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Structural Integrity Assessment of Office Building Development in FCT-Abuja, Using Non-Destructive Testing Method

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Abstract: This paper present structural integrity assessment of the remodelled office building for the National Directorate of Employment (NDE), Abuja. Structural and the architectural drawings were reviewed. Visual inspections, soil investigation, and in-situ concrete testing were carried out. However, to identify structural flaws and the type of reinforcement bar used; structural elements were measured, photographed were taken, Ground Penetrating Radar (GPR) was used to assessed the reinforcement in all the structural elements (columns, beams and slabs). A total station survey of the structure utilizing structural Non- Destructive Test Unmanned Aerial Vehicle (NDTUAV) was used to create the as-built plan for the building. The elevations inside the construction area were surveyed to determine the slope's orientation in order to assess the effects of wetting on the building foundation. There was no indication of structural fatigue on the structural components at the time of the visit. The structural members' in-situ compressive strength tests were satisfactory. The geotechnical investigation yielded the permissible soil carrying capacity between the range of 96.63 kN/m^2 to 278.76 kN/m^2. The structural members were constructed based on accepted engineering principles and the structural components were found to comply with the design specification. As a result, the structure is safe, reliable, and passed the structural integrity assessment.

Keywords: Concrete Strength, Rebound Hammer Value, Integrity Test, Soil Bearing Capacity

1. Introduction

Structural assessment of an existing building structure made up of reinforced concrete that host a large number of people and other equipment with a view to evaluating its performance is very crucial [1]. Consequences of collapse building structure cannot be underestimated as a bungalow that collapses on the tenant of the building cannot be regarded as a small loss. Neither will a multi-storey building that collapse with no human casualty be regarded as no loss as both involve loss of properties and human casualty. It has been observed that a number of structures are built with foundations that are not appropriate for the soil conditions. Although, due to inadequate land space, some structures are built on land that have no good bearing capacity to support the structure. The consequence of the above is that, when the soil conditions change, the soil may no longer bear the full weight of the foundation, [2], which may lead to structural collapse. It was reported by Ayedun, et'al [3] that, owners and stakeholders in failed structure often die of high blood pressure or other related diseases associate with high blood pressure.

Nigeria does not have a history or record of natural disasters like earthquake in the past as compared to other countries of the world except in 2016 where an earth tremor was reported in some part of norther Nigeria. Despite the absence of earthquake, the collapse of building structures in the last ten (10) years especially in Nigeria has called for active methods for evaluating the structural integrity of reinforced concrete buildings. Ironically, the country has had its share of man-made disasters as it was reported that most of the causes of building collapse in Nigeria are attributed to structural defect, poor design, abuse of building codes, use of substandard construction materials, poor workmanship and corruption, among others [4-6]. Ede [7] and Olagunju [8] reported that, poor maintenance culture of our building structures contributes to the crisis of building collapse in Nigeria which was supported by Fagbenle and Oluwunmi [9], Babalola [10] and Etim [11]. It was also reported that lack of assessing the structural integrity of a reinforced concrete building led to four collapses that included residential buildings in 2006 in Ebute Metta, Lagos, Lagos state where 37 lives were lost [12]. It was reported by Adegoroye [13] that in 2006, the Nigerian Industrial Development Bank building collapsed, and that collapsed claimed two (2) human lives and twenty-three (23) sustain various degrees of injuring [12]. In 2007, Oloyede, Akinjare, & Omoogun [12] reported that two-storey building collapsed along Okegbogbo Street in which one live was lost and fifteen other people sustained serious degrees of injuries.

It is worthy to note that structural integrity assessment of reinforced concrete structure is anticipated to detect the problem in the building structure before its failure and recommendation will be given to prevent unnecessary collapse.

There are two basic methods of assessing the structural integrity of any structural element. The methods are; Destructive Test Method and Non-Destructive Test (NDT) method. The Destructive Test Methods used in assessing the quality of concrete have several disadvantages such as; cost in implementation of the test, delay in carried the exercise, strength properties of a concrete specimen depend on its size and shape, just to mention but few. In order to overcome the disadvantages state above, NDT was developed [14, 15], for use, as it imparts little or no damage to concrete, although it usually requires sampling or removing a small amount on the building structures.

Most accidences of building collapse in Nigeria could have been averted or minimized if quality control measures were taken through NDT during the construction of new buildings as well as structural checkups for existing ones. Thus, this research evaluated the structural integrity of an existing office building for the National Directorate of Employment (NDE), Abuja that has been subjected to various conditions including high temperature, wind, rain and cold weather over the years using NDT Method (Rebound Hammer and Ultrasonic Pulse Velocity Test) to ascertain the safe use of the structure.

1.1. Aim of the Investigation

Amsalco Suites Limited of Adetokumbo Ademola Wuse II, Abuja requested for structural integrity assessment to determine the status of its proposed building, with a view to ascertain the reliability of the entire structural elements for the purpose of remodeling the structure.

