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Article

Non-Linear Finite Element Analysis and Design of RC Shear Wall: Nigeria Earth Tremor as Case Study

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Abstract: In Nigeria, it is common to design buildings first for gravity loads and then assess the structure's suitability for safety against lateral loads. It is well known that lateral loads influence the design of multi-story buildings, hence the designer's first priority should be to ensure that the structure is sufficiently safe from lateral loads. Nigeria has a large number of RC frame building that are not designed to resist seismic load because of the belief that Nigeria does not have area that are prone to earthquake, but Nigeria is no longer free from earthquake due to the occurrence of earth tremors in Nigeria in the past. This study focused on the design of RC shear wall in three storey building that assume to be place in seismic prone area in Nigeria which is capable of resisting Earthquake. The data of the magnitudes of earth tremors that have occurred in Nigeria was collected from Centre of Geodesy and Geodynamic to determine the seismic load to EC8 specification. Extended Three-Dimensional Analysis of Building System (ETABS) was used to analyze and design the shear wall. ETABS 2016 software was incorporated with all the major analysis engines that is static, dynamic, Linear and non-linear, etc. This tool was used for the modeling, analyses and design of RC shear wall for three storey building to resist Earthquake load. Hence, providing shear walls at adequate locations substantially reduce structural vulnerability and absorb Earthquake energy through inelastic deformation and prevent collapse and lose of lives.

Keywords: earthquake; nonlinear finite element analysis; Etabs; RC shear wall

1. Introduction

Following a string of recent earth tremors in various sections of the country, Nigerian seismologists unanimously concur that the country is no longer an earthquake-free zone (aseismic), as was formerly thought. In light of this scenario, steps must be taken to lessen the catastrophic consequences of a significant earthquake in Nigeria.

Nigeria's history of earthquakes began in the 1930s, when small earthquakes were recorded in Warri in 1933 and in some areas of Ibadan on June 22, 1939, (Ananaba, 1991). Parts of Ile-Ife and Lagos were also affected by the 1939 incident, which was most likely connected to the Accra earthquake that day (Ajakaiye, et al., 1987). On December 21, 1963, at approximately 18:30 Greenwich Mean Time (GMT), another occurrence was observed at Ijebu-Ode, with an epicentral intensity of roughly V. The most widely publicized episode took place on Saturday, July 28, 1984, and it affected South-Western Nigeria's Ibadan, Ijebu-Ode, Shagamu, and Abeokuta. Ajakaiye et al. (1987) ascribed this to the fact that these regions are part of the Nigerian basement complex, which was previously believed to be tectonically stable. Many people in these places felt the tremor very intensely; trees and buildings shook, objects on shelves toppled, and the timing of the incident was recorded as 12:10 GMT.

Nigeria is far from known world active plate boundaries. It is believed that it is not known to be seismo-genic but historical records and recent findings have shown that Nigeria may not be completely free from earthquakes (Adepelumi, 2009; Onuoha, 2010; Akpan & Yakubu, 2010). Since tremors were recorded in Nigeria in the past in the Ifewara—Zungeru fault zone (Figure 1), any future occurrences of Earth tremors in the country are likely going to occur along this fault zone which has been shown to be linked with the Atlantic fracture system (Anifowose, 2010; Adepelumi, 2008; Olujide & Udoh, 1989.; Olorunfemi, et al., 1986)

The National Agency for Science and Engineering Infrastructure (NASENI) in Abuja created the Nigerian National Network of Seismological Stations (NNNSS), which was moved to the Center for Geodesy and Geodynamics in Toro, Bauchi State, in 2006. NASENI built the Nigerian National Network of Seismographic Stations (NNNSS), now managed by the Centre for Geodesy and Geodynamics (CGG) in Toro. CGG has been tracking earthquake activity in Nigeria since 2006. Figure 2, shows the different seismic stations in Nigeria (Afegbua, 2011).

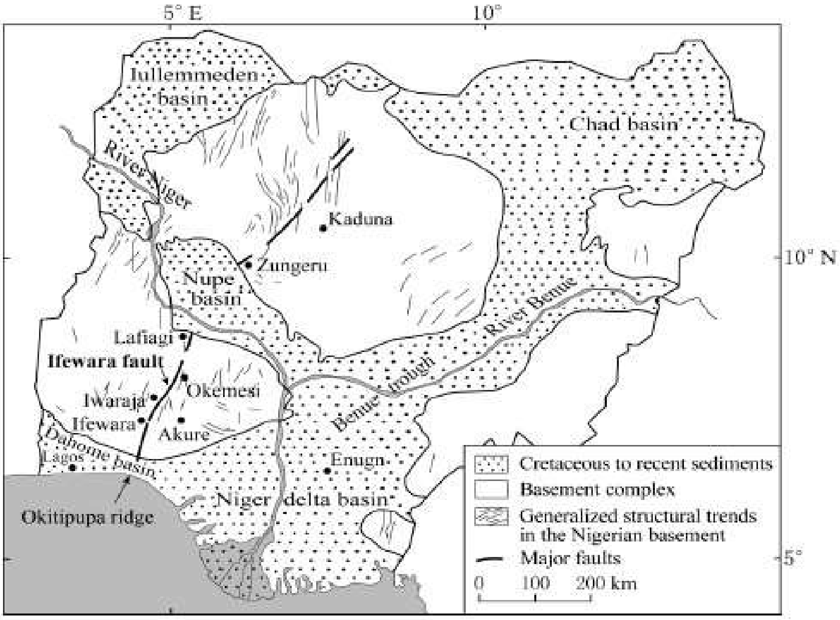


Figure 1. Map of Nigeria showing the Zungeru-Ifewara fault (Akpan & Yakubu, 2010).

