Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-1, Issue-4, June, 2021
www.jiengtech.com
Research Paper Open Access

SENSITIVITY ANALYSIS ON SELECTED COLLAPSED BUILDING STRUCTURES IN ANAMBRA STATE

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ABSTRACT*: This study is on the sensitivity analysis of collapsed building structures, studied were carried out using five (5) different sites of collapsed building in Anambra state as a case study. Many researches has evaluated the causes of building failures using different approaches including the probabilistic methods of analysis, but the sensitivity method of analyzing the causes of collapsed indices has not been evaluated. The sensitivity indices approach tends to show the severity classification of the z component of resolution, in terms of the indices being low, moderate and high. The application of sensitivity model gives the Z components of the resolution to make sound engineering judgment by linking directly the major causes of collapse. Five numbers of collapsed multi storey sites were studied and destructive and non destructive tests were carried out. Nine grouped indices were studied; the structural element, which includes Design cause, foundation cause, quality control cause, Engagement of quacks , detailing and specification causes and procedural causes . From the experimental study it was deduced that the sensitivity of the reinforcement detail is moderate, the sensitivity of construction method is high; it was also observed that the sensitivity of the foundation type is high; the sensitivity of using quacks is high. The sensitivity of Development control cause is high. The sensitivity of quality control is moderate. The, the sensitivity of detailing and specification is low. The sensitivity of construction cause is moderate.*

KEYWORDS*: Buildings, Causes, Collapsed, Sensitivity and Test*

Date of Submission: 27-05-2021 Date of acceptance: 02-06-2021

I. INTRODUCTION

The frequent collapse of structures in recent past has been a source of serious concern to structural engineers. Collapses are generally investigated by specialist forensic engineering teams with a view of finding the causes and possible solutions to forestall future occurrence. Findings are usually published as white papers for the information of the public. Nigeria in the recent past has had her share of building collapses especially in Lagos, Port Harcourt including Awka and its Environs. Aniekwu, and Orie 2005, Arayela and Adam 2001, Ezeagu 2007 , Ezeagu and Okolie 2016 Ezeagu, Udebunu and Obiorah (2015) The sad part of the story is that while collapses are investigated and findings are published as a professional requirement, In Nigeria, collapses have mostly been played down on and where investigations were done, they were either frustrated or findings suppressed. Various factors causes collapses of building structures in Nigeria. Such causes range from activities of quack professionals to lack of quality monitoring from development control organization of government. This project recognizes the need for an in depth investigation into the causes of building collapses in southern Nigeria. Since the remains of collapses are quickly removed or access to such sites are restricted, it is considered expedient to postulate reasonable hypothesis based on materials gathered from technical literature on selected collapsed buildings in Nigeria with a view to developing measures for eliminating or controlling them in design, construction and operations. Such studies should start at local levels to capture the local conditions such that a national data bank can be generated for the planning and management of developmental projects.

The cases of building collapses have been reported in Nigeria and many authors has proffered solutions and the problem persists. This work tends to study this problem by carrying out postmortem analysis using destructive and non destructive methods on five (5) collapsed building site in Anambra state and consequently develop sensitivity models and fits in the results obtained experimentally into both the sensitivity models for the purpose of reinstatement of the building and prevention of future occurrence.

AI. REVIEW OF RELATED WORKS

Various factors have been identified as the possible causes of structural failure of building in the background information, which include use of sub-standard material, engagement of quacks in the design and construction of building, lack of quality control, lack of soil test for foundation design, improper detailing of design etc. Several studies have identified faulty construction as one of the causes of structural failure. The most recent of these works include those of Alfred (2002), Deny (2003), Akobo and Orumu (2005). Faulty construction on site include the use of salty Sand to make concrete, the substitution of inferior steels for that specified, bad riveting or even improper tightening torque of nuts, bad welds, construction of alternative structure instead of the approved one, use of decayed formwork and placement of vertical props used for slab formwork in an unsettled soil.

