ANALYSIS OF THE CAUSES OF FAILURE OF A STOREY BUIDING ALONG OSUN STATE UNIVERSITY ROAD, OSOGBO.

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Abstract

Building collapse has become a very common occurrence in Nigeria. For this current study, relevant analysis cum investigations carried out on a collapsed building along Osun State University Road, Osogbo include site reconnaissance survey, soil test, particle size distribution and non-destructive test of the remaining debris of the structural elements of the collapsed building. The results show that the building was under designed in critical areas of the building elements such as; columns, beams, and slabs. Also, investigation reveals that the client did not employ qualified personnel to provide detailed working drawing and thorough supervision which contributed majorly to the collapse of the building. Results also show that the fine and coarse aggregate used were uniformly graded, thereby satisfying the requirement of BS EN 12620 (2008) for fine and coarse aggregate used for the building concrete. This study observed importantly that the characteristic compressive strength; fcu = (20N/mm^2) recommended for reinforce-concrete was not met by the constructors. It is therefore concluded that lack of detailed working drawings, supervision, use of inappropriate sandcrete block, poor concrete production, improper reinforcement placement among others, contributed to the collapse of the building.

Key Words: concrete, compressive strength, reinforcing bar, BS: British Standard etc.

Introduction

Building collapse has become a serious recurring problem in Nigeria that seems to defy solution. Ogunbiyi et al (2015), suggested that among contributing factors to building collapse are; structural under-design, greed, incompetence (designers and constructors), corruption, poor planning, poor workmanship, lack or improper supervision, poor or non-enforcement of prevailing codes, inadequate public awareness and education and limited financial and technical expertise among other factors. These have resulted to loss of lives and properties. Apart from old and dilapidated buildings, buildings under construction are collapsing at an alarming rate especially during the rainy season. There is no exception in terms of location or region to this serious problem. A place like Osogbo, where the geological formation is reasonably firm and well compressed, it will be expected that building collapse will be rare but alas, it is rife. One of such series of collapses is a single storey building located along the University Road, Oke-Baale, Osogbo, the subject of this study. At first glance, it is apparent that the geological formation in the area is competent to support the simplest of foundation for a storey building and work carried out in the same area confirm that the shear strength of the soil in this locality is good to bear medium sized building akin to the one that collapsed under construction. The collapse occurred at the time of casting the first floor slab according to information gathered. The extent of the collapse was total with little remnants of blockwork remaining. From the physical site investigation, it was clear that the building was built as a load-bearing block support structure. The layout of the structural members is evident from the ground floor plan exposed after the rubbles were cleared. The exposed reinforcement bars of the beams, columns and slab shows low reinforcement provision. It is based on the foregoing facts that this study intends to investigate and analyze the cause(s) of the collapse of the one storey at Oke-Baale, Osogbo, Osun State, Nigeria.

Figures: 1 & 2 Map of the Site of the Collapsed Building.

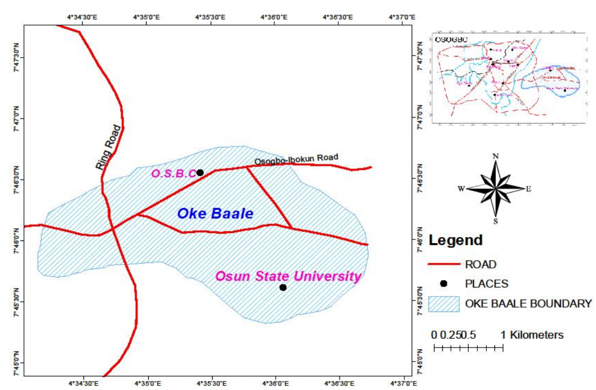

Figure 1: Map of Oke Baale area of within Osogbo Metropolis

Figure 2: Remnant of the Collapsed Building on the Site along University Road, Osogbo.