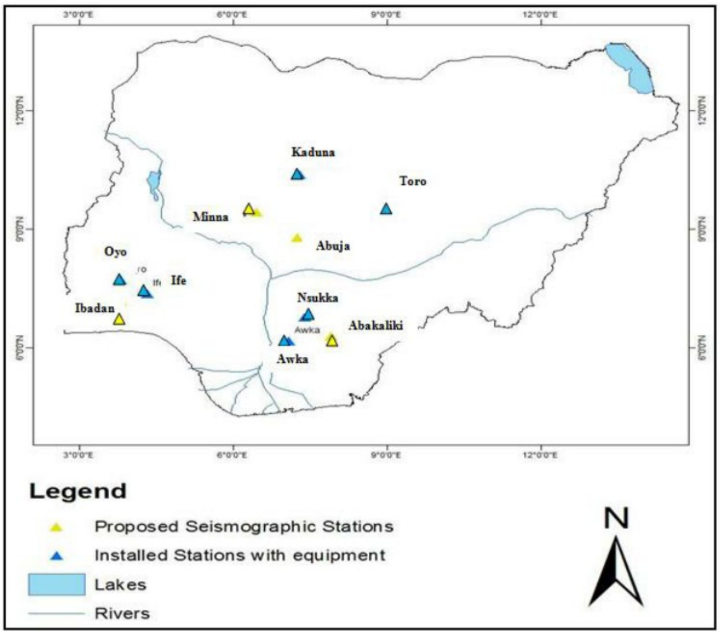


Figure 2. Distribution of seismic stations. The blue triangles represent those stations that are operational whilst the yellow triangles indicate the proposed stations.

It is possible to minimize the potential risks to humans and damage potential to structures by using ground motion records from past earthquakes and advanced technologies that make it nearly possible to predict earthquake, ground motion with proper understanding of seismic sources and properties of seismic waves. A consequent lateral force or horizontal ground motion action that is comparable to the impact of a horizontal force operating on a building is known as seismic load. Structure engineers are concerned about building safety and provide RC shear walls or other structural elements to withstand seismic loads. The RC Shear walls, in addition to slabs, beams, and columns, are reinforced concrete structures that resemble vertical plates. Usually beginning at the foundation, these walls run the length of the building. They can range in thickness from 150 mm to 400 mm in high-rise structures. This study focused on the design of RC shear wall in three storey building that assume to be place in seismic prone area in Nigeria which is capable of resisting Earthquake.

2. Materials and Methods

2.1. Basic Properties of Concrete

Concrete has many microcracks, particularly where the mortar and coarser grains meet. This characteristic is essential to concrete's mechanical behavior. These microcracks spread during loading, which results in volume expansion close to failure and nonlinear behavior of the concrete at low stress levels. (Chen, 1982; Penelis & Kappos, 1997; Paulay & Priestley, 1992) provide an overview of such attributes.

2.2. Response to Monotonic Loading and Modulus of Elasticity

Tests on cylinders of different concrete grades produced the curve of concrete stress σc versus strain ε for monotonic compression, which is displayed in Figure 3. Figure 3 shows that the curve has three components (Chen, 1982):

1. The cracks that were present in the concrete prior to loading essentially stay the same for stresses in the area up to roughly 30% of the concrete's maximum compressive strength f_c.
2. Because of stress concentrations at the crack points, bond cracks begin to spread at stresses between 30 and 50 percent of f_c.
3. Some fractures at adjacent aggregate surfaces begin to bridge as mortar cracks at stresses between 50 and 75 percent of f_c. Other bond cracks, meanwhile, are still steadily expanding. Critical lengths of the biggest cracks are reached at compressive loads greater than approximately 75 percent of f_c.

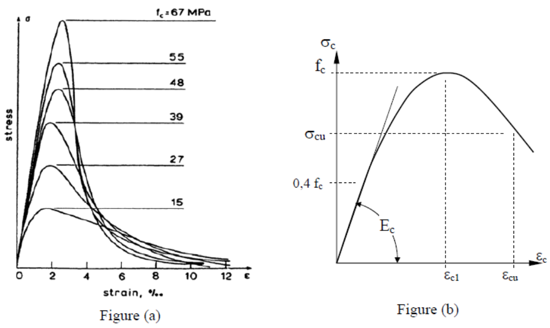


Figure 3. (**a** and **b**) Stress-strain diagrams from cylinders of concrete subjected to uniaxial compression (**a**) for various concrete grades (Chen, 1982) and (**b**) a sketch used in concrete design.

The Eurocode 2 (Eurocode, 2004) stress-strain diagram for uniaxial compression is shown in Figure 3b. The maximum compression strength is denoted by f_c, the strain at f_c is denoted by εc1, and the ultimate strain is denoted by εcu. The maximum useable strain for concrete is defined by Eurocode 2 (EC2) as εcu = 0.35%, with the supposition that no stress reduction occurs up to this degree of deformation. A compression strain of 0.4% is advised for seismic loading (Paulay & Priestley, 1992).

In addition, the modulus of elasticity (Figure 3b) that is used in design is also influenced by the aggregates' characteristics and other mix design and environmental factors (CEN, 1991).

In EC2 the modulus of elasticity is defined by a line between $\sigma_c = 0$ and $\sigma_c = 0.4\ f_c$ (see Figure 3b) or $E_c = 9500\ (f_{ck} + 8)^{1/3}$.