1.2. Site Location

The building is located at plot 1076, cadastral zone, Sestor B18, Gudu District, Abuja with coordinate N09.00088, E07.47525 at an elevation of 477m above sea level as shown in the Google map (see Figure 1a), while Figure 1b shows the back view of the NDE building.

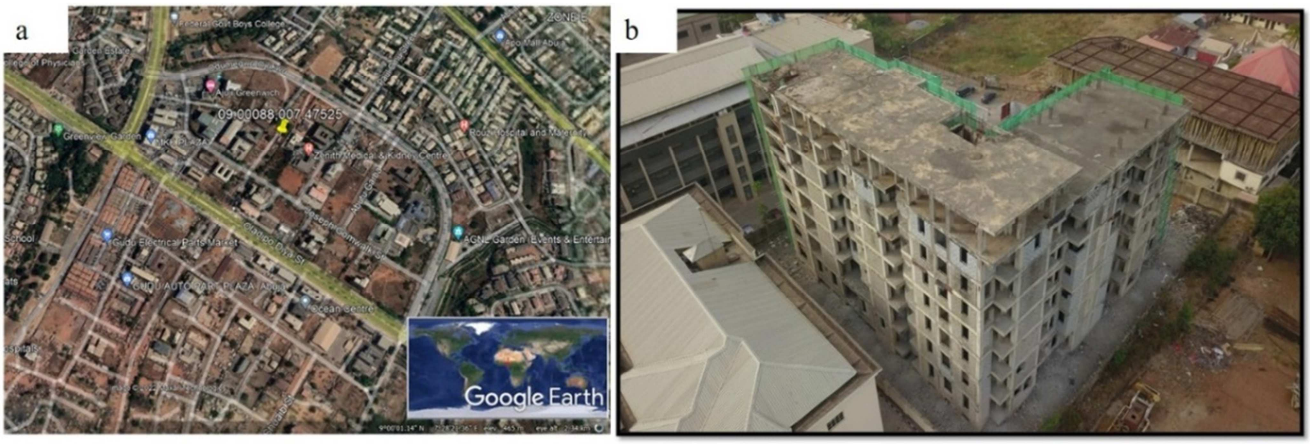

Figure 1. *(a) Earth map showing location of NDE buildings (Source Google Earth) (b) The back view of the NDE building.*

2. Methodology

A number of tests including site visit were carried out in order to analyzed the structural integrity of the targeted structure which is the National Directorate of Employment (NDE) building.

2.1. Site Visit

On March 24, 2022, the team visited the construction site. A thorough physical inspection of the building was carried out. The subsequent actions were taken to fully assess the issue and create a final test protocol. Visual evaluation was done to look for structural flaws such as structural distress and deformation, and material deterioration. The potential impact of non-structural elements on building services was also evaluated. In general, the relevant documents were reviewed, the entire structure was visually assessed, the strength of the structural components (such as the slabs, beams, columns, and foundations) were evaluated, and soil sample for testing was done.

2.1.1. The Land Use of the Area

The land is used for commercial purposes.

2.1.2. General Terrain

The area is relatively flat with no mining activities and an existing pond seen close to the building. There is also no existing gully, or stream close to the building.

2.1.3. Relevant Documents

At the time of the visit, soil and concrete cube test results were not available for scrutiny. However, structural drawings were assessed; the document shows that the structural elements such as slabs, beams, columns, and foundations were properly designed.

2.1.4. Visual Inspection of the Structure

The building was framed structure. In order to determine the types of structural defects; such as, structural distress and deformation, as well as material deterioration, a thorough visual inspection of the structure was conducted.

2.2. Compressive Strength Test

Some of the common methods that are employed in assessing the in-situ strength of concrete include Rebound Hammer Test (RHT), Ultrasonic Pulse Velocity Test (USPVT) and others. This research uses these two-method due to the fact that every method has its own limitation and hence using multiple methods will provide more reliable data for predicting the strength of a concrete [16].

2.2.1. Rebound Hammer Test

The Rebound Hammer Test was carried out with the view of assessing the in-situ strength of the structural members. In practice, the results from these tests are dependent upon the surface condition and moisture content of the concrete as well as the ratio of aggregate to cement paste. Prior to testing, a grinding stone was used to smooth the test surface, and then a rag is used to remove all dust from the tested area. Figure 2 (a) shows how the test was carried out. The test procedure based on ASTM C805/C05M [17] for Rebound Hammer was adhered to for accurate result.

2.2.2. Ultrasonic Pulse Velocity Test

Ultrasonic scanning is a recognized non-destructive evaluation to qualitatively assess the homogeneity and integrity of concrete. The test was based on the EN-12504-4 [18] specification. With this technique, the qualitative assessment of concrete strength and its gradation at different locations of the structural members can be assessed. Figure 2 (b) shows how the test was carried out.