Literature Review

Marshall & Nelson (1981) defined structure as a body capable of resisting applied loads without any deformation of part relative to one another. In a simpler form, a structure is that which carries load and transfers the load from the point of load application to the point of the support into the founding medium. The structure of the building is therefore that part of building which gives the construction sufficient strength and skeletal frame-work to withstand the load to which the whole building is subjected. A building structure does this by carrying the load imposed on it, self-load and transferring same safely to the foundation, and consequently into the ground. Iyagba (2005) stated that doctors kill in unit while constructors kill in tens. This statement has come to past as a result of the increasing building collapse that has claimed many lives in our society. Buildings fail, not only because of how they are designed, but also because of how they are constructed and managed during its life-cycle.

Generally loads designed for in Nigeria are the characteristic dead and live loads; on rare occasion the building is engineered for wind-load effects. Most times failure to consider wind-load, has been responsible for either partial or total collapse of buildings especially, light structures such as steel structures. In many earthquake prone countries, ground motion is accommodated in the design of buildings. In fact, locations of high wind speeds, dynamic effect of the wind must be accounted for in addition to its static effect. Many load specifying codes such BS 6399 Part 2 (1997) presents comprehensive wind-load evaluation approach. It is hereby suggested that older codes, such as, CP3 Chapter V (1972) should not be used any longer because of its limitations in structural design. Building collapse according to the Dictionary of Architecture and Construction refers to mechanical failure. Structure collapse is the loss of structural integrity of a building or any structure that results in injury, death, or imposing major economic loss. A building collapses when one or more of its structural elements fail and when the building has reached the Ultimate Limit State (ULS).

The causes of building collapse can be attributed to either natural or man-made phenomenon. A natural phenomenon may consist of wind, sinkholes, earthquakes and tsunamis etc., while man-made phenomena consist of disasters which may be borne out of man's negligence, incompetency, design errors, faults in structural design and in most cases, lack of quality control and management during and after construction. There are unenviable statistics of building collapse in Nigeria and the intensity of such has increased unabated in the country. People are desperate to own their homes to reduce cost of living. This leads to under-designed and resourced building development leading to increase in collapse. Amobi (2006) classified factors that contribute to sub structural components failures to include differential settlement of foundation, shear, plastic and design failures; and super structural components failures to include overloading, bulking, natural disaster, poor structural design, inferior materials, poor workmanship and overloading. Ayininuola and Olalusi (2004) identified factors contributing to building failure as including the use of substandard materials and engagement of quacks rather than professionals by clients in an attempt to cut down construction cost. Olajumoke et al (2006) identified causes of structural failure in slabs to inadequate thickness and inadequate reinforcement. According to Ilesanmi (1988), individual consideration of each component could help to prevent failure at low cost. In his report, Adeoye (1998) noted that between December 1976 and January 1995, there were over 30 cases of collapse buildings reported across Nigeria with well over 250 persons losing their lives and several others being severely injured.

In addition, Amanda-Ayafa (2000) noted that between May 1987 and April 2000 over 22 cases of building failure were reported in Lagos State alone and between January 2005 and August 2006, an average eight cases of building collapse were recorded across different States in the country. Hence, as a matter of responsibility, the Federal Government, Ministry of Works and Housing, State and Local Governments, including private individuals and professional bodies should be concerned about the unabated disasters of building collapse in the country. The cost of prosecuting building right from planning and design to construction can be huge for the average citizen in Nigeria; therefore, the propensity to cut corners is high leading to abuse of the science and art of building. The negligence of the importance of foundation soil in building construction alone can be catastrophic. McCarthy (1999) stressed the importance of soil test to determine the type of foundation for a building. Olateju (1991) noted that foundation failure may be due to any or combination of the followings:

Absence of a proper investigation of the site or wrong interpretation of the results of such investigation.

Faulty design of Foundation.

Bad workmanship in the construction of foundation.

Poor construction materials during the construction of the foundation due to financial constraints.