According to Isaac, Akobo and Orumu (2006) wrong choice of foundation type in given soil situation is likely to lead to differential settlement of the structure with attendant cracks and sub sequent failure. In the investigations carried out on some collapsed building in Port-Harcourt and Lagos by Ephraim (2006), Oriaku (2006), Isaac, Akobo and Orumu (2006) identified lack of soil test for the design of foundation as one of the major causes of structural failure. Also Calvert (2003) attributed collapsed structure to foundation failure. Akobo et al (2003). Improper detailing and specifications such as inconsistency in reinforcement bar marks, specification of concrete cover, concrete mix and concrete strength requirement were identified. According to Reddy et al (2004), the satisfactory performance of RC structure is dependent on the accurate placement of carefully detailed reinforcements; otherwise concrete elements are marred by cracking, rust marks and similar problems directly related to workmanship. Certain defects result from poor design work, poor detailing does not permit application of satisfactory workmanship and faulty dimensioning of such critical details as location and cover to reinforcements. Akobo et al (2006). Olajumoke (2006) and Ephraim (2006), on collapsed building in Port-Harcourt, Lagos and Osun. The investigations revealed that there was no quality control undertaken during the course of the construction of the various building investigated. According to the twelfth report of the standing committee on structural safety of London (1999), lack of quality control was also identified in the investigation relating to the rams gate walkway failure. One of the main criticisms of the client was his failure to stipulate in the contractual arrangement adequate requirement for quality assurance. Rachael (2003) on the collapsed of Hartford Civic Center Roof 1978, inability to have a person responsible for the overall coordination of the construction work was one of the causes of the collapsed structure. The British standard codes BS8 8110 and BS 5950 also make it clear that in respect of overall structure stability; there should be a designer charged with the responsibility of overseeing the entire construction work in a project. According to the standing committee on Structural Safety (1999), structural failure can be guided against addressing the risk management issues as question regarding how satisfactory are the assumptions or how robust is the analysis or still what else can crop up in the process. According to the report, these issues can be handled through the following actions a. Derive specification for models, b. Validate models c. Implement sensitivity analysis d. Understand mathematical model, e. Do a simple calculation The report also stated that the importance of validation and certification of the analysis is amply demonstrated through the example of the offshore platform failure (Skiper, 1991) and the Hartford Civic Center Roof (1978). In the case of offshore platform failure, despite the huge amount of money spent on computer analysis and design, a simple hand a1culation, after the event had revealed the significant shear deficiency that resulted in failure. Also, in the case of Hartford Civic Center, the failure to allow for strut eccentricities in the analysis and design led to the collapse. The report also stated that these examples emphasized the importance generally of ensuring an understanding of site tolerance at interim stages of construction, and other matter, which might invalidate result. Extraordinary loads are often natural, such as an earthquake, hurricane or manmade as in bomb blast and terrorist act. A structure that is intended to stand the test of time should be able to meet these challenges. The World Trade Center (WTC) in New York City is a case of reference for extraordinary load causes. The studies carried out by the Federal Emergency Management Agency (PEMA), Charles Clifton (2001), Tim Wikinson (2006), National Institute of Standard and Technology (NIST) in the U.S, attributed the collapse of the Twin Tower buildings to extraordinary load factors resulting from impact of the Jet Airliners (Boeing 767-2000ER American Air lines Flight 11 and Boeing 767-200 United Airlines flight 175), which hit the towers. The flight 11 hit the WTC1 at the 99" and 93'' floors and flight 175 hit the WTC2 at 88th and 77" floors. The impact also caused the fire that engulfed the trade center complex according to their studies. The works of Zderek, Bazant and Yong Zhou attributed the cause of the collapse to the numerous weight of the portion of the towers above the impact areas which overwhelmed the load bearing capacity of the structure beneath them in addition to the impact of the jet air lines. The Nigerian construction industry has been characterized by quacks who are now parading themselves as Engineers. They engage in construction works, which they have little or no knowledge of the techniques involved. According to Ephraim (2006), considering the impact of construction in the National budget and the economy as a whole, and the abandonment of construction industry to quacks constitutes gross negligence and emphasized the need for government and professional bodies to bringing greater seriousness into the construction industry. The various investigations on collapsed buildings in Port Harcourt and Lagos also identified this factor as one of causes of structural failure in Nigeria, Ephraim (2005, 2006), Akobo & Orumu (2005, 2006).The safety of our structure cannot be guaranteed if the development control issues are not properly addressed. These control issues cut across the three tiers of government: the federal government, the state government and the local government authority. Their roles in this regard are well defined in the various policies established by the federal government. The most outstanding of these policies is the Nigeria Urban and Regional Planning Decree 88 of 1992. The decree specifies the responsibilities of the three tiers of government (Federal, State and Local).