For design purposes, E_{C2} presents Poisson's ratio as 0.2, but if cracking is allowed for concrete in tension, Poisson's ratio may be assumed to be zero. E_c and f_{ck} are in MPa Poisson's ratio, v of concrete under uniaxial compressive loading that ranges between 0.15 and 0.22 (Chen, 1982). f_{ck} is the characteristic compressive cylinder strength, which is defined as the value of strength below which 5% fractile.

$$f_t = 0.3(f_{ck})^{2/3}$$

where, f_t and f_{ck} are in MPa.

2.3. Reinforcing Steel Bars

The stress (σs)-strain (εs) graphs for different steel grades are subjected to monotonic tensile loading in Figure 4. These figures make it evident that steel's ultimate deformation diminishes with increasing strength, a tendency that is comparable to—but more pronounced than—that of plain concrete. Furthermore, the ratio of yield stress (f_y) to maximum stress (f_u) rises with steel grade; in other words, strain hardening has a greater effect on high strength steel, whose hardening branch threshold is near the yield strain, than on low strength steel.

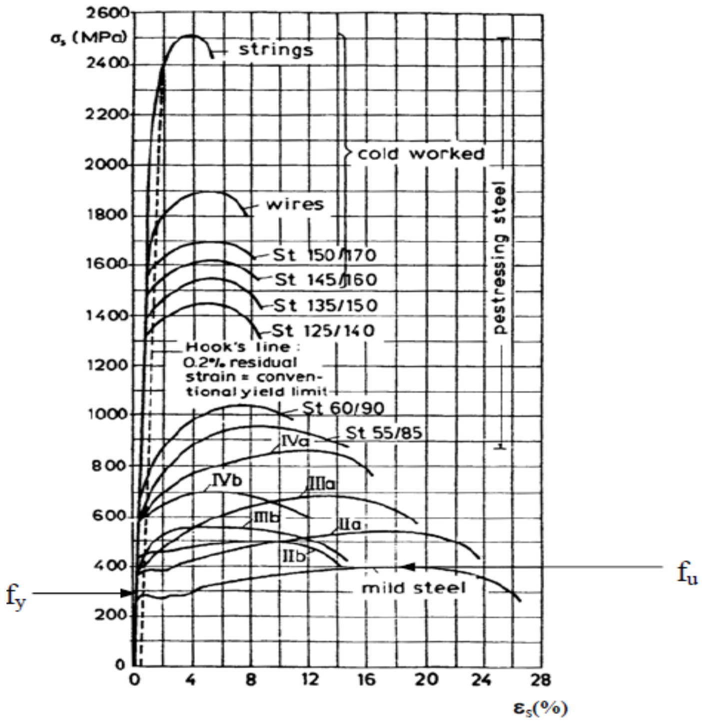


Figure 4. Stress-strain diagrams for steel bars of various grades (Penelis & Kappos, 1997).

2.4. Load–Lateral Force Method of Analysis

Under a set of lateral forces applied independently in two orthogonal horizontal directions, x and y, a linear static analysis of the structure is carried out using the lateral force method. The goal of these forces is to replicate the peak inertia load that the horizontal component of the seismic activity induces in the x and y directions. This approach has long been and continues to be the mainstay of practical seismic design since structural engineers are accustomed to and have expertise with elastic analysis for static loads (caused by gravity, wind, or other static actions).

EC8:4.3.3.2.1(1) P states that buildings whose response is not substantially impacted by contributions from vibration modes higher than the basic mode in each primary direction can use the lateral force approach. In the two primary directions, the fundamental period of vibration, T_1, need to be less than:

$$T_1 \leq \sum_{2s}^{4T_C} \tag{1}$$

where $T_c = 0$ is found in EC8, and the building shall meet the criteria for regularity in elevation, given in EC8: 4.2.3.3.

According to EC8: 4.3.3.2.2, the seismic base shear force, F_b for the horizontal direction.

$$F_b = S_d(T_1).\text{m}.\boldsymbol{\lambda} \tag{2}$$

where:

S_d (T_1) is the ordinate of the design spectrum at period T_1. (See EC8: 3.2.2.5) m is the total mass of the building computed in accordance with EC8:3.2.4(2), λ is the correction factor. Here, $\boldsymbol{\lambda} = 0{:}85$ if $T1 < 2Tc$ and the building has more than two stories.

T_1 can be approximated as follows:

$$T_1 = C_t H^{3/4} \quad \text{and } C_t \text{ is a constant} \tag{3}$$

where

$$C_t = \frac{0.075}{\sqrt{A_c}} \tag{4}$$

Ac for a concrete shear wall is the total effective area of the shear wall.
Ac is given by the equation:

$$Ac = \sum(A_i.(0.2 + (l_{wi}/\text{H}).2) \tag{5}$$

where Ai is the effective cross sectional area of the shear wall in the first storey of the building in m^2.
l_{wi} is the length of the shear wall in the first storey in the direction parallel to the applied forces, in m, H is the height of the building, in m, from the foundation or the top of the rigid basement And $l_{wi}= H$ should not exceed 0.9.

Load Distributions

The way the base shear is distributed over the height of the building, EC8 permit the assumption of deflection shape is linear. With this assumption, the inertia force generated at a given storey is proportional to the product of the storey height mass and its height from base. (See EC8: 3.6.3.1, 3.6.3.2 or 3.6.3.3). Equation 4.11 in EC8 therefore gives the force on storey k to be:

$$F_k = \frac{F_b Z_k M_k}{\sum Z_j M_i} \tag{6}$$

2.5. Extended Three-Dimensional Analysis of Building System (ETABS)

ETABS is a special-purpose computer program developed specially for building structures (Anjaneyulu & Prakash, 2016). It is currently the most popular design software available. This study, primarily focuses on the design and comparative analysis of a reinforced concrete shear wall structure using ETABS software. The nonlinear analysis and design of reinforced concrete shear walls is the exclusive subject of this paper.