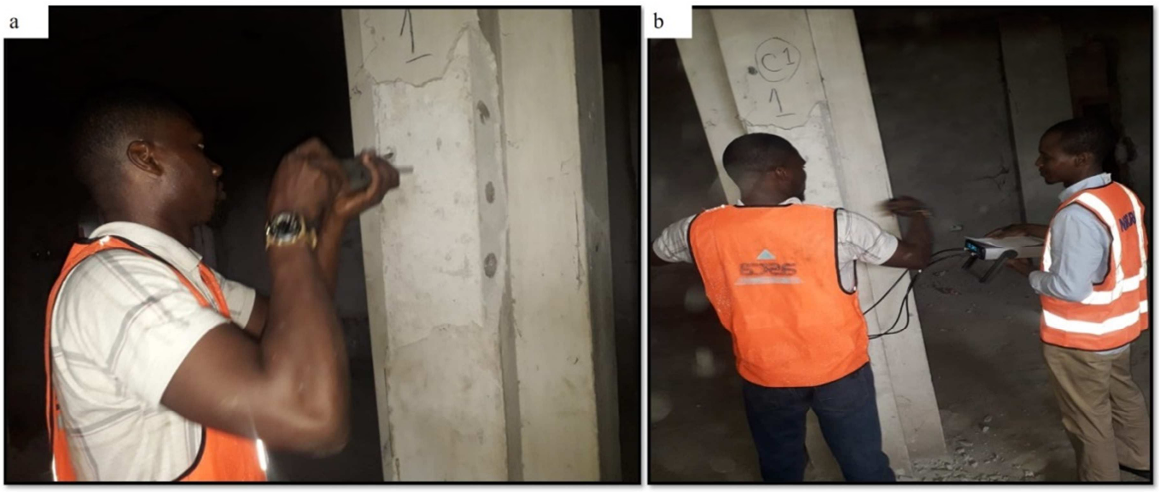

Figure 2. *(a) Testing one of the internal column using Rebound hammer (b) Testing the internal column using Ultrasonic Pulse Velocity.*

2.2.3. Geotechnical Investigation

An underground investigation was conducted to evaluate the condition of the foundation soil. Three (3) trial pits were carefully excavated to collect soil samples for laboratory tests (See Figure 3). Disturbed soil samples were obtained using a special coring machine and transported to the Nigerian Building and Road Research Institute material testing laboratory in Abuja.

The following tests were carried out on the collected soil sample:

1. Particle size analysis.
2. Atterberg Limit tests for the purpose of soil classification
3. Direct Shear Test
4. Laboratory Consolidation Test

All tests were carried out in accordance with relevant standards and relevant literature in the area of concrete structures and geotechnical engineering, namely [19, 20].

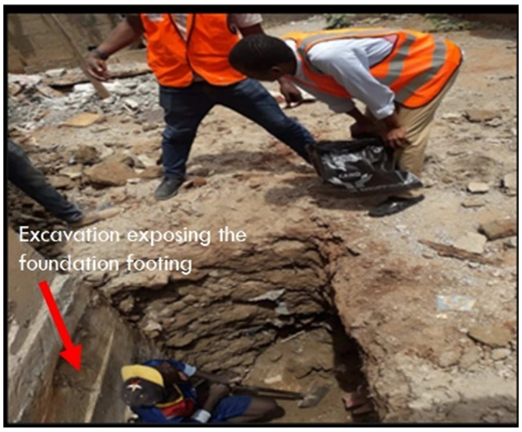

Figure 3. *One of the Excavated pit for soil sample.*

3. Results and Discussion

The oral interview, physical observations, soil laboratory test results, concrete strength test results, rebar sizes and depth using radar machine, and foundation analysis were all analyzed and discussed.

3.1. Oral Interview

The oral interviews conducted confirm that there were no mining activities as well as an existing pond close to the building. There was also no existing gully, or stream close to the buildings.

3.2. Physical Observation

The building is relatively in stable condition at the time of the visit. No cracks were seen on the walls, as well as structural elements of the building, except around the slanted wall section at the last floor of the building that showed exposure of reinforcement bars due to poor formwork as shown in Figure 4.

Figure 4. *Exposed reinforcement bars at the last floor of the building.*

3.3. Compressive Strength Test

3.3.1. Rebound Hammer

The assessment of columns, beams, and slab sections revealed that many of the tested members had good rebound values (See Figure 5 – 7). The quality of concrete may be interpreted as shown in the Table 1.

Table 1. *Average Rebound number and quality of concrete [22].*

Average Rebound Number	Quality of Concrete
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated

At the column, a total of one hundred and fourty five (145) points on the building were identified and tested. Figure 5 shows the quality of the selected critical column at different floors in the building which ranges from 33.20 – 37.40 Average Rebound Numbers (RNs). According to the table for Standard Rebound Rating of Concretes by Anand & Ankush [21], the quality of the concrete layers is good which indicate that majority of the concrete strengths are within acceptable bounds. The column marked 1C2 at the first floor with an Average RN 37.40 is the strongest element of all the twenty nine (29) columns tested while the column marked 4C4 at the fourth floor with an average RN 33.20 is the least element.

