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An Assessment of Causative Factors of Building Collapse using Physical Analysis Tests: The Case of Oko, Anambra State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Incessant building collapses in Anambra State Nigeria is posing serious challenges to all the stakeholders in the building industry - building consultants, governments, developers, landlords and users. This has evoked great concern to all key players of the building industry. Thus, this study assessed the causative factors of building collapses in one of the cases, a collapsed uncompleted 3-story building which was reported in Oko town, Anambra State, Nigeria. A qualitative methodology involving subsoil and geotechnical investigation and also destructive testing of collapsed structural elements including sandcrete blocks, concrete and reinforcement bars; to establish the subsoil conditions, compressive strength, the yield stress as well as ductility of the reinforcements bars was adopted for this study. The results of the test carried out on the mass concrete, revealed a compressive strength ranging from 1.4N/mm^2 to 3.1N/mm^2 (standard compressive strength of 25N/mm^2), 6" solid block ranging from 0.3N/mm^2 to 0.4N/mm^2 and 6" hollow block ranging from 0.2N/mm^2, (standard strength value of 1.5 N/mm^2 for a non-load bearing sandcrete block in accordance to NIS: 587:2007). The tensile stress of the reinforcement bars (12mm and 16mm) ranging from 280.29N/mm^2 to 303.91N/mm^2 (According to NIS: 117:2004, standard yield stress value of 410N/mm^2 and ductility of 12%). The CPT revealed that the subsoil is generally too soft and the fine aggregate (sand) was poor for concreting. The findings suggest that poor foundation structure, inappropriate mix of concrete, the use of substandard materials, inadequate

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reinforcement and poor project supervision, contributed to the structural failure that lead to the collapse of the building. Therefore, this research recommends that mandatory, periodic or conditional structural integrity assessment of buildings in use and under construction becomes an exclusive preserve of highly qualified construction professionals. Standard organization of Nigeria should be vigilant to ensure that building materials imported into the country conforms to standard requirements especially the reinforcement bars.

Keywords: Building collapse; sub-soil investigation; destructive test; compressive strength, tensile stress.

1. INTRODUCTION

Man has depended on shelter from time immemorial for protection and survival against adverse weather conditions, as well as a safe place of dwelling. Using available local materials as building elements, safety, durability and strength of the materials were of utmost importance in the construction of shelters. The durability of any building material indicates the extent to which it sustains its original strength and function over a given period [1]. Like many other countries in the world, Nigeria experiences an alarming rate of building collapse. This incessant collapse of buildings has evoked great concern to all key stakeholders in the building industry including Architects, Mechanical Engineers, Structural Engineers, and Governmental housing organizations, as well as private developers, clients and users.

Studies document that structural failures in slabs have been attributed to inadequate thickness and inadequate reinforcement [2]. Furthermore, major causes of building failure are the use of substandard building materials and the employment of unqualified workers (quacks) in the building industry in an attempt to save cost and maximize profit thereby jeopardizing the quality of material, specifications and professional supervision [3,4]. A quack is a term used to refer to a person who claims to possess specific skills and can execute a job he/she does not have any or an acceptable knowledge about [5]. Unfortunately, these impostors have terribly infiltrated almost every professional sector and the Nigerian labour market today, resulting to substandard product delivery of services and incessant building failures in construction.

Failure in buildings can occur in two different ways, namely, cosmetics and structural defects. The former occurs when something has been added to or subtracted from the building, thus affecting the building fabrics and its stability. The later affects both the physical outlook and structural stability of the building [4]. In line with the above assertions, building collapse can simply be defined as a total or partial failure of one or more components of a building leading to the inability of the building to perform its principal function of comfort, satisfaction, safety and stability.

Building collapse incidence is still regularly occurring despite increasing diffusion of engineering knowledge over the years. This calls for some re-examination of control process [6]. The menace also casts a slur on the competence of the building professionals, who are responsible for designing and monitoring of building construction works. These professionals are being attacked from all angles because of the recurring incidents of building collapse. [7] however asserted that building professionals should not bear the blame because so many factors contribute to the failure of a building ranging from client’s decision, development control and building contractors.