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be divided and allocated to different sources of uncertainty in its inputs. A related practice is uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty; ideally, uncertainty and sensitivity analysis should be run in tandem. The process of recalculating outcomes under alternative assumptions to determine the impact of a variable under sensitivity analysis can be useful for a range of purposes, including: i. Testing the robustness of the results of a model or system in the presence of uncertainty. ii. Increased understanding of the relationships between input and output variables in a system or model. iii. Uncertainty reduction, through the identification of model input that cause significant uncertainty in the output and should therefore be the focus of attention in order to increase robustness (perhaps by further research) .iv. Searching for errors in the model (by encountering unexpected relationships between inputs and outputs).v. Model simplification – fixing model input that has no effect on the output, or identifying and removing redundant parts of the model structure, enhancing communication from modelers to decision makers. There are a large number of approaches to performing a sensitivity analysis, many of which have been developed to address one or more of the constraints discussed above. They are also distinguished by the type of sensitivity measure, be it based on (for example) variance decompositions, partial derivatives or elementary effects. Variance-based methods: Variance-based sensitivity analysis. Variance-based method is a class of probabilistic approaches which quantify the input and output uncertainties as probability distributions, and decompose the output variance into parts attributable to input variables and combinations of variables. The sensitivity of the output to an input variable is therefore measured by the amount of variance in the output caused by that input. From the foregoing discussion, cases of building collapse have been reported in Nigeria and many authors has proffered solutions and the problem persists. This work tends to study this problem by carrying out postmortem analysis using non destructive methods on five {5} collapsed building site in Anambra State and consequently develop sensitivity models and fits in the results obtained experimentally into the sensitivity models for the purpose of reinstatement of the building and prevention of future occurrence.

BI. MATERIALS AND METHODS

The method of research adopted for this project included the use of experiments and different test comparing the material used in the collapsed buildings and the standard obtainable within the built industry. This work tends to study this problem by carrying out post failure analysis using destructive and non destructive methods on five {5} collapsed building site in Anambra state and consequently develop sensitivity models and fits in the results obtained experimentally into the sensitivity models and for the purpose of reinstatement of the building and prevention of future occurrence.

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A. Static Analysis

a) Surface observation and close examination of the remnants of the building.
b) Inspection of the rubble to determine if the structural elements used were appropriately sized.
c) Retrieval from the debris of useful materials for laboratory destructive and non-destructive tests.
d) Verbal feed information from the neighbours and witnesses.

B. Dynamic Analysis

a) Random collection of samples from the site. The samples include;
i) Soil samples
ii) Concrete mass samples
iii) Masonry blocks of different sizes (225mmx225mm, 150mmx225mm solid).
iv) Reinforcement bars of different sizes (12mm and 16mm respectively.
b) Testing of the materials used for construction to determine if they were of expected standard.
c) Analyzing the expected performance of the components and compact load bearing capacity of the structural elements.
d) In-situ probing of the foundation to establish the type of foundation used and its dimensions after the rubbles and back filled materials had been cleared.

.C. Research Design

Schmidt Hammer Test: The compressive test of the concrete for the columns and beams were determined using the Schmidt hammer equipment. This is a device that measures the strength of a concrete, it is considered as a non-destructive test as no destroyed specimens takes place in it, the test hammer will hit the concrete at a defined energy and its rebound is dependent on the hardness of the concrete and then the compressive strength is read from the Schmidt hammer device. When conducting the test the hammer should be held at right angles to the surface. As this test is sensitive to the presence of aggregates and voids, multiple readings are taken in the test area and there average is taken as the compressive strength of the concrete.

