Story1	3	Top	22532.5624	22479.4261
Base	0	Top	36859.9947	36727.8845

The overturning moment is maximum at based and approximately equal in both directions. It decreased with increase in the height of the building till it reached zero at the storey-4 level.

3.1.5. Modal Results

The results displayed in the Table 4 to Table 6 for the 12 modes selected for the modeled 3-storey building show that the clause 4.3.3.3.1 (3) is satisfied.

Table 4 Response Spectrum Modal Participating Mass Ratios (Part 1 of 2)

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ
Modal	1	0.488	0.8632	4.449E-05	0	0.8632	4.449E-05	0
Modal	2	0.475	0.0001	0.8694	0	0.8633	0.8695	0
Modal	3	0.443	0.0044	0.0013	0	0.8677	0.8708	0
Modal	4	0.161	0.0992	8.143E-06	0	0.9669	0.8708	0
Modal	5	0.157	1.358E-05	0.0977	0	0.9669	0.9686	0
Modal	6	0.146	0.0004	0.0001	0	0.9674	0.9687	0
Modal	7	0.111	1.44E-05	0.0001	0	0.9674	0.9688	0
Modal	8	0.101	0.0186	0.0024	0	0.9859	0.9712	0
Modal	9	0.101	0.0027	0.0174	0	0.9887	0.9886	0
Modal	10	0.092	0.0064	1.36E-05	0	0.9951	0.9886	0
Modal	11	0.089	0.0001	0.0001	0	0.9952	0.9887	0
Modal	12	0.088	0.0001	0.0095	0	0.9953	0.9982	0

Table 5 Response Spectrum Modal Participating Mass Ratios (Part 2 of 2)

Case	Mode	RX	RY	RZ	Sum RX	Sum RY	Sum RZ
Modal	1	8.246E-06	0.1471	0.0045	8.246E-06	0.1471	0.0045
Modal	2	0.1447	1.583E-05	0.0013	0.1447	0.1471	0.0058
Modal	3	0.0002	0.001	0.8568	0.1448	0.1481	0.8626
Modal	4	0.0001	0.7604	0.0005	0.1449	0.9086	0.8631
Modal	5	0.7695	0.0001	0.0001	0.9143	0.9087	0.8632
Modal	6	0.0011	0.0033	0.0991	0.9154	0.912	0.9623
Modal	7	0.0002	4.712E-05	0	0.9156	0.912	0.9623
Modal	8	0.004	0.033	1.147E-05	0.9196	0.945	0.9623
Modal	9	0.0282	0.0048	1.453E-05	0.9478	0.9499	0.9623
Modal	10	2.226E-05	0.0079	0.0011	0.9478	0.9578	0.9634
Modal	11	0.0001	0.0001	0.0274	0.9479	0.9579	0.9908
Modal	12	0.0235	0.0003	0.0003	0.9714	0.9582	0.9911

Table 6 Response Spectrum Modal Load Participation Ratios

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	99.99	99.53
Modal	Acceleration	UY	99.99	99.82
Modal	Acceleration	UZ	0	0

According to clause 4.3.3.3.1 (3), when the effective modal masses for all the modes are added together, it must be at least 90% of the total mass of the structure. In the table 4 and table 5, the modal mass participating ratios summed up at modal 12 for the columns of SUM RX (x-direction) and SUM RY (y-direction) are above 90% of the total mass of the building. The modal load participation ratio presented in the table 6 for both dynamic and static analysis are also greater than the required 90%. Hence the 12 modes selected to analyze the building is sufficient.

4. CONCLUSION

The response analysis carried for typical buildings in the south-western region of Nigeria showed higher drift and deflection in the x-direction with the highest drift at the storey-2 level and the highest deflection at the storey-4 level. The overturning moment which is approximately equal in the both directions is highest at the base of the structure while the stiffness attained highest value at the storey-1 level and gradual reduced continually with increase in the building's height.

5. RECOMMENDATION

Response Spectrum analysis basically helps in the design of structures to resist ground motion. It is recommended that the results of the response spectrum analysis should guide designers in the design of subsequent buildings in the south-west and especially in the regions surrounding the lines of faults in the South-west. Seismic retrofitting is also recommended for the already built buildings especially for areas surrounding the active fault in the south-west.

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