Therefore, this study deems it very important to unravel the causative factors of a collapsed 3-story on-going building which was reported in Oko town, Anambra State, Nigeria.

1.1 An Overview of the Causes of Building Collapses in Nigeria

Building failure occurs when there is a defect in the building. Building is an enclosure designed for specific use, meant to control local climate, distribute services and evacuate waste as well having the capacity of transmitting weight to the ground [8]. Additionally, they are structures designed for human activities with the intentions of providing safety for the occupants [7]. However, the same building has been posing threats and danger to people either during or after construction as a result of its collapse. Building collapse may arise as a result of failure in building, as the building may be either a partial, progressive and total or sudden collapse.

Studies have associated building collapse to the negligence of vital aspects of the construction process including soil assessment, structural design considerations regarding live loads and dead load as well as environmental analysis such as wind and earthquakes [9].

Furthermore, building collapse or failure may either be of natural cause or as a result of man-made phenomena. Buttressing this view, [10] suggested that natural phenomenon may include typhoons and earthquakes while man-made phenomena are associated with disasters caused by man's activities with the natural environment and negligence to appropriate design consideration to building codes, heights, and load as well as quality of building materials and craftsmanship.

It is important to note that the type of soil, the use of substandard materials, poor workmanship and supervision could also lead to building collapse in most cases. It is therefore pertinent to embark on a soil test to determine the most suitable foundation type to adopt. This is because diverse soil types can cause varying problems to the foundations and subsequently affect the structural integrity of an entire building. Based on this view, [11] suggested that it is necessary to carry out a thorough soil survey to establish the true condition and compatibility of the soil in a particular site to the proposed foundation type.

Furthermore, research have shown that causes of a building failure is unique to each building, but could be attributed to several factors including quality of concrete, reinforcements, and sandcrete block as well as weak soil type, and inappropriate soil compaction [12]. Structural failure in buildings, in broad terms comes in various factors including corruption, greed, incompetence, poor planning and enforcement of building codes, as well as inadequate public awareness and education, and limited financial and technical resources [13]. These failures present themselves in a various level of severity; the worst of which is a collapse. For example, 'ready-made' hollow sandcrete blocks sold by some block-making industries do not measure up to standard due to anticipated abnormal profits. Until these lapses are put to check, the quality of the sub-structure or super-structure cannot be guaranteed. Additionally, deterioration or decay especially of material strength of a building can be attributed to the failure of some sort but a total loss of bearing strength resulting in a sudden breakdown, physical depletion and/or falling apart which is termed as collapse [14]. [4] Pointed accusing finger to all parties in the building industry, clients, and stakeholders, stating that they have contributed to building failures in various dimensions. Research evidence suggests that the experience, skill and quality of artisans in building construction is highly important in creating sound and stable structures, as it is a measure of their effectiveness and efficiency at all times during construction [15].

2. MATERIALS AND METHODS

The materials used for the test were obtained in situ at the site of the collapsed building. They include soil samples, concrete mass samples, masonry blocks; reinforcement bars (see plate 1 for the picture collapsed on-going 3 story building). The methods employed in discovering the reasons behind the collapse incidents of the studied sites are discussed below.

Subsoil Investigation: From surface observations and examination, it was ascertained that the site under investigation is prone to lots of surface water during rainy season and this can result to weakening in foundation/sub structure. The Subsoil Investigation comprise of two (2) numbers borehole to a maximum depth of 25.5m and four (4) numbers CPT (Cone Penetrometer Test).

Borehole Drilling: The geotechnical borehole was drilled using a standard shell and auger percussion rig. It was used to cut down borehole through the sandy and clayey strata. The borehole was lined with either 150mm or 250mm diameter steel drilling casings, utilizing the 250mm diameter casings to a depth of 6m before changing to the 150mm diameter until the termination of the hole.