At the beam, a total of one hundred (100) points on the building were identified and tested. Figure 6 shows the quality of the selected critical beams at different floors in the building which ranges from 33.80 – 37.60 Average Rebound Numbers (RNs), indicating that majority of the concrete strengths of the beams are within acceptable bounds as reported by Anand & Ankush [21]. The beam marked 0BM1 at the ground floor with an Average RN 37.60 is the strongest element of all the twenty (20) beams tested while the beam marked 4BM4 at the fourth floor and beam marked 5BM3 at the fifth floor with an average RN 33.80 were the least element.

Similarly, at the slab panals, a total of eighty (80) points were identified and tested. Figure 7 shows the quality of the selected critical slab panals at different floors in the building ranges from 32.80 – 38.00 Average Rebound Numbers (RNs), indicating that the concrete strengths of the slab panals are good according to Anand & Ankush [21]. The slab panal marked 1SL4 at the first floor with an Average RN 38.00 is the strongest element of all the sixteen (16) panals tested while the slab panal marked 6SL1 at the sixth floor with an average RN 32.80 was the least element.

3.3.2. Ultrasonic Pulse Velocity

Based on the guidelines as reported by Kumar, M. J. et'al, [22] in Table 2, the result shows that the concretes are of good quality (See Figure 8, 9 and Figure 10).

Table 2. *Classification of concrete by the ultrasonic pulse velocity test [21].*

Range of ultrasonic pulse velocity results (km/s)	Classification of concrete
>4.5	Excellent
3.5 – 4.5	Good
3.0 – 3.5	Medium
<3.0	Doubtful

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(FEDERAL MINISTRY OF SCIENCE, TECHNOLOGY & INNOVATION)

NON DESTRUCTIVE TEST

LOCATION : Plot 1076, cadastral zone, Sestor B18, Gudu District, Abuja — Date : 27/04/22

PROJECT: STRUCTURAL INTEGRITY TEST OF NATIONAL DIRECTORATE OF EMPLOYMENT (NDE), ABUJA NIGERIA. — Con. Grade :25

CLIENT: Eldov Consultants Nigeria Limited of Suite A13, Saham Plaza, 10 Alexander Crescent, Wuse 2, Abuja — 1st, 2nd, 3rd, 4th, 5th & 6th Floors

S/N	Column Mark	VALUES OF REBOUND NUMBER FOR SOME SELECTED CRITICAL COLUMNS													Average Rebound Values
	FIRST FLOOR							FOURTH FLOOR							
1	1C1	34	38	34	38	40	**36.80**	16	4C1	32	34	40	37	39	**36.40**
2	1C2	37	40	36	33	41	**37.40**	17	4C2	36	31	36	32	40	**35.00**
3	1C3	37	32	39	33	32	**34.60**	18	4C3	33	36	41	36	34	**36.00**
4	1C4	38	34	36	40	37	**37.00**	19	4C4	38	30	32	31	35	**33.20**
5	1C5	30	37	34	30	38	**33.80**	20	4C5	32	32	40	32	39	**35.00**
	SECOND FLOOR							FIFTH FLOOR							
6	2C1	40	32	34	36	38	**36.00**	21	5C1	30	35	34	37	41	**35.40**
7	2C2	38	37	35	40	30	**36.00**	22	5C2	34	40	36	33	32	**35.00**
8	2C3	38	31	35	35	38	**35.40**	23	5C3	37	35	30	41	30	**34.60**
9	2C4	35	33	32	37	36	**34.60**	24	5C4	32	32	38	33	34	**33.80**
10	2C5	30	38	40	37	31	**35.20**	25	5C5	38	32	40	30	32	**34.40**
	THIRD FLOOR							SIXTH FLOOR							
11	3C1	35	32	35	38	35	**35.00**	26	6C1	33	37	34	32	36	**34.40**
12	3C2	35	38	33	35	38	**35.80**	27	6C2	37	30	37	30	38	**34.40**
13	3C3	33	36	34	32	36	**34.20**	28	6C3	35	37	32	34	37	**35.00**
14	3C4	33	36	33	31	35	**33.60**	29	6C4	34	36	41	30	39	**36.00**
15	3C5	35	35	36	32	35	**34.60**								

REMARKS:

Conducted by	Mr. Sylvanus Okhomeh
Checked by	Engr. Miiraj A. M.
Approved by	Engr. Dr. Jibrin Sule

Figure 5. *Average rebound hammer value of the selected critical column at different floors in the building.*

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S/N	Beam Mark	VALUES OF REBOUND NUMBER FOR SOME SELECTED CRITICAL BEAMS													Average Rebound Values
	GROUND FLOOR							FOURTH FLOOR							
1	0BM1	30	38	40	38	42	**37.60**	14	4BM1	35	31	37	40	32	**35.00**
2	0BM2	42	31	41	30	37	**36.20**	15	4BM2	35	33	40	36	37	**36.20**
3	0BM3	33	31	41	39	32	**35.20**	16	4BM3	33	40	33	38	35	**35.80**
4	0BM4	33	37	32	42	30	**34.80**	17	4BM4	32	33	38	30	36	**33.80**
5	0BM5	34	32	41	30	42	**35.80**								
	FIRST FLOOR							FIFTH FLOOR							
6	1BM1	31	41	31	40	33	**35.20**	18	5BM1	33	32	35	38	32	**34.00**
7	1BM2	33	32	37	38	35	**35.00**	19	5BM2	34	37	34	40	31	**35.20**
8	1BM3	36	41	32	34	40	**36.60**	20	5BM3	30	32	35	38	34	**33.80**
	THIRD FLOOR														
9	3BM1	34	40	36	33	40	**36.60**								
10	3BM2	33	36	32	40	33	**34.80**								
11	3BM3	34	37	32	37	35	**35.00**								
12	3BM4	33	37	32	34	40	**35.20**								
13	3BM5	35	35	36	32	35	**34.60**								