Another contributor to building collapse is the use of poor and inappropriate materials. Uzokwe (2001) observed that the cause of a building failure can be majorly linked to the quality of materials of constructions such as poor blocks, weak concrete, low strength reinforcement and many others. Olawale et al. (2017) investigated the compressive strength of sandcrete blocks produced along the University Road, which is the source of supply by the builders responsible for the current collapsed building along the University Road, Osogbo. It was found that the maximum average compressive strength of the sandcrete blocks employed for the building is about 0.3 MPa instead of a minimum of 2.5MPa. Most of the buildings along the location of the investigated collapsed building are load bearing wall constructions. Mohammed Azad Hossain (2009) recognized the importance of good materials to avoid building collapse.

Another contributing factor is poor workmanship. In a country like Nigeria, where control of the building profession is poor, bricklayers are often referred to as engineers. Quite often, the bricklayers are the architects and structural engineers on most building sites. This, quite often leads to poor workmanship and poor finished products. Adebayo (2000) also attested to this problem of low quality ready-made hollow sandcrete blocks. He stressed the wide spread of such inadequate blocks across the country and there is no regulation of the block making industry in Nigeria. Subair (2008) reported that the use of poor materials and low standard of workmanship could fuel the building collapse phenomenon extensively. In most building sites in the country today, hardly can one find qualified professionals in charge of the sites. Majority of building constructions going on in the country is at level of low income earners. Akeju (1984) noted this earlier in his publication. Although post construction failure is of concern but the focus of analyzes and investigation for the current work is limited to the collapsed one storey building under construction along University road, Osogbo. The current work is limited to the probable causes for the collapse of this particular building under construction.

Materials and Methods:

The approach adopted for this study is to use the materials found on site so as to replicate as closely as possible what would have been the situations at the time of collapse. The samples collected at the collapsed building site included 150mm and 225mm hollow sandcrete blocks, remnant of the fine and coarse aggregates, some hardened concrete from beams, columns and slabs. Also collected are soil samples at 1.2m depth to determine the suitability of the foundation medium for the collapsed building. There are no structural drawings to determine the suitability of the structural scheme, the layout was reproduced from the foundation base arrangement and the way the collapsed beams and columns were framed together after the collapse. It was evident that the structural scheme was faulty and the need to redesign the frame was inevitable. The reinforcement in the beams, columns and slab could be estimated from the exposed parts. Re-designing of the structure was carried out using the BS 8110 (1997) code of practice.

Materials:

Prior to the re-designing re-enacting the state of the collapsed structure, the client of the collapsed building was approached but was not willing to provide the architectural and structural detailing plans used for the construction. Consequentially, as-built architectural plans and the structural scheme were re-produced from site inspection and remodeling.

Cement:

The cement used was Portland cement (Dangote brand) which is in accordance with BS EN 197-1 (2011).

Aggregates:

Both fine and coarse aggregates were obtained from the stockpile of rubbles on the site and they were air dried before the particle size distribution analysis was carried out in accordance with BS 410 (1986).

Water:

Water which is equally suitable for human consumption obtained from the Departmental laboratory of the Osun State University was used for mixing and curing of specimens.

Hardened Concrete:

Samples from the collapsed structural elements were taken for non- destructive testing.

Sandcrete Block:

Sandcrete blocks found on the sites were collected. Both 150mm and 225mm blocks were collected for compressive testing in the laboratory.

Soil Sample:

Soil samples were taken at 1.2m below the surface level for complete Atterberg Limits tests in accordance with BS 1377 -1 (1990) to determine the plasticity index of the soil and shear strength tests.

Methods:

The methods of testing include the determination of the soil plasticity index and shear strength of the founding medium. The compressive strengths of both the non-destructive and destructive types were obtained.

Soil tests:

The determination of plasticity index is carried out using Casangrande apparatus. This is done with soil of at least 200g that passed through sieve number 40 (425µm aperture). The sample was prepared by mixing the soil sample with clean potable water until consistency is obtained. A portion of the soil-water mixture was then placed in the cup of the Casangrande apparatus, leveled off parallel to the base and a groove is then cut at the centre of the soil paste, with standard grooving tool. The cup was then lifted up and dropped by turning the crank until the two parts of the soil came into contact at the bottom of the groove. The number of blows at which that occurred was be recorded and a little quantity of the soil collected to determine its moisture content.