The EC8 specification is used to calculate seismic loads based on seismic mass and the acceleration of the largest earthquake to have occurred in Nigeria. Because the structure will pick a load period that is close to its natural period during the earthquake, a seismic analysis must adequately account for the dynamic amplification of earthquake ground motions due to resonance.

The normal way of doing this is by using a response spectrum. The analysis of the effect of an earthquake has two stages:

a. Calculation of the structure's dynamic features, including its natural period or periods.
b. A response computation specific to the load scenario in question.

Linear analysis-based methods are frequently used. In this instance, the ductility-modified response spectrum is used to address non-linearity. The building's elevation Figure 4 and plan are both regular. The use of a planar structural model and an analogous static analysis approach is thus permitted by EC8, which includes estimating the building's seismic mass and self-weight, calculating base shear in the x-direction, and calculating the distribution of lateral loads. ETABS software was then used to simulate, analyze, and design the impact of seismic loads on the shear wall.

2.6. Data Collection

The data for this design work was collected from centre of Geodesy and Geodynamic, the Federal government agency monitoring the trend of Earthquake in Nigeria. The Centre for Geodesy and Geodynamics has carried out the spot assessment, survey and investigation on the recent and past occurrence of earthquakes in Nigeria. The Table 1 below show available recorded magnitude of earthquakes that have occurred in Nigeria.

Table 1. Information about the previously occurred earthquake in Nigeria.

Date	Origin Time	Felt Area	Magnitude	Probable epicentre
1994-11-07	05:07:51	Ibadan	4.2(ms)	Dan Gulbi
2000-03-07	15:53:54	Ibadan, Akure, Abeokuta, Ijebu-Ode and Oyo	4.5(ms)	Close to Okitipupa
2009-09-11	Nil	Lagos, Ibadan and Allada, Ogun state	4.4 (ms)	Benin Republic
2016-09-12	03:11:20	Kaduna state (kwoi)	3.1 (ms)	Ifewara-Zungeru fault

Source: (Centre for Geodesy and Geodynamics).

2.7. Building and the Load

This section describes the building under analysis, calculates the total seismic mass, and calculates the applied load that an earthquake would place on the structure. The house, a three-story structure that does not actually exist, is thought to be situated in a seismically active region of Nigeria.

2.7.1. The Building

Figures 3 and 4 display drawings of the building. With slabs, beams, columns, and shear walls of the same size and a concrete roof assumed to be monotonic, the building is a conventional RC construction. The shape of the wall under analysis is depicted in Figure 4, and it is assumed that only the shear wall provides resistance to seismic loads.

The concrete strength of grade C30 as well as the wall thickness of 200 mm was incorporated in this design work. The dimensions of the building were presented in Figures 5 and 6 while the necessary parameters related to the building can be seen in Table 2.

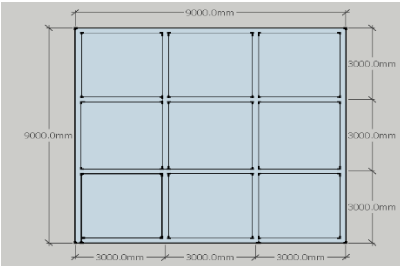


Figure 5. Plan View.

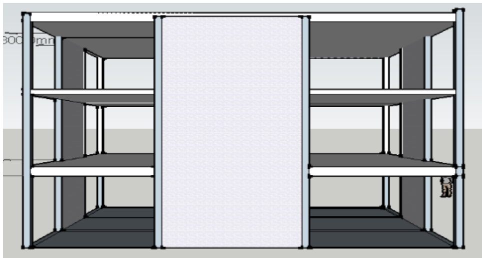


Figure 6. The elevation.

2.7.2. The mass of the Building

Even though only one wall of the building is analyzed, the weight of the whole building was calculated to obtain the total earthquake force applied on the wall. Figure 4 shows the elevation of the shear wall.

Table 2. Design parameter.

Parameters	Values
Building Height	H = 10.2 m
Building Width	W = 9 m
Building Length	L = 9m
Storey Height	H = 3m
Thickness of the Wall	t_w = 200 mm
Length of Shear Wall	l_w = 2800 mm
Density of the Concrete	ρ_c = 25 KN/m^3
Concrete strength	C_c = 30 N/mm^2
Strength of reinforcement	F_y = 410 N/mm^2

Data
Beam = 250 mm × 400 mm
Slab = 180 mm
Column = 200 mm× 500 mm
Live load = 3 KN/m^2
Wall = 200 mm

Live Loads on the floor = 3 × 9 × 9 = 243 KN
EC 8 EN 1990: 2002, 6.4.34 specified Q_k value of 0.3 as the live load contributing to seismic Load.

$$0.3 \times 243 = 72.9 \text{ KN}$$

Seismic loads for the symmetric floors

$$= \frac{720}{2} + \frac{720}{2} + 180 + \frac{120}{2} + \frac{120}{2} + 364.5 + 72.9 = 1457.4 \text{ KN}$$

Seismic loads for the roof

$$= \frac{720}{2} + 180 + \frac{120}{2} + 364.5 = 964.5 \text{ KN}$$

Roof load	964.5 KN
2nd floor loads	1457.4 KN
1st floors load	1457.4 KN
Total seismic loads	3879.3 KN

$$\text{Seismic mass} = 3{,}873.3 \times \frac{1000}{9.81} = 395{,}443.4\text{Kg}$$