REMARKS

Conducted by	Mr. Sylvanus Okhomeh
Checked by	Engr. Miiraj A. M.
Approved by	Engr. Dr. Jibrin Sule

Figure 6. *Average rebound hammer value of the selected critical beam at different floors in the building.*

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S/N	Slab Mark	VALUES OF REBOUND NUMBER FOR SOME SELECTED CRITICAL SLABS PANELS													Average Rebound Values
	FIRST FLOOR							FIFTH FLOOR							
1	1SL 1	33	30	32	35	38	**33.60**	10	5SL 1	30	34	36	33	32	**33.00**
2	1SL 2	30	34	38	37	40	**35.80**	11	5SL 2	31	32	40	37	33	**34.60**
3	1SL 3	33	31	30	40	31	**33.00**	12	5SL 3	32	40	33	39	36	**36.00**
4	1SL 4	35	38	39	40	41	**38.60**	13	5SL 4	33	38	35	38	30	**34.80**
	THIRD FLOOR							SIXTH FLOOR							
5	3SL 1	37	38	32	37	34	**35.60**	14	6SL 1	33	35	36	29	31	**32.80**
6	3SL 2	34	35	35	34	34	**34.40**	15	6SL 2	35	39	35	32	34	**35.00**
7	3SL 3	35	36	33	38	30	**34.40**	16	6SL 3	39	38	37	32	37	**36.60**
	FOURTH FLOOR														
8	4SL 1	34	36	38	33	39	**36.00**								
9	4SL 2	39	40	37	35	33	**36.80**								

REMARKS:

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Figure 7. *Average rebound hammer value of the selected critical slab panals at different floors in the building.*

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NON DESTRUCTIVE TEST

	Date	27-Apr-22
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CLIENT: Eldov Consultants Nigeria Limited of Suite A13, Saham Plaza, 10 Alexander Crescent, Wuse 2, Abuja	1st, 2nd, 3rd, 4th, 5th, & 6th Floors	

S/N	COLUMN MARK	ULTRASONIC PULSE VELOCITY (UPV)	REMARK	S/N	COLUMN MARK	ULTRASONIC PULSE VELOCITY (UPV)	REMARK
	FIRST FLOOR			FOURTH FLOOR			
1	1C1	4.153	**Good**	1	4C1	4.631	**Excellent**
2	1C2	3.964	**Good**	2	4C2	3.546	**Good**
3	1C3	3.771	**Good**	3	4C3	3.887	**Good**
4	1C4	3.765	**Good**	4	4C4	3.761	**Good**
5	1C5	4.007	**Good**	5	4C5	3.901	**Good**
	SECOND FLOOR				FIFTH FLOOR		
1	2C1	3.879	**Good**	6	5C1	3.980	**Good**
2	2C2	4.129	**Good**	7	5C2	3.664	**Good**
3	2C3	3.891	**Good**	8	5C3	3.987	**Good**
4	2C4	3.749	**Good**	9	5C4	4.120	**Good**
5	2C5	3.832	**Good**	10	5C5	3.659	**Good**
	THIRD FLOOR				SIXTH FLOOR		
1	3C1	4.213	**Good**	11	6C1	4.003	**Good**
2	3C2	3.901	**Good**	12	6C2	3.812	**Good**
3	3C3	3.897	**Good**	13	6C3	3.902	**Good**
4	3C4	3.876	**Good**	14	6C4	3.784	**Good**
5	3C5	4.201	**Good**				

REMARKS:

Conducted by	Mr. Sylvanus Okhomeh
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Approved by	Engr. Dr. Jibrin Sule

Figure 8. *Ultrasonic Pulse Velocity Value of the selected critical columns at different floors in the building.*