Brinnel Hardness Test: The tensile strength of the reinforcing bars were determined by the Brinnel hardness testing and chemical analysis of the reinforcing bars from the collapsed sites, Brinnel hardness test is an hardness test that can provide us with useful information about metallic materials, the information obtained correlate to tensile strength and ductility of the material.

Geotechnical Properties of Soil: These tests include:

A. SUBSOIL INVESTIGATION: Standard Penetration Test/Cone Penetrometer Test to determine the soil bearing capacity adequacy.

Geotechnical Tests: Sieve Analysis (fine aggregate), Bulk Density (fine aggregate). Particle Density Test (Specific Gravity). Sieve analysis was carried out on the local aggregate materials at the site to determine the grain size analysis for the local aggregate by mechanical sieve analysis method. Reconnaissance surveys were carried out by visiting some of the collapsed sites. On the collapsed site, physical observations of the materials used in the construction of buildings.

Destructive Tests. The test includes

I. determination of the compressive strength of concrete samples
AI. masonry blocks
BI. Yield stress of steel reinforcement.

The following process was carried out

i. Coring, Curing and Crushing of concrete samples to determine their compressive strength.
ii. Crushing of blocks to determine their compressive strength.
iii. Tensile test of the steel bars.

Framed Structure Analyses: To check if the building was adequately framed structurally to bear the expected loads.

Purpose Of Investigation. The purpose of investigation includes the following

- **i.** To determine the general Subsoil condition of the collapse site in connection with the foundation state.
- **ii.** To analyze the structural elements and determine the adequacy of the dimensions as well as the quality of the reinforcement bars.
- **iii.** To determine the integrity and stability of the major structural elements with respect to standard.

Subsoil Investigation: As at the time of Investigation, there were heaps of debris from the collapsed building at the site. 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 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.

The drilling tools consisted of an open-tube with a non-return flap valve at one end called a shell**,** for non-cohesive (sandy) strata, and mixed soils. A clay cutter is normally employed to drill through stiff cohesive soils. This is attached to the drilling weight called sinker-bar and subsequently attached to the drilling string.

The borehole casings were turned down using chain grips, but in occasional cases, may be driven down using a special hammer. 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. These samples are usually taken at depths relevant to the objectives of the investigation. In-situ Standard Penetration Tests were performed in the boreholes. All samples comprised those from the split spoon sampler of the standard penetration test, and those from the cutting shoe of 100mm diameter sampler. All data and information so observed during the test were carefully recorded on the borehole log presented in the appendix of this report

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.

The resistance to penetration of the cone registered on the pressure gauge connected to the pressure capsule is recorded. The tube is then pushed down to the cone and the process described above is repeated.

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)

Sensitivity Analysis:

A sensitivity analysis determines the effect of various values of an independent variable on a particular dependent variable under given set of assumptions. A study of how a set of uncertainty control the model general

,$Z = X^2 + Y^2$…………………………………………………… 3. Output within specific conditions.

Sensitivity analysis is an analysis technique that works on the basis of what-if analysis like how independent factors can affect the dependent factor and is used to predict the outcome when analysis is performed under certain conditions. Sensitivity Analysis Formula: The formula for sensitivity analysis is basically a model in excel used to identify the key variables for the output formula and then assess the output based on different combinations of the independent variables.

Mathematically, the dependent output formula is represented as

$Z = X^2 + Y^2$………………………. 3. output within specific conditions.

IV. RESULTS AND DISCUSSIONS

The table hence created is the sensitivity table. Summary of the average compressive strength of concrete obtained from non destructive test using Rebound Hammer in site 1, site 2, site 3, site 4 and site 5.

Table 1. The average compressive strength of concrete obtained from non destructive test using Rebound Hammer in site 1, site 2, site 3, site 4 and site 5.

	AVERAGE COMPRESSIVE STRESS FOR COLUMN (N/mm^2)	AVERAGE COMPRESSIVE STRESS FOR BEAM (N/mm^2)	AVERAGE COMPRESSIVE STRESS FOR SLAB (N/mm^2)	CONTROL (N/mm^2)
SITE 1	10.88	10.8	10.84	25
SITE 2	8.4	8.2	8.35	25
SITE 3	15.21	14.8	15.12	25
SITE 4	9.56	9.23	9.13	25
SITE 5	6.73	6.79	6.8	25

 A l l R i g h t s R e s e r v e d .