According to EC8:4.3.3.2.1(1) P, the lateral force method can be applied to buildings whose response is not affected significantly by contributions from modes of vibration that is higher than the fundamental mode in each principal direction.

$$T_1 = \ \leq \sum_{2s}^{4T_c} \qquad \text{(from equation 1)}$$

where T_1 is equal to the natural vibrating period of the building

$$T_1 = C_t H^{3/4} \qquad \text{(from equation 3)}$$

where $C_t = \frac{0.075}{\sqrt{A_c}}$ (from equation 4)

$$A_c = \sum(A_i.(0.2+(l_{wi}/\text{H}).2) \qquad \text{(from equation 5)}$$

It is assumed that the building has two opposite shear wall

$$A_i = 10.2 \times 0.2 = 2.04 \text{ m}^2$$

$$A_c = 2 \times (2.04\ (0.2 + (\frac{2.8}{9})^2) = 4.24 \text{ m}^2$$

Then $C_t = \frac{0.075}{\sqrt{A_c}} = \frac{0.075}{\sqrt{4.24}} = 0.036$

The natural period of the building

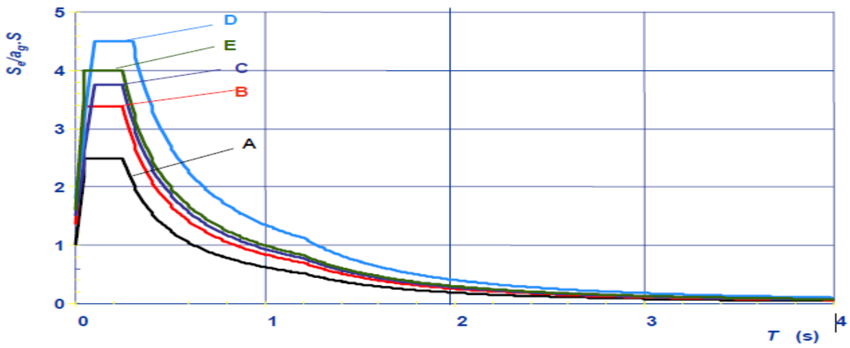
$$T_1 = 0.036 \times 9^{3/4} = 0.19\text{s}$$

2.8. Computation of Seismic Base Shear

Based on the information regarding the previous Earthquake in Nigeria (Table 3), the magnitude of earthquake ranges from 4.2 to 4.5. The maximum body magnitude of Earthquakes that have occurred in Nigeria is less than 5.5. EC8 provides elastic responds spectrum type 2 Figure 7 for calculation of horizontal spectrum accelerations for earthquake magnitude less than 5.5. However, the value of the following periods, soil type and ground acceleration can be obtained from Table 4.

Table 3. Properties of structural elements.

Element	Sizes	No of Members	Density (KN/m^3)	Load (KN)
Wall	$3 \times 0.2 \times 3$	20	20	720
Beams	$0.25 \times 0.4 \times 3$	24	25	180
Column	$0.2 \times 0.5 \times 3$	16	25	120
Slab	$0.18 \times 9 \times 9$	1	25	364.5



Type 2 - $M_s \leq 5,5$

Figure 7. Recommended spectral shapes for Type 2 seismic action (Ms < 5.5) for various ground types.

Ground type	S	T_b (s)	T_c (s)	T_d(s)
A	1	0.05	0.25	1.2

a_{gr}= 2.5 m/s^2 (spectrum type 2 EC8)

$T_b < T_1 < T_c$ $\quad T_1 = 0.19$s

$4\, T_c = 4 \times 0.25 = 1$

$T_1 < 4\, T_c$

2.8.1. Lateral Load Force Can Be Used

Therefore design spectral acceleration $S_d(T_1) = a_{gr} \times S \times 2.5/q$

EC8 provide behaviour factor q for uncouple walls is 3

$$S_d(T_1) = 2.5 \times 1 \times 2.5/3$$

$$= 2.08 \text{ m/s}^2$$

In accordance to EC8 4.3.3.22 the shear base force in horizontal direction

$$F_b = \lambda S_d(T1).m. \quad \text{From Equation} \quad 2.2$$

$$= 0.85 \times 395443.4 \times 2.08 = 699.14 \text{ KN}$$

2.8.2. Load Distributions and Moment

EC8 allows the assumption that the deflection form is linear with respect to the distribution of base shear over the building's height. According to this theory, the inertia force produced at a specific storey is proportional to the product of the mass of the storey and its height above the base.
From equation 6, $F_k = F_b Z_k M_k / \sum Z_j M_i$.

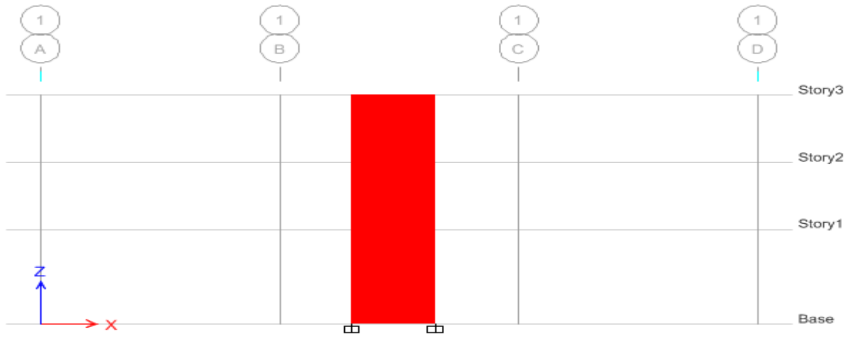
Table 4. Mode shape approximation.