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					Concrete Grade		25
CLIENT: Eldov Consultants Nigeria Limited of Suite A13, Saham Plaza, 10 Alexander Crescent, Wuse 2, Abuja					Ground, 1st, 3rd, 4th & 5th Floors		
S/N	**BEAM MARK**	**ULTRASONIC PULSE VELOCITY (UPV)**	**REMARK**	**S/N**	**BEAM MARK**	**ULTRASONIC PULSE VELOCITY (UPV)**	**REMARK**
	GROUND FLOOR			**FOURTH FLOOR**			
1	0BM1	3.878	**Good**	1	4BM1	3.913	**Good**
2	0BM2	3.976	**Good**	2	4BM2	3.546	**Good**
3	0BM3	3.523	**Good**	3	4BM3	3.887	**Good**
4	0BM4	3.543	**Good**	4	4BM4	3.761	**Good**
5	0BM5	4.241	**Good**				
	FIRST FLOOR				**FIFTH FLOOR**		
1	1BM1	4.126	**Good**	1	5BM1	3.983	**Good**
2	1BM2	3.932	**Good**	2	5BM2	4.134	**Good**
3	1BM3	4.241	**Good**	3	5BM3	3.815	**Good**
	THIRD FLOOR						
1	3BM1	4.134	**Good**				
2	3BM2	3.783	**Good**				
3	3BM3	3.951	**Good**				
4	3BM4	4.032	**Good**				
5	3BM5	3.851	**Good**				
REMARKS:							
Conducted by			Mr. Sylvanus Okhomeh				
Checked by			Engr. Miiraj A. M.				
Approved by			Engr. Dr. Jibrin Sule				

Figure 9. *Ultrasonic Pulse Velocity Value of of the selected critical beams at different floors in the building.*

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PROJECT: STRUCTURAL INTEGRITY TEST OF NATIONAL DIRECTORATE OF EMPLOYMENT (NDE), ABUJA NIGERIA.					Date		27-Apr-22
					Concrete Grade		25
CLIENT: Eldov Consultants Nigeria Limited of Suite A13, Saham Plaza, 10 Alexander Crescent, Wuse 2, Abuja					1st, 3rd, 4th, 5th, & 6th Floors		
S/N	**SLAB MARK**	**ULTRASONIC PULSE VELOCITY (UPV)**	**REMARK**	**S/N**	**SLAB MARK**	**ULTRASONIC PULSE VELOCITY (UPV)**	**REMARK**
	FIRST FLOOR			**FIFTH FLOOR**			
1	1SL 1	3.850	**Good**	1	5SL 1	3.980	**Good**
2	1SL 2	4.150	**Good**	2	5SL 2	3.664	**Good**
3	1SL 3	3.720	**Good**	3	5SL 3	3.987	**Good**
4	1SL 4	3.940	**Good**	4	5SL 4	4.120	**Good**
	THIRD FLOOR				**SIXTH FLOOR**		
1	3SL 1	3.890	**Good**	1	6SL 1	3.780	**Good**
2	3SL 2	4.210	**Good**	2	6SL 2	4.100	**Good**
3	3SL 3	3.930	**Good**	3	6SL 3	3.976	**Good**
	FOURTH FLOOR						
1	4SL 1	4.620	**Excellent**				
2	4SL 2	3.890	**Good**				
REMARKS:							
Conducted by			Mr. Sylvanus Okhomeh				
Checked by			Engr. Miiraj A. M.				
Approved by			Engr. Dr. Jibrin Sule				

Figure 10. *Ultrasonic Pulse Velocity Value of of the selected critical slab panals at different floors in the building.*

3.3.3. Rebar Sizes and Depth Using Radar Machine

The radar method is a technology that transmits and receives high-frequency electromagnetic waves to picture the subsurface of materials. Ground Penetrating Radar (GPR) has proven to be a useful technique for the non-destructive analysis of concrete structures and it allows engineers to quickly trace electrical conduits, detect voids, recognize reinforcing elements and quantify slab thickness, on the site. This research uses this technique to assesses reinforcement in the building. The tested points were randomly selected though with emphasis on critical structural members. Table 3 – 6 shows details of the reinforcement in the building.

Table 3. *Ground floor Columns.*

S/N	Test Point	Size	Reinforcement			Remark
		Columns Size (mm x mm)	Main	Stirrups	Cover	
1	C1	600X300	20YØ25mm	@ 175c/c	25	Satisfactory
2	C2	750X230	14YØ25mm	@ 175c/c	25	Satisfactory
3	C3	600X230	12YØ25mm	@ 175c/c	24	Satisfactory
4	C4	450X230	12YØ25mm	@ 175c/c	26	Satisfactory
5	C5	450X400	14YØ25mm	@ 175c/c	25	Satisfactory
6	C6	NIL	-	-	-	-
7	C7	600x230	12YØ25mm	@ 175c/c	25	Satisfactory
8	C8	450x230	8YØ16mm	@ 175c/c	24	Satisfactory
9	C9	NIL	-	-	-	-
10	C10	450x230	8YØ25mm	@ 175c/c	27	Satisfactory

Table 4. *First Floor columns.*

S/N	Test Point	Size	Reinforcement			Remark
		Columns Size (mm x mm)	Main	Stirrups	Cover	
1	C1	600X300	18YØ25mm	@ 175c/c	27	Satisfactory
2	C2	750X230	14YØ25mm	@ 175c/c	24	Satisfactory
3	C3	600X230	12YØ25mm	@ 175c/c	26	Satisfactory
4	C4	450X230	12YØ25mm	@ 175c/c	25	Satisfactory
5	C5	450X400	10YØ25mm	@ 175c/c	26	Satisfactory
6	C6	NIL	-	-	-	-
7	C7	600x230	10YØ25mm	@ 175c/c	25	Satisfactory
8	C8	450x230	8YØ25mm	@ 175c/c	28	Satisfactory
9	C9	NIL	-	-	-	-
10	C10	450x230	8YØ25mm	@ 175c/c	26	Satisfactory