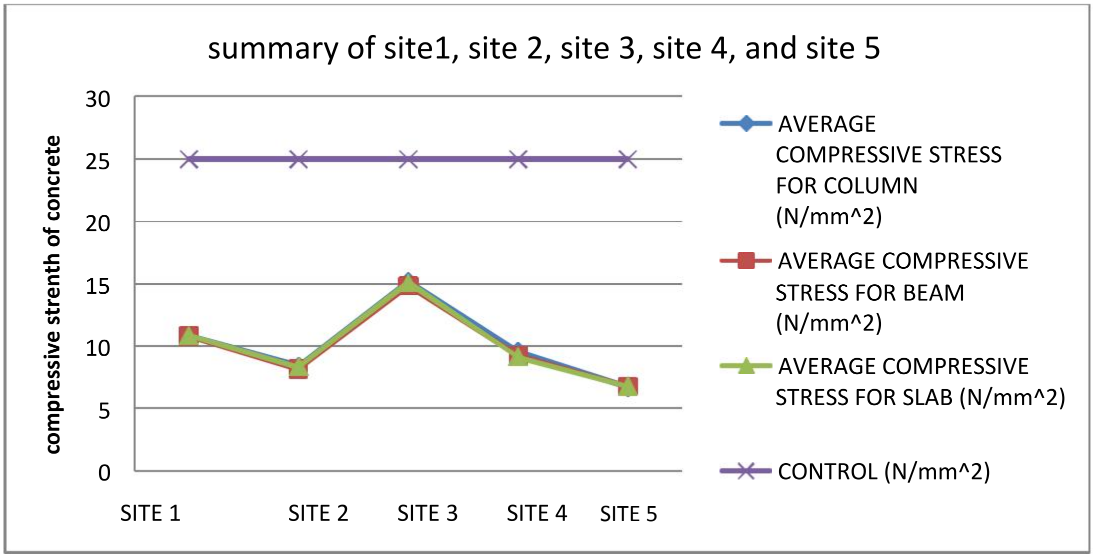

Fig.1. Summary of the various compressive strength of concrete obtained from Smith hammer test (non destructive test)

Fig.1 shows the summary of the various compressive strength of concrete obtained from Smith hammer test (non destructive test) for the various site visited, it shows that the compressive strength of concrete used for the construction does not meet up with the recommended in BS 8110 code which is 25N/mm^2. Therefore we can say that the one of the major factor that contributed their collapse is Material factor which involves weak concrete; it means sensitivity of concrete is high

Destructive Test:

Summary of Borehole Results:

The result of the tests conducted on the subsoil is as below:

i. Lack of Subsoil Investigation which would have led to the choice of appropriate foundation type, size and depth may have contributed largely as a major cause of failure that led to the collapse.
ii. Inadequate Foundation type, size and depth used for the construction of the collapsed building contributed largely to failure and the subsequent collapse of building.
Raft Foundation type should have been safely adopted.
iii. The Laboratory analysis shows the subsoil as susceptible to expansion and contraction, magnitude depending on the level of rainfall saturation.

Summary of Sub Soil Result:

The result of the test conducted on the subsoil is thus: The subsoil strata encountered while carrying out the boring and Cone Penetration Test comprise of Reddish Brown Lateritic sandy Clay with gravel, which indicates a very stable bearing capacity for the soil. From the Soil Profile Analysis, it can be inferred that the bearing capacity of the investigated soil was adequate for the imposed load and so could not have been the Probable cause of Collapse. It was not possible to determine the adequacy and state of the foundation elements at the time of collapse. However, lack of geotechnical investigation may have led to improper and wrong foundation works.

The subsoil investigation works for the collapsed building has been carried out in accordance with accepted geotechnical engineering practice as stipulated in standard code of practice which includes the following.

i. B.S. 1377 (1990)– Method of Testing Soils for Civil Eng. Purposes.
ii. B.S. 5930 (1999)– Code of Practice for Site Investigations.
iii. B.S. 8004 (1981)– Code of Practice for Foundations.