Level	Height	Mass	$Z_k M_k$(KNm)	Force(KN)
Roof	10.20	964.50	9837.90	260.02
2nd floor	7.20	1457.40	10493.28	277.34
1st floor	4.20	1457.40	6121.08	161.78

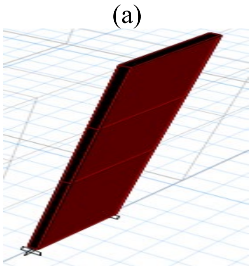
2.9. Analysis and Design Method in Accordance with ETABS (2016)

The summary of the steps involved in running of ETABS software for shear wall modeling, analysis and design are presented as follows:

1. Design Codes: The Options menu > Preferences > Shear Wall Design command is used to set the design code, which is one of several codes built into the ETABS design software. EC8 (2004) was used for the research and design of this design project.
2. Units: Any set of consistent units can be entered into this program to construct shear walls. Additionally, the unit system in use is subject to change at any time. Design codes are usually based on a single set of units. For analysis and design, a metric unit was chosen.
3. Defining of property: Select define menu > material properties. Add new material in the defining material property the concrete of C30 and steel of grade 410 kN/m^2.Also define section name, load pattern and loads case. For this work, the size of structural components (shear wall) is taken as per the requirement. Table 2 shows the design parameter input into ETABS software for the analysis and design.
4. Drawing of the wall as it was specified in the input data: Select draw menu > Draw shear wall. Choose shear wall type and add sizes of the shear wall. The modeled shear wall is as shown in Figure 8a–c.
5. Assigning Supports: Using the assign menu > joint > Restraints (supports) > fixed, choose the shear wall base supports while maintaining the plan at the base of the structure. Assign joint loads as well. The seismic load along the shear wall's height is depicted in Figure 9.
6. The model is examined following the completion of the aforementioned procedures. After choosing the "Analyze" menu and selecting "Check Model," the analysis was completed and any errors were checked.
7. Design: Following analysis, the structural element was designed in accordance with EC8, 2004. To execute the shear wall design, select the Design menu > Shear Wall Design > Start Design/Check of Structure command.
8. Use one of the following methods to examine the shear wall design outcomes: (a) To view design input and output data on the model, select the Design menu > Shear Wall Design > Display Design Info command. (a) To access the interactive wall design mode, right-click on a pier or while the design results are shown on it. Keep in mind that you can edit, replace, and view the updated design results instantly while in this mode.



(a)



(b)

Story	Height m	Elevation m	Master Story	Similar To	Splice Story	Splice Height m	Story Color
Story3	3	10.2	No	None	No	0	
Story2	3	7.2	No	None	No	0	
Story1	4.2	4.2	No	None	No	0	
Base		0					

(c)

Figure 8 (**a**) Modeled RC Shear Wall. (**b**) RC Shear Wall Isometric View. (**c**) Elevation of various storey height RC shear wall.

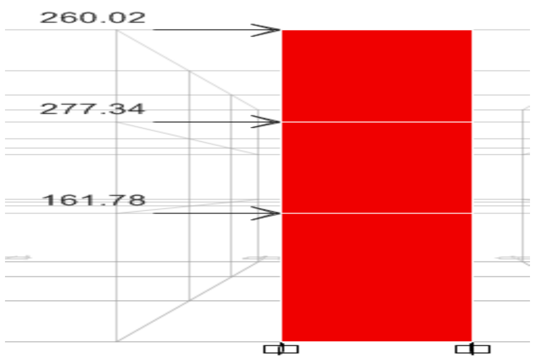


Figure 9. Load along the elevation of shear wall.

3. Results and Discussion

The results obtained from the structural modeling, analysis and design in ETABS (a finite element and design software) as well as the outcomes of this research on the deflection, internal forces, and moment generated during the analysis are presented and discussed. The design for the shear wall to resist the internal forces and moments due self weight and seismic loads result are also presented. Detailing of reinforcement provided by ETABS software also was well presented.

3.1. Analysis of RC shear wall

3.1.1. Analysis

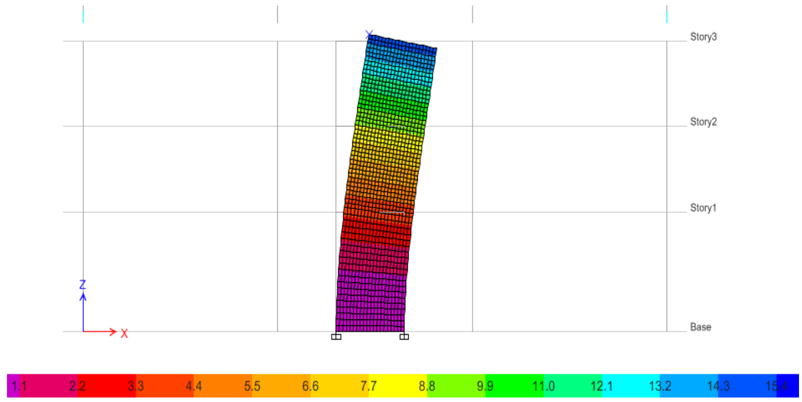
Analysis of RC shear wall is done using ETABS and the model was prepared in the ETABS. The analysis involves the mathematical calculations of all the forces in the structure to be designed against to ensure that the structure is safe. The forces in RC shear wall due to seismic load and gravity load of the shear wall is determine by ETABS.

3.1.2. Deflection Result

No structural member may be deformed to the point that it impairs the structure's ability to perform and look its best. The displacement brought on by the lateral force acting on each storey level of the structure is the proper limit value of deflection when considering the nature of the structure for its serviceability limit state and deflections. The top floor will be more affected by lateral displacement than other storeys (see Figure 10a). Following the RC Shear wall analysis, the model's results about the wall's displacement are tabulated and displayed on the displacement plot in Figure 10b and 10c.