Table 5. *Second Floor Columns.*

SN	Test Point	Size	Reinforcement			Remark
		Columns Size (mm x mm)	Main	Stirrups	Cover	
1	C1	600x300x300	16YØ25mm	@ 175c/c	27	Satisfactory
2	C2	700X230	14YØ25mm	@ 175c/c	25	Satisfactory
3	C3	600X230	10YØ25mm	@ 175c/c	25	Satisfactory
4	C4	450X230	12YØ25mm	@ 175c/c	26	Satisfactory
5	C5	450x400	12YØ25mm	@ 175c/c	24	Satisfactory
6	C6	NIL	-	-	-	-
7	C7	600X230	12YØ25mm	@ 175c/c	25	Satisfactory
8	C8	450x230	8YØ25mm	@ 175c/c	26	Satisfactory
9	C9	NIL	-	-	-	-
10	C10	450x230	8YØ25mm	@ 175c/c	24	Satisfactory

Table 6. *Third Floor Columns.*

SN	Test Point	Size	Reinforcement			Remark
		Columns Size (mm x mm)	Main	Stirrups	Cover	
1	C1	NILL	-	-	-	-
2	C2	750X230	14YØ25mm	@ 175c/c	25	Satisfactory
3	C3	600x230	12YØ25mm	@ 175c/c	27	Satisfactory
4	C4	600x230	10YØ25mm	@ 175c/c	26	Satisfactory
5	C5	450x400	12YØ25mm	@ 175c/c	24	Satisfactory
6	C6	600x300	10YØ25mm	@ 175c/c	27	Satisfactory
7	C7	600x230	10YØ25mm	@ 175c/c	25	Satisfactory
8	C8	400x230	8YØ25mm	@ 175c/c	24	Satisfactory
9	C9	NILL	-	-	-	-
10	C10	NILL	-	-	-	-

3.4. Geotechnical Investigation

Soil is typically tested to determine its variability and to obtain data for specific geotechnical calculations. The following tests were carried out in the laboratory based on the client's requested.

3.4.1. Natural Moisture Content

Table 7 presents results of the natural moisture content of soils encountered on the building site under investigation. The results depict the moisture level of existing soils consistent with the rainy season encountered during the time of sample collection. Natural moisture content values ranged from 12.65 to 22.4%.

Table 7. *Natural moisture content of soils.*

Trial Pit (TP)	TP1	TP2	TP3
Natural Moisture Content (%)	12.65	22.4	20.53

3.4.2. Specific Gravity of Soils

Table 8 presents results of specific gravities of soils encountered on the site. Specific gravity values ranged from 2.31 to 2.63.

Table 8. *Specific gravity of soils.*

Trial Pit (TP)	TP1	TP2	TP3
Specific Gravity	2.31	2.49	2.63

3.4.3. Particle Size Distribution of Soils

According to Table 9, an examination of the particle size distribution for soil samples taken from the building under investigation reveals that the samples are coarse-grained (sandy) soils with sizable proportions of fines (silt and clay) and a negligible proportion of gravel. The trial pit soils had a sizable amount of sand in them. The silt and clay content for all three (3) trial pits was less than 15%, and the gravel content was less than 4%. Given the characteristics of these soils, areas with excessive fines must be taken into account in order to prevent uneven settlements on the site.

Table 9. *Particle Size Distribution.*

Trial Pit (TP)	TP 1	TP 2	TP 3
Gravel (%)	0.35	1.12	2.38
Sand (%)	87.79	90.94	84.75
Silt + Clay (%)	12.21	7.93	12.87

3.4.4. Atterberg Limits of Soils

The outcomes of the Atterberg limit tests for the building are shown in Table 10. According to the results of the liquid limit tests, most of the soils had liquid limits that were lower than 50% across all trial pits, indicating medium to high soil plasticity. Consequently, the soil is non-plastic (NP) in all of the trial pits.

Table 10. *Atterberg Limits.*

Trial Pit (TP)	TP 1	TP 2	TP 3
Liquid Limit (%)	48.5	37.50	42.0
Plastic Limit (%)	NP	NP	NP
Plasticity Index (%)	NA	NP	NP
Shrinkage Limit (%)	NA	NA	NA

3.4.5. Classification of Soils

According to the Unified Soils Classification System (USCS), soils are coarse-grained if less than 50% pass through sieve size No. 200. Based on this criterion, most of the soil samples tested are coarse-grained soils. Results are presented in Table 11. Most soils encountered on the investigated site were classified as Clayey Sand (SC) and Silty Sand (SM), which are predominantly clayey sands or sand-silt mixtures with low to medium plasticity and generally good to poor bearing capacity as foundation materials.