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Table 2: Average compressive strength of concrete of site 1,2,3,4 and site 5

	COMPRESSIVE STRENGHT (N/MM^2)	COMPRESSIVE STRENGHT(N/mm^2)
SITE 1	2.5	25
SITE 2	3	25
SITE 3	3.4	25
SITE 4	6.5	25
SITE 5	5	25

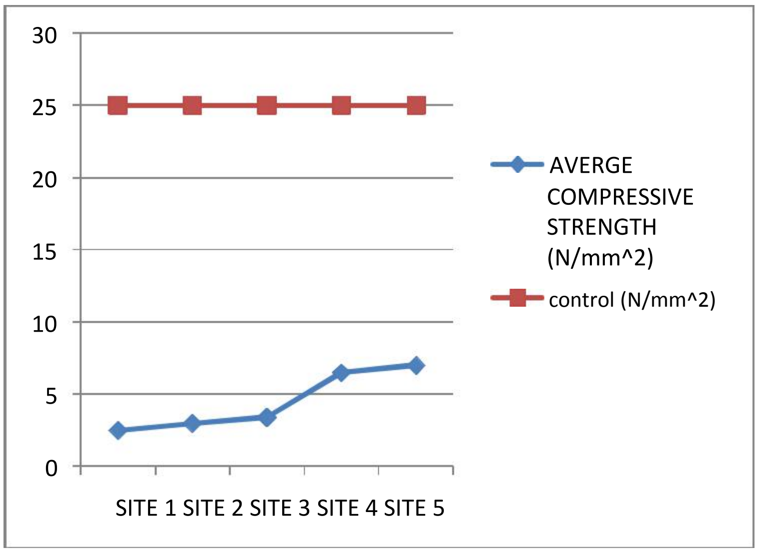

Fig. 2. Summary of the various compressive strength of concrete in the five sites

From the graph shown in Fig.2, it was observed that the compressive strength of concrete in all the five sites is far less than the control (25N/mm^2), therefore we can assert that poor material standard played a major role in the collapse of all the five collapsed building sites visited.

Sandcrete Blocks:

Randomly hand picking of used (or to be used) sandcrete/masonry block samples (six inches hollow and solid blocks) from the heap of debris generated from the collapsed building. Compressive test was carried out on the sandcrete/masonry block using a 3000 KN compressive test machine (see table 2 for more details).From the laboratory tests results obtained from compressive strength tests on sandcrete/masonry block samples, the following conclusions were deduced; The compressive strength result of the tested six inches (6'') solid & six inches (6'') hollow non-load bearing sandcrete/masonry block was of 0.3 N/mm^2 to 0.4 N/mm^{2}range and the latter 0.2 N/mm^2. (See table 2 & 3 of the report for more details). This emphatically shows that the compressive strength values are far less than the accepted standard of compressive strength value of 1.5 N/mm^2 for a non-load bearing sandcrete/masonry block in accordance with NIS: 587:2007 and therefore were remarked NOT SATISFACTORY.

SUMMARY:

Thus, Failure of any structural elements/components either due to poor concrete strength, substandard building materials or any other defect may have contributed to progressive collapse.

Concrete Reinforcement Bar:

Randomly hand picking of used concrete reinforcement bar samples 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.

From the laboratory results obtained from the tensile stress test on the concrete reinforcement bar samples, the following conclusions were deduced; The tensile stress test conducted on the high yield concrete reinforcement bars samples (sizes of 12 mm & 16 mm) shows that all the reinforcement bars failed and the values (280.29 N/mm^2 – 303.91 N/mm^2) are far below the accepted standard and thus were remarked as NOTSATISFACTORY (In accordance to NIS: 117:2004, Yield stress values of 410 N/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 were 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.