Plastic limit:

Some portion of the soil used for the liquid limit test was retained for the determination of plastic limit and a ball of the soil was kneaded between the fingers and rolled between the palms of the hand until it dried sufficiently. The sample was then divided into approximately four equal parts. Each of the parts was rolled into a thread between the first finger and the thumb. The thread was then rolled between the tip of the fingers of one hand and the glass; this continued until the diameter of the thread is reduced to about 3mm in five to ten forward and backward movements of the hand. The crumbled soil was then put in the moisture container and the moisture content determined.

Plastic index:

The plasticity index of the soil mix is the difference between the liquid limits of the soil and their plastic limits.

$$\boldsymbol{PI = LL - PL} - - - - - - - - - - - \quad (3.3)$$

Where PI = plasticity index

LL = liquid limit

PL = plastic limit.

Particle size distribution test:

Materials were prepared and weighed accordingly; the sieves were arranged with the largest opening at the top and the pan at the bottom, pouring the aggregate at the top and shaking thoroughly, determining individual weights to the nearest 0.1g of aggregate retained on each sieve.

Compressive strength tests:

Three compressive strength tests were carried out. The cube strength test, non-destructive test (NDT) of the concrete remnants found on the site and compressive strength test of sandcrete blocks found on the site as well. The cube compressive tests are needed to establish the matric for the design while the NDT is to provide basis for comparison. It was assumed that the block walls essentially played the role of load bearing because of the inappropriate structural scheme. Although the walls were not intended or designed to carry the loads, load transfer to the foundation was assumed to essentially pass through the walls because of weak and flexible frame arrangement.

Cube compressive strength test:

The mold size of 150 x 150 x 150mm was used to cast the specimen for this test with the scavenged available materials on the site. The concrete cubes were cured for curing ages of 7, 14, 21 and 28 days. The mixing ratio used is 1:2:4 for C25 concrete grade. The cubes were removed from water at each curing age and air dried before crushing to determine the crushing load. The failure load is used to calculate the compressive strength given as:

s = Fu /A

Where Fu is the failure load (N) and A is the cross section area (mm2)

Non- destructive test (NDT):

In order to assess the compressive strength of concrete the damaged beams and columns, non-destructive test (NDT) was conducted. A rebound hammer method of determination of the compressive strength was employed. Rebound hammer consisting of a spring – loaded steel hammer that when released strikes a steel plunger in contact with the concrete surface. The spring – loaded hammer must travel with a consistent and reproducible velocity. The rebound distance of the steel hammer from the steel plunger is measured on a linear scale attached to the frame of the instrument. The test was carried out on site by holding the instrument firmly so that the plunger is perpendicular to the test surface. Gradually, the instrument was pushed towards the test surface until the hammer impacted. After impacting, the initial pressure on the instrument was maintained; this was done repeatedly up to three times, therefore the button on the side of the instrument later depressed in other to lock the plunger in its retracted position. The calibrated number on the rebound hammer was checked so as to record the rebound number. The compressive strength is then read off the calibrated chart.

Sandcrete block compressive strength test:

Three samples each of 150mm and 225mm sandcrete blocks were collected from the site. The samples were crushed to the failure point and the compressive strength computed using the failure load and the net contact surface area of the block. The block sizes are 450 x 225 x 150mm and 450 x 225 x 225mm for 150 and 225mm hollow blocks respectively. The tests were carried out in accordance with BS 1881-120 (1983).

Standard penetrometer test (SPT):

Ogunbiyi et al (2016) had worked on the classification of soil load-bearing capacity of Uniosun main campus and environs that includes the site under investigation. They established that the average shear strength of the soil close to the vicinity of the collapsed building is 187.17 kN/m2. Therefore, no further test was carried out.

Structural elements re-design:

The structural element re-design covers both the ultimate and serviceability limit states (ULS & SLS) in accordance with BS8110 provisions. The essence of the re-design is to check the adequacy of the provided reinforcements in the structural elements of the collapsed building. The elements re-designed are the solid slab, beams, columns and foundation pad footings.