During drilling operations, disturbed samples were regularly taken at depth interval of 0.75m and whenever changes of soil type were observed. In cohesive soil strata, apart from the usual disturbed samples, undisturbed soil samples were taken using the conventional open tube sampler by driving a 100mm diameter sampler through a total of 450mm length. The subsoil strata encountered during drilling operation are presented in the borehole log; (however, the summary of the subsoil strata is presented in Table 1). According to B.S. 1377 (1990) – Method of Testing Soils for Civil Eng. Purposes.

Table 1. Subsoil conditions of site

BH No.	Top Stratum (m)	Base Stratum (m)	Description of Stratum	Thickness of Stratum (m)	Total Depth of BH (m)
BH 1	0.0	0.2	Top soil, dark brown silty sand with plant matter	0.2	25.5
	2.0	25.5	Reddish brown lateritic sandy silty clay	25.3	
BH 2	0.0	0.2	Top soil, dark brown silty sand with plant matter	0.2	20.0
	2	20.0	Reddish brown lateritic clayey sand	19.8	

Source: Researchers' fieldwork

Cone Penetration Test (CPT): The cone penetration tests (CPT) were executed using 2.5 tons capacity Dutch Cone Penetrometer Machine. This machine is a precise instrument which measures the resistance to penetration into soil layers. The sequence of layers is interpreted from the variations of the cone end resistance with depth. The cone is pushed into the ground for 20 or 25cm by means of attached winch system at a uniform rate of about 20mm per seconds.

From the series of recorded gauge readings, a plot of the cone resistance against depth and forms a resistance profile which indicates the strata sequences penetrated.

qa =2.7 x qc (Meyerhof equation)
qa = allowable bearing pressure (KN/m^2)
qc = bearing capacity (kg/Cm^2).

Geotechnical Tests: The following tests were conducted on the fine aggregates (sand) collected from the collapsed site: sieve analysis (fine aggregate), bulk density (fine aggregate) and particle density test (specific gravity).

Sample Preparation: The samples (fine aggregates) were oven dried for 24 hours between 105^{o}c - 110^{o}C, after which they were left to cool to natural room temperature for two (2) hours. Afterwards, the samples were then divided into various groups in relation to the tests done in this report.

Sieve Analysis: This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates.

Apparatus Used: A sample divider, a thermostatically controlled oven, weighing balance, BS test sieves, a mechanical sieve shaker, trays, containers.

Test Procedure: The test procedure was according to BS 882 Part: 1992

Bulk Density Test: This method is used to determine the bulk density of given specimen fine aggregates (sand) during the concrete mix design.

Apparatus Used: Weighing Balance, Measuring Cylinder, Container.

Test Procedure: The test procedure was according to ASTM C 29

2.1 Particle Density Test (Specific Gravity)

Specific gravity is defined as the ratio of the density of a given solid or liquid substance to the density of water at a specific temperature and pressure, making it a dimensionless quantity.

Apparatus Used: weighing balance, density bottle (50ml), thermostatically controlled oven, distilled water.

Test Procedure: The test procedure was done according to ASTM 128

3. DETERMINATION OF THE COMPRESSIVE STRENGTH OF CONCRETE SAMPLES, SANDCRETE BLOCKS AND YIELD STRESS OF CONCRETE REINFORCEMENT BAR

3.1 Concrete Mass

- Concrete mass samples were randomly picked from the heap of debris generated from the collapsed building.

- Coring was done on the concrete mass samples using a core drilling machine with 100 mm diamond bit.
- The cored concrete samples were later cured in water tank for 24 hours before being subjected to compression test.
- Compressive strength tests were carried out on the cured samples using a 3000 KN capacity compression machine to determine the compressive strength of the concrete mix (see Table 2 for more details).

3.2 Sandcrete Blocks

- Sandcrete/masonry block samples (six inches hollow and solid blocks) were picked from the heap of debris generated from the collapsed building.
- Compressive strength test was carried out on the sandcrete/masonry block using a 3000 KN compressive test machine (see Tables 3 and 4 for more details).