Table 3: Tensile Strength And Ductility Test For Site 1,2,3,4 And 5

	YIELD STRESS (N/mm^2)	YIELD CONTROL (N/mm^2)	ULTIMATE STRESS (N/mm^2)	ULTIMATE CONTROL (N/mm^2)	ELONGATION (%)	CONTROL (%)
SITE 1	284.43	410	406.34	460	12.01	12
SITE 2	316.89	410	452.02	460	14.03	12
SITE 3	419.35	410	599.08	460	12.73	12
SITE 4	341.33	410	642.24	460	12.51	12
SITE 5	431.56	410	6126.11	460	12.38	12

Table 4 : Tensile Strength Result Of 12mm Reinforcement Site 1, Site 2, Site 3, Site 4 And Site 5.

	YIELD STRESS (N/mm^2)	YIELD CONTROL (N/mm^2)	ULTIMATE STRESS (N/mm^2)	ULTIMATE CONTROL (N/mm^2)
SITE 1	284.43	410	406.34	460
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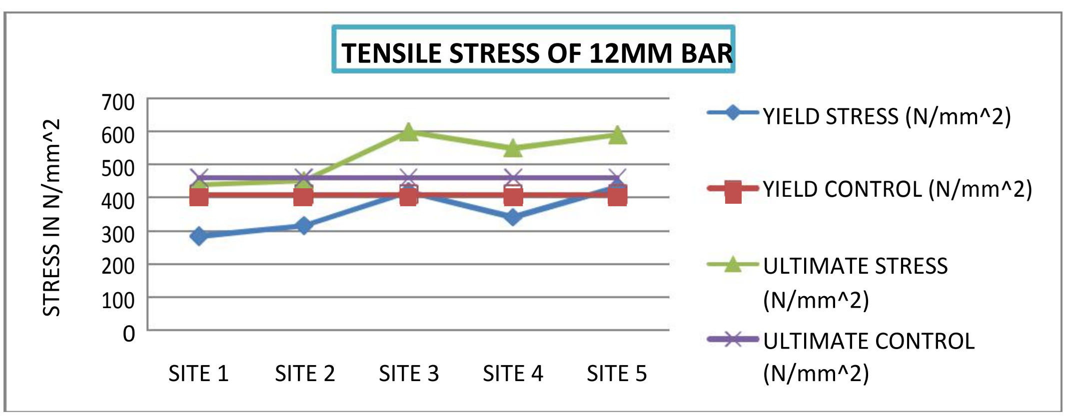

Fig. 3. Plot of Tensile stress of 12mm Bar

Table 5. Comparing 12mm bar ductility of site 1, site 2, site 3, site 4 and site 5.

	ELONGATION (%)	CONTROL (%)
SITE 1	12.01	12
SITE 2	14.03	12
SITE 3	12.73	12
SITE 4	12.51	12

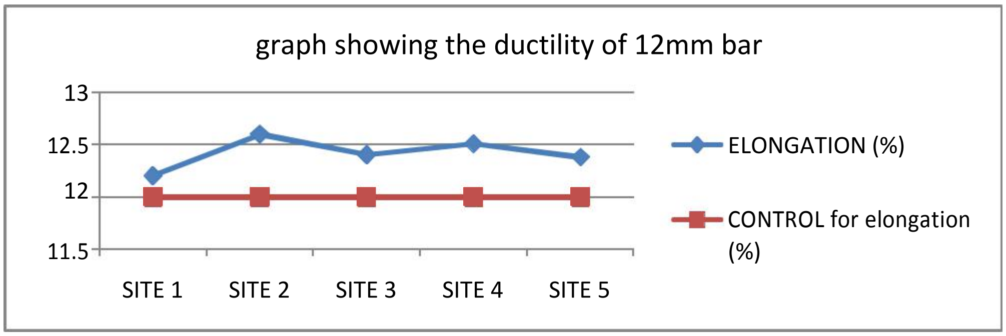

Fig. 4. Graph of ductility of 12mm bar

Table 6. Tensile Strength Result Of 16mm Reinforcement Site 1,2, 3, 4 AND SITE 5.