Results and Discussion:

Results of all the tests and re-designs are presented in this section, also included are the structural design deficiency when the built system is compared to what it is supposed to be originally

Soil test results:

The shear strength classification of the soil in the vicinity of the collapsed building has been done by Ogunbiyi et al (2016) and the shear strength is about 187kN/m2. The only test results for this work is the plastic limit test results as presented in Table 1 blow. It is evident from the table that the soil is of good quality. It is however noted that soil characteristics from the site of the collapse are good enough for even far heavier structure with pad footings as foundation.

Table 1: Results of Atterberg Limit Tests

Samples	Liquid Limit	Plastic Limit	Plasticity Index
1	45	35	10
2	48.3	38	10.1

Sieve analysis:

The results of fine aggregates sieve analysis are presented in Tables 2 and the plot of the same is presented in Figure 1. It can be seen that the fine aggregates are uniformly graded and that they conform to near single sized particles. The results of coarse aggregate sieve analysis are also presented in Table 3 and Figure 2 respectively. It can be seen that the coarse aggregates are also uniformly graded and that they conform to near single sized particles. Both the fine and coarse aggregates on site satisfy the requirements of BS EN 12620 (2008),

Table 2: Sieve Analysis of fine aggregate

Sieve sizes (mm)	Total mass (Kg)	Percentage Retain (%)	Percentage Passing (%)
2.36	580.75	38.72	61.28
1.18	320	21.33	39.95
0.6000	250	16.67	23.28
0.3000	198	13.2	10.08
0.150	65	4.33`	5.75

0.075	75	5	0.75
Pan Total	11.25 1500	0.75	0.00

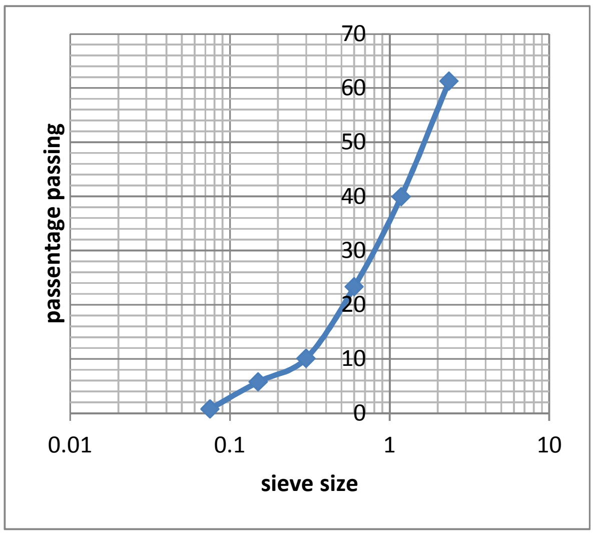

Fig 1: Curve of Sieve Analysis of Fine Aggregate

Table 3: Sieve Analysis of Coarse aggregate

Sieve sizes (mm)	Total mass (Kg)	Percentage Retain (%)	Percentage Passing (%)
37.5	-	-	100
20	99	19.8	80.2
14	151	30.2	50
10	110.4	22.08	27.92
4.5	72	14.4	13.52
Pan Total	67.6 500	13.52	0.00

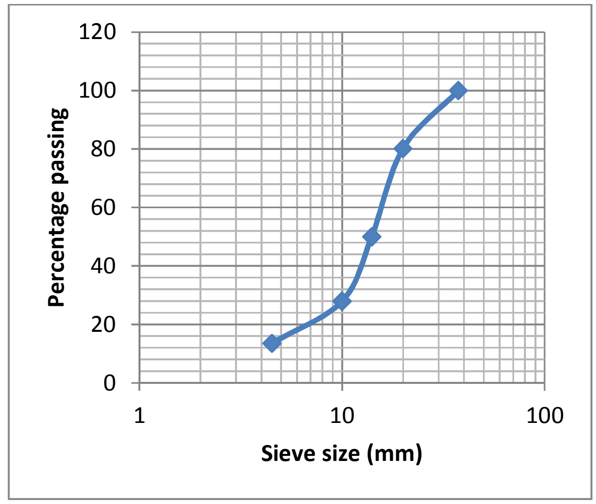

Fig 2: Curve of Sieve Analysis for Coarse Aggregate

Sandcrete compressive test results:

Results of compressive strength test carried out on the remnant samples of hollow sandcrete block collected from the site are presented in Table 4. The average compressive strength of 150mm and 225mm blocks are 0.24 and 0.27N/mm^2 respectively. These values are fractions of the recommended standard minimum values of 2.5N/mm^2 and 3.45N/mm^2 respectively. This could be one of the causes for the collapse of the building.