3.3 Concrete Reinforcement Bars

- Concrete reinforcement bar samples were randomly picked from the heap of debris generated from the collapsed building.
- Tensile test was carried out on the concrete reinforcement bar samples to provide information for ductility, ultimate and yield stress on the reinforcement bars under uniaxial tensile stress (see Table 5 for more details).

Table 2. Concrete compressive strength test.

S/n	Parameter	Sample a	Sample a	Sample b	Sample c	Sample c
1	Diameter (mm)	98	98	98	98	98
2	Height (mm)	100	100	100	100	100
3	Cross Section area (mm^2)	7544	7544	7544	7544	7544
4	Volume (m^3)	0.000754	0.000754	0.000754	0.000754	0.000754
5	Mass (kg)	1.65	1.70	1.80	1.70	1.75
6	Density (kg/m^3)	2188.33	2254.64	2387.27	2254.64	2320.95
7	Load (KN)	10.6	11.2	11.9	16.6	20.2
8	Compressive Strength (N/mm^2)	1.4	1.4	1.5	2.2	2.6

Source: Researchers' fieldwork

Table 3. Sandcrete six inches (6'') solid block compressive strength test

S/N	Parameter	Sample A	Sample B	Sample C
1	Cross Section area (mm^2)	67500	67500	67500
2	Volume (m^3)	0.01519	0.01519	0.01519
3	Mass (kg)	26.35	26.90	26.90
4	Density (kg/m^3)	1734.69	1770.90	1770.90
5	Load (KN)	23.45	30.76	29.75
6	Compressive Strength (N/mm^2)	0.3	0.4	0.4

Source: Researchers' fieldwork

Table 4. Sandcrete six inches (6'') hallow block compressive strength test

S/N	Parameter	Sample 1A
1	Cross Section area (mm^2)	67500
2	Volume (m^3)	0.01519
3	Mass (kg)	14.90
4	Density (kg/m^3)	980.91
5	Load (KN)	12.32
6	Compressive Strength (N/mm^2)	0.2

Source: Researchers' fieldwork

Table 5. Tensile test result on steel reinforcement:

Bar size		yield		Ultimate			
		Load (KN)	Stress N/mm^2	Load (KN)	Stress N/mm^2	Elongation %	Weight Kg
12mm	A	37.26	279.94	45.23	399.91	12.07	
	B	33.15	293.06	47.35	418.66	12.74	
	C	31.70	280.29	45.29	400.42	12.73	
Average		34.04	284.43	45.96	406.33	12.51	0.20
16mm	A	61.05	303.56	87.21	433.66	15.72	
	B	61.10	303.81	87.28	434.01	15.77	
	C	61.12	303.91	87.31	434.15	15.69	
Average		61.09	303.76	87.27	433.94	15.73	0.40

Source: Researchers' fieldwork

STANDARD: NIS 117:2004 YIELD ≥ 410/mm^2 ELONGATION ≥ 12%

STANDARD: BS 4449:1998 YIELD ≥ 460/mm^2

4. RESULTS AND DISCUSSION

4.1 Subsoil Investigation

The samples recovered from the respective boreholes in Table 1 are sandy silty clay and clayey sand.
From the CPT readings in Table 1, it was observed that the subsoil is generally soft.

4.2 Geotechnical Tests

The sieve analysis of the fine aggregates (sand) shows that it falls within the grading zone 3 and is predominantly fine to medium grain size, which is poor for concreting. Fine aggregates (sand) that falls within the grading zone 2 are considered good for concreting. The value of the bulk density (1.46Mg/m^3) for sand did not fall within the required specification. Bulk density of value (1.7Mg/m^3-1.8Mg/m^3) for fine aggregates fall into the required specification. The Particle density test of the sand shows an unsatisfactory result with 2.59Mg/m^{3}which does not fall within the required specification.

In conclusion the fine aggregate (sand) was poor for concreting. N.B: coarse aggregate i.e. Sandstone of range 75mm-150mm was used for concreting. This type of coarse aggregate does not meet the required specification for appropriate concreting.