Table 11. *Classification of soils.*

Trial Pit	USCS	Remarks
TP1	SM (Silty sand)	Silty sands or sand silt mixtures which generally have a good to poor bearing capacity value as foundation materials
TP2	SC (Clayey sand)	Clayey sands or sand silt mixtures which generally have a good to poor bearing capacity value as foundation materials
TP3	SC (Clayey sand)	Clayey sands or sand silt mixtures which generally have a good to poor bearing capacity value as foundation materials

3.4.6. Direct Shear Test Results

The findings from the direct shear tests, which are shown in Table 12, reveal that the soils from the building site have medium cohesion values between 3.66 and 4.41 kN/m2, which may be related to medium to high bearing capacity, and angles of internal friction between 30.9 and 42.1°.

Table 12. *Shear Strength Parameters from the building site.*

Trial Pits (TP)	TP1	TP2	TP3
Cohesion kN/m2	3.66	4.07	4.41
Angle of Internal Friction (°)	30.9	42.1	33.3

3.4.7. Bearing Capacity Analysis

The ultimate bearing capacity for foundations can be evaluated using shear strength parameters obtained from in situ or laboratory tests with suitable theoretical analysis. The Terzaghie quations, which are applicable to foundations where the depth of foundation is less than the minimum width, can be used as follows:

For square footing,

$$q_u = 1.3cN_c + \gamma Z(N_q - 1) + 0.4\gamma BN_\gamma$$

Where: q_u – Ultimate bearing capacity (kN/m^2)

c – Cohesion (kN/m^2)
γ – Unit weight (kN/m^2)
Z – Depth of footing (m)
B – Width of footing (m)
N_c, N_q, and N_γ are bearing capacity factors dependent on the angle of internal friction (φ)

The ultimate bearing capacity was calculated using the results from the direct shear test on samples collected from the trial pits.

Based on partial safety factors of 1.25, 1.50 and 1.75 on γ, φ and c respectively, and a load factor of 3, the computations for safe, Ultimate and allowable bearing capacities were made. Table 13 presents the allowable bearing capacity for an isolated square footing assuming a width of 1.2m for the trial pits.

The result from the bearing capacity analysis of the building under investigation at 1.5m shows that the site has a lower allowable bearing pressure of 96.63.1kN/m^2 and the highest value of 278.76 kN/m^2 bearing capacity.

Table 13. *Allowable Bearing pressures.*

Trial Pit (TP)	q_{ult}	q_{safe}	q_{all}
Tp1	1076.17	289.88	96.63
Tp2	5033.22	836.28	278.76
Tp3	1464.28	359.59	119.86

3.4.8. Consolidation Test

The consolidation test (also known as the oedometer test) is the primary laboratory test used to study the settlement and expansion behaviour of soils. The consolidation test performed was a one-dimensional consolidation test and was conducted in accordance with clause 3 of BS 1377: Part 5: 1990 [23]. Table 14 shows the outcomes of the one-dimensional consolidation test. The findings demonstrate that all soil samples are highly compressible for the tested stress ranges, with maximum expected vertical settlements of about 82.8 mm and minimum vertical settlements of 57.96 mm. The result indicates that the settlements are above the tolerable limit as recommended by EN 1997-1 Eurocode 7 [24]. For serviceability limits, the maximum total settlement should not exceed 25 mm.

Table 14. *Consolidation Parameters.*

Trial Pit	Depth (m)	Coefficient of Consolidation (m^2/yr)			Volume Compressibility (m^2/MN)			Remark	Settlement (mm)
		0-138	138-275	275 -550	0-138	138-275	275 -550		
1	1.5	6.1	30	18	0.28	0.046	0.056	High compressibility	57.96
2	1.5	6	29	17	0.4	0.039	0.022	High compressibility	82.8
3	1.5	6.1	30	18	0.28	0.046	0.058	High compressibility	57.96

4. Conclusions and Recommendations

4.1. Conclusions

The structural components of the National Directorate of Employment (NDE) located at Plot 1076, Cadastral Zone, Sestor B18, Gudu District, Abuja, the Nigeria Federal Capital was inspected, analysed, subjected to structural design checks, field and laboratory testing. From the results obtained and presented, the following general judgements are made.

1. According to the USCS soil classification system, the soil is predominantly clayey sands and sand-silt mixtures with low to medium plasticity and generally good to poor bearing capacity values.
2. The soil is within the acceptable range with a lower allowable bearing pressure of 96.63 kN/m^2 and a higher allowable bearing pressure of 278.76 kN/m^2.
3. The settlement is above the recommended limit as recommended by Eurocode 7 for serviceability limits. This is because the soils in all the trial pits are highly compressible and the settlement is within the tolerable limit.
4. The quality of the concrete layers were good (with Average Rebound Number between 30 to 40) which indicate that majority of the concrete strengths are within acceptable bounds.
5. The structural elements met the ultimate and serviceability requirement specifications.
6. The structural components' reliability and safety were confirmed, and they passed the integrity test.

4.2. Recommendations

The following suggestions were made;

1. All exposed reinforcement should be covered to avoid further deterioration.
2. Areas with poor concreting should be amended.
3. The roof slab should be adequately protected.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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