3.1.3. Check for Allowable Deflection

EC2: 7.4 specify the upward deflection of cantilever subjected lateral force should not exceeded $\frac{H}{250}$ Max. Deflection against Earthquake allowed is given as $\frac{H}{250} = \frac{10200}{250} = 40$ mm. The maximum displacement at the top story is 15.166 mm from Figure 7a which is lesser than the allowable deflection value of 40 mm. Hence, the deflection is okay. This shows that the RC shear wall is stiff enough to resist the seismic load. Shear walls have very high in plane stiffness that reduces its tendency to deflect.

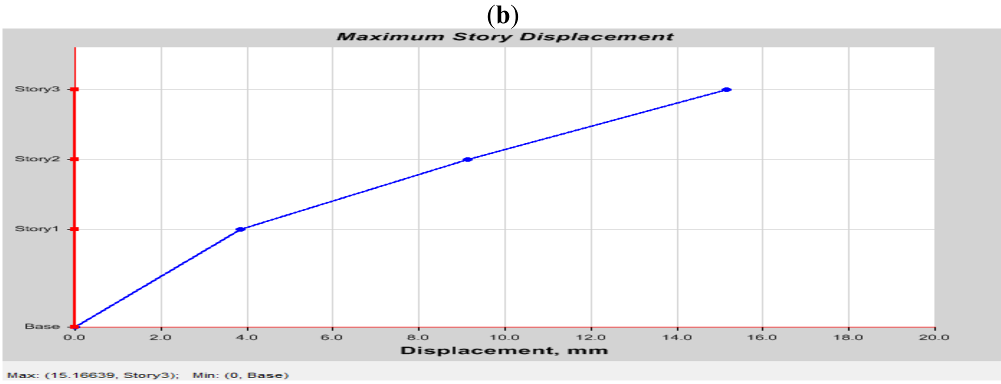


(**a**)

Joint Displacements

Label	Unique Name	Load Case/Combo	UX mm	UY mm	UZ mm	RX rad	RY rad	RZ rad
3	16	Dead	0	0	-0.076	0	0	0
3	16	seismic Max	15.166	0	2.838	0	0.003587	0
3	16	seismic Min	15.166	0	2.838	0	0.003587	0
3	16	Comb1	15.166	0	2.735	0	0.003587	0

(**b**)



(**c**)

Figure 10. (**a**) Deformed shapes due to dead and seismic loads. (**b**) Joint displacements due to dead and seismic loads. (**c**) Joint displacements plot due to dead and seismic.

3.1.4. Limitation of Inter Storey Drift

The displacement of one level in relation to another level above or below is the limit of inter-story drift. For buildings with non-structural elements of brittle materials attached to the structure, EC8:4.4.3.2

stipulated that the drift in any level could not be greater than 0.005 times the storey height.
Height of first Storey = 4200 mm.

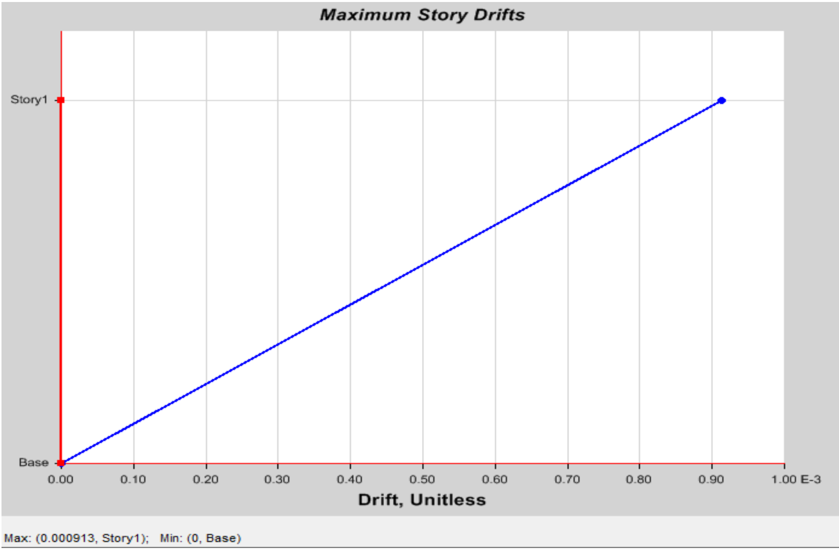
$$0.005(h) = 0.005(4200) = 21 \text{ mm}$$

The maximum inter-storey drift for the first storey is 0.000913 mm as obtained from Figure 11a is lesser than 21 mm. This is satisfactorily ok.