Mass Cored Concrete: According to deductions made in Table 2, the compressive strength test results of the tested cored concrete samples ranged from 1.4N/mm^2 to 2.6N/mm^2 and were remarked extremely low and not satisfactory. This emphatically shows that the concrete compressive strength values are far less than the required standard value of 25 N/mm^2.

Sandcrete Blocks: From results obtained in Tables 3 and 4, the compressive strength test of the tested six inches (6'') solid & six inches (6'') hollow non-load bearing sandcrete/ masonry block were ranging from 0.3N/mm^2 to 0.4N/mm^2 range and the latter 0.2N/mm^2. This emphatically shows that the compressive strength values are far less than the accepted standard of compressive strength value of 1.5N/mm^2 for a non-load bearing sandcrete/ masonry block in accordance with NIS: 587:2007 and therefore were remarked not satisfactory.

Concrete Reinforcement Bars: In line with Table 5 result, the tensile stress test conducted on the high yield concrete reinforcement bars samples (sizes of 12mm & 16mm) shows that all the reinforcement bars failed and the values (284.43N/mm^2 – 303.76N/mm^2) are far below the accepted standard and thus were remarked as NOT SATISFACTORY (In accordance to NIS: 117:2004, Yield stress values of 410N/mm^2 and ductility of 12% and above are considered SATISFACTORY).

Thus, it could be inferred that the yield stress of the tested concrete reinforcement bar samples was not of expected standard and this could be one of the major errors in construction procedure that may have compromised the integrity of the building.

5. CONCLUSION

On account of the collapsed structure, from investigations from the samples collected on site, laboratory tests and relevant discussions, the following deductions were noted;

1. Foundations were on individual footings where the load of the building was carried by the columns. The footings were resting directly on the floor without adequate concrete screeding, they were not connected by any plinth or horizontal beams to allow for even settlement of the structure.
2. The sieve analysis of the fine aggregates (sand) shows that it falls within the grading zone 3 and is predominantly fine to medium grain size, which is poor for concreting. The value of the bulk density (1.46Mg/m^3) for sand did not fall within the required specification. The Particle density test of the sand shows an unsatisfactory result with 2.59Mg/m^{3}which does not fall within the required specification.
3. The load bearing walls were grossly inadequate in compressive strength.
4. The internal partitioning acted as load bearing walls. The building did not have decking beams causing the suspended slabs to rest directly on the weak sandcrete block walls as there were no beams/girders to help transmit the floor loads to the columns.
5. The reinforcement bars used on the columns were inadequately sized, and the columns were found to be inadequately reinforced to safely accommodate the transmittable loads of the structure. The sizes of the stirrups were also inadequate and were widely spaced on the reinforcement bars.
6. The concrete compressive strength values from the tested cored concrete were far below the required concrete compressive strength of 25N/mm^2 which means that the concrete used was of low grade and unfit for a structural frame of that number of floors.

This research therefore attributes the probable causes of building collapse to poor foundation structures, inadequate reinforcement, poor concrete mix and weak subsoil structure.

6. RECOMMENDATIONS

The following recommendations should be ensured to avert the danger of building collapse:

- Building industry professionals should maintain their integrity and professional ethics by ensuring that work is executed to standard practice procedures laid down by the standard form of building contracts.
- Proper supervision, inspection and monitoring of construction works by town development agencies.
- Town development agencies should enforce control of building works in their localities as laid down in the building codes and bye laws.
- Soil investigation and material tests should be made compulsory for all institutional, industrial, residential and commercial buildings.
- All building plans tendered by any developer for approval must comply with the Nigeria's national building code and local bye laws and regulations.
- There is need to empower and restructure available materials testing laboratories in the country.
- Standard organization of Nigeria, (SON) should monitor the standard of blocks moulded in block industries and impose minimum standard in terms of sand-cement ratios.
- Standard organization of Nigeria should be vigilant to ensure that building materials imported into the country conforms to standard requirements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Plate 1. Picture of the 3-Storey- Collapsed Building at Oko, Anambra State Nigeria.