Table 4: Compressive Strength of Sandcrete blocks

Sample	**Weight (kg)**	**compressive strength (N/mm)**
six inches	16.32	0.32
	16.72	0.26
	16.21	0.25
Nine inches	24.31	0.22
	22.31	0.2
	17.04	0.18

Non-destructive test results (NDT):

The results of the NDT test carried out on the remnants of the structural elements are presented in Table 5. The average compressive strength for slab, beam and column are 8.92, 9.3 and 9.8 MPa respectively. These are clearly less than half of the recommended 20 MPa for grade 20 concrete the building structural elements were supposed to be designed for. This also could be one of the causes of collapse because the building was supposed to be designed and built on structural frame system for load transfer. The structural elements are grossly inadequate to withstand less than half the load of design at both ultimate and serviceability limit levels.

Table 5: NDT Compressive Test results

Structural members	Compressive strength (N/ mm2)	Average strength (N/mm2)
SLAB	8.37	8.92
	8.95	
	9.45	
BEAM	10.3	9.3
	8.4	
	9.2	
COLUMN	10.2	9.79
	9.4	
	9.6	

Cube compressive strength test results:

Table 6 shows the cube compressive strength test results for 7, 14, 21 and 28 curing ages. These were obtained using remnants of materials on site. The design mix of 1:2:4 claimed to have been used on the casting of the collapsed building reenacted as well. It is evident that the cube strength test results confirm that the design mix and the materials are adequate and of good quality because at 28 day curing age, the average compressive strength is 26.4 MPa. The disparity in the NDT and cube test results could be attributable to low quality control or things were done in a non-professional manner.

Table 6: Cube Compressive Strength

Curing Age (days)	Weight (kg)	Average compressive strength (N/mm2)
7	8.42	15.7
	8.05	
	8,61	
14	8.2	17.3
	8.52	
	8.46	
21	7.99	22
	8.74	
	8.32	
28	8.95	26.4
	8.78	
	8.94	

Structural elements design comparison:

The summary of reassessment of structural elements for flexural and shear reinforcements is shown in Table 7. It is clear from the data presented in the table that the structural elements are grossly under reinforced. This can lead to progressive failure. The maximum deficiency is in the beams of about 156% deficit. The beams are very critical in transmitting the slab loads to the columns and subsequently to the foundation.

Table 7: Comparison of steel provided with steel required

STRUCTURAL ELEMENT	PROVIDED	REQUIRED	% Deficit
Main steel (Beam)	3T16 (603mm2)	3T16 and 3T20 (603 + 943=1546mm2)	156
Main steel (Column)	6T12 (679mm2)	4T16 (804mm2)	18.4
Main steel (Slab)	T12 at 225 c/c (502mm2)	T12 at 150 c/c (754mm2)	50.2
Shear steel (Beam)	T10 at 300c/c (263mm2)	T10 at 200c/c (393mm2)	49.4
Shear steel (Column)	T10 at 300c/c	T10 at 200c/c (393mm2)	49.4

	(263mm2)		

Conclusion:

From the above discussion, it is evident that many factors are responsible for the collapse of the building at the location of study. These factors include but not limited to the followings:

Poor quality control and gross deviation from the design recommendation.

Structural scheme on site does not have clear load path leading to wall being loaded beyond their capacities.

The sandcrete blocks used on the project were clearly below minimum standard. This is grave because the same sources of supply of these blocks are still servicing the demands in the locality.

Therefore, it is very clear from this study that there is complete lack of enforcement of building regulations in Osun State in particular and Nigeria in general.

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