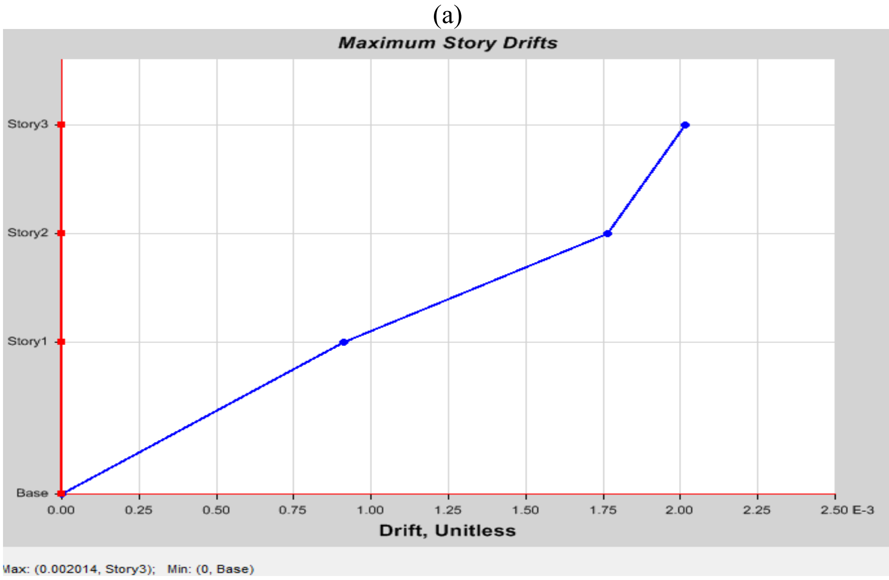
Height of 2nd and 3rd Storey = 3000 mm

$$0.005(h) = 0.005(3000) = 15 \text{ mm}$$

The maximum inter-storey drift for the other storey is 0.002014 mm as obtained from Figure 11b which was lesser than 15 mm. Hence, it is ok.



(a)



(b)

Figure 11. (**a**) Inter storey drift for the first storey (**b**) Inter-storey drift for the all storey.

3.2. Moment and Shear Force Diagram

The analysis and determination of the internal and external forces acting on a RC shear wall with ETABS indicates that the moment attained has the highest value at the base of the shear wall. The maximum value of the bending moment is 5328.52 KNm while the shear force at apex at the base of the RC shear wall has the estimated value of 699.14 KN. Figure 12 shows the variation of moment along the height of the shear wall and Figure 13 reveals the shear forces along the height of shear wall.

3.3. Design of RC Shear Wall

The primary aim of design is to ensure that at no point in the structure shall the design loads exceed the design strengths of the materials. This is achieved by using ETABS to design the RC shear wall to resist loads while ensuring that the design strength of shear wall materials greater than design loads.

3.3.1. Vertical Reinforcement (Flexural Reinforcement)

According to EC2: Clause 9.6.1(1) (2), the minimum area of reinforcement is $0.002A_c$, where A_c is the corresponding concrete section area. In general, where the minimum area of reinforcement controls the design, half of this reinforcement should be located at each face. The total area of vertical reinforcement provided by the ETABS software is 1400 mm^2 shown in Figure 14.

The minimum area required = $0.002A_c$.

$$=0.002 \times 200 \times 2800 = 1120\ mm^2$$

Area provided is 1400 mm^2, which is ok.

3.3.2. Horizontal Reinforcement (Shear Reinforcement)

Horizontal reinforcement running parallel to the faces of the wall (and to the free edges) should be provided and arranged at each surface between the vertical reinforcement and the nearest surface. It should not be less than $0.001A_c$.

$$= 0.001 \times 200 \times 3000 \ = 600\ mm^2$$

The design software provided 200 mm^2/m which is 600 mm^2 in three metre run.

The horizontal reinforcement provided is ok. Figure 15 shows the area provided for the horizontal reinforcement. The cage reinforcement and elevation detailing are shown below in Figures 16 and 17.

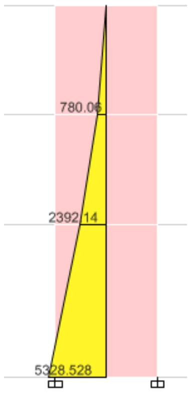


Figure 12. Variation of bending moment.

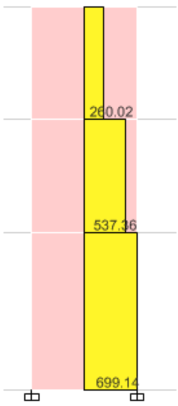


Figure 13. Variation of shear force.

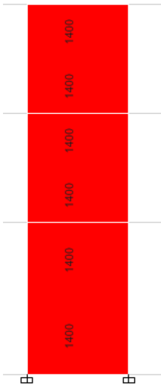


Figure 14. Area of vertical reinforcement.

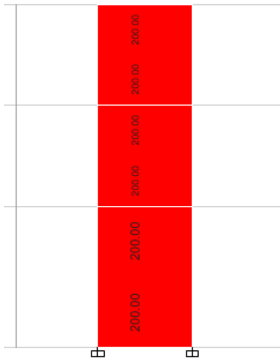


Figure 15. Area of horizontal reinforcement.

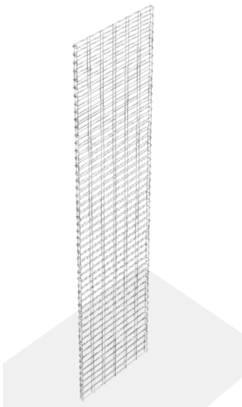


Figure 16. Cage reinforcement of Shear Wall.

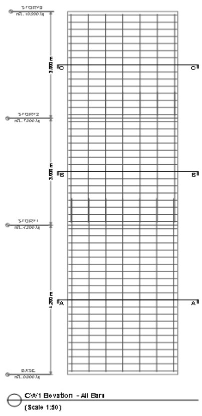


Figure 17. Elevation Detailing.

4. Conclusions

Seismic nonlinear finite element analysis and design of shear wall external reinforced shear wall to earthquake loading has been carried out. The design was carried out in compliance to relevant codes of practice. This following can be concluded from the analysis and design of the external reinforced concrete shear wall:

- The project demonstrates the capacity of the external reinforced shear wall to resist the effect of seismic loads.
- It demonstrates adequate provision of reinforcement to resist internal and external forces due to seismic loading.
- It also demonstrates that adequate design of shear wall can prove effective against resisting the effect of earthquake loading.

This study thus predict a structural safe and reliable solution to the problem of earthquake loading.

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