Plate 2. Samples from the collapsed building site

Plate 3. Coring of the concrete mass sample

Plate 4: Cored Concrete mass samples

Plate 5. Curing of sample specimen for 24 hours

Plate 6. Subjected crushed concrete sample

Plate 7. Tensile strength test of reinforcement steel sample

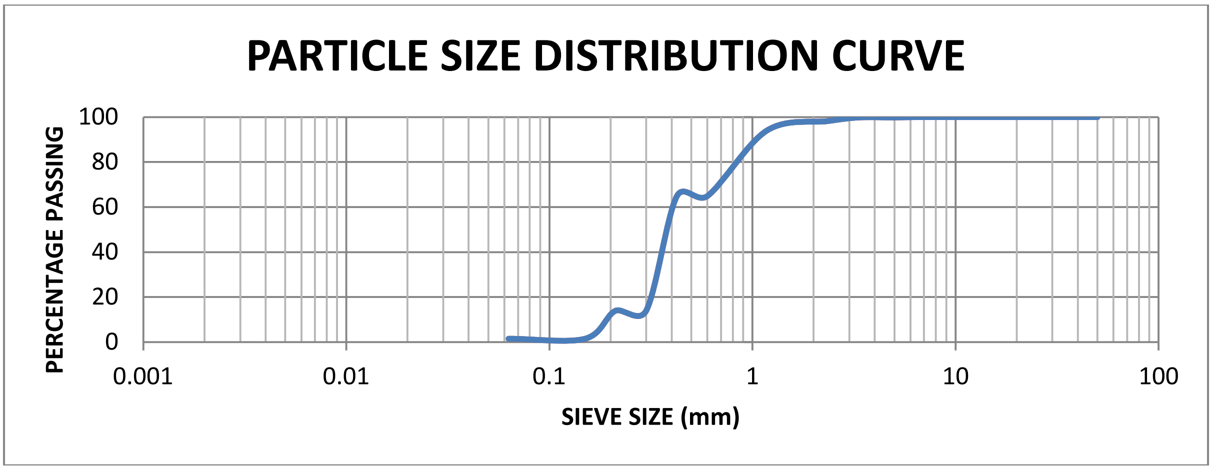
PARTICLE SIZE DISTRIBUTION (BS 1377:2:1990)

SAMPLE DESCRIPTION: MEDIUM TO FINE SAND

TOTAL MASS OF DRY SAMPLE: 1000g

Wt Retained	Cumm. Wt Retained	% Retained	Cumm % Retained	Sieve Size	% Passing
0.00	0	0.00	0.00	75	
0.00	0	0.00	0.00	63	
0.00	0	0.00	0.00	50	
0.00	0	0.00	0.00	37.5	
0.00	0	0.00	0.00	28	
0.00	0	0.00	0.00	20	
0.00	0	0.00	0.00	14	
0.00	0	0.00	0.00	10	
0.00	0	0.00	0.00	6.3	100.00
1.42	1.42	0.14	0.14	5	99.86
0.00	1.42	0.00	0.14	3.35	99.86
16.10	17.52	1.61	1.75	2.36	98.25
41.87	59.39	4.19	5.94	1.18	94.06
291.72	351.11	29.17	35.11	0.6	64.89
0.00	351.11	0.00	35.11	0.425	64.89
509.53	860.64	50.95	86.06	0.3	13.94
0.00	860.64	0.00	86.06	0.212	13.94
124.61	985.25	12.46	98.53	0.15	1.48
0.00	985.25	0.00	98.53	0.063	1.48
14.75	1000.00	1.48	100.00	Pan	
1000.00		100			

Soil Analysis (%)	
Coarse Gravel -	
Fine Gravel -	0.00
Coarse Sand -	1.75
Medium Sand -	33.36
Fine Sand -	63.41
Fines -	1.48



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