	YIELD STRESS (N/mm^2)	YIELD CONTROL (N/mm^2)	ULTIMATE STRESS (N/mm^2)	ULTIMATE CONTROL (N/mm^2)
SITE 1	303.76	410	433.94	460
SITE 2	397.57	410	567.95	460
SITE 3	435.87	410	622.67	460
SITE 4	436.89	410	624.09	460
SITE 5	385.84	410	608.12	460

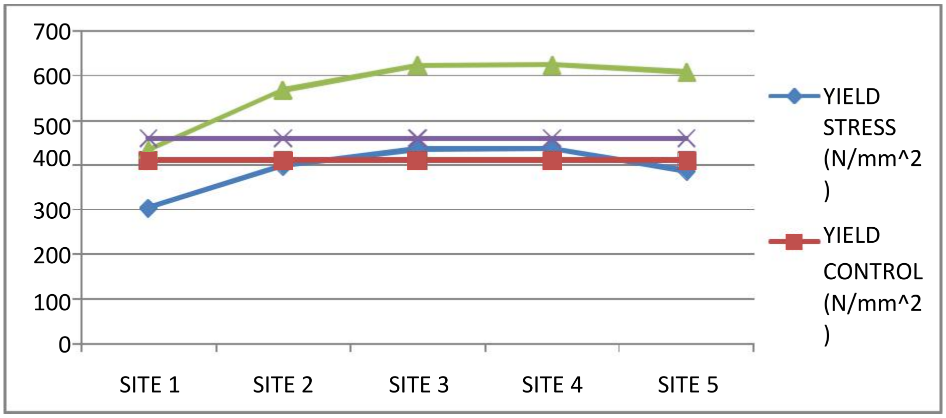

Fig. 5. Plot of ductility of 12 mm bar

Table 7. Comparing 16mm bar ductility of site 1, site 2, site 3, site 4 and site 5.

	ELONGATION (%)	CONTROL (%)
SITE 1	12.07	12
SITE 2	12.06	12
SITE 3	11.2	12
SITE 4	11.8	12
SITE 5	11.34	12

Table 8. Tensile Strength Result Of 10mm Reinforcement Site 1, 2, 3, 4 And Site 5.

	YIELD STRESS (N/mm^2)	YIELD CONTROL (N/mm^2)	ULTIMATE STRESS (N/mm^2)	ULTIMATE CONTROL (N/mm^2)
SITE 1	300.76	410	608.22	460
SITE 2	407.57	410	540.23	460
SITE 3	425.87	410	530.23	460
SITE 4	456.89	410	513.06	460
SITE 5	375.84	410	420.45	460

Fig.6 depicts a graph showing the tensile strength result obtained from site 1,2,3,4 and 5 against the control

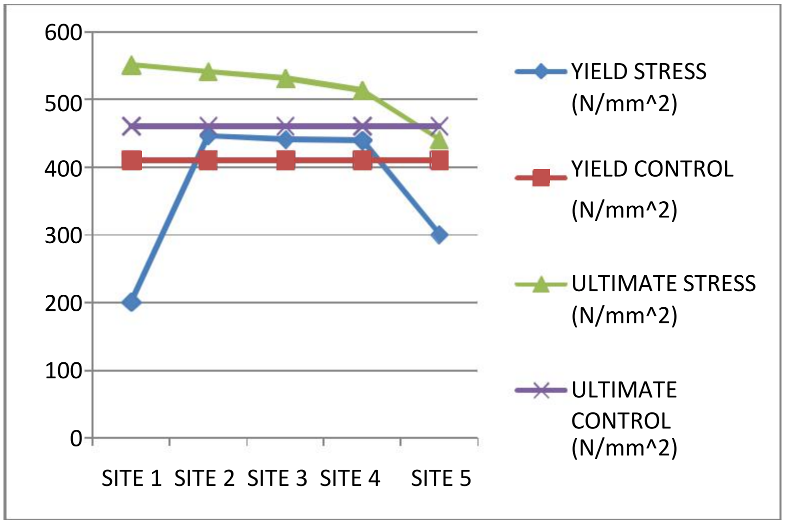

Fig. 6. A graph showing the tensile strength result obtained from site 1,2,3,4 and 5 against the control

Table 9. Comparing 10mm bar ductility of site 1, site 2, site 3, site 4 and site 5.

	ELONGATION (%)	CONTROL (%)
SITE 1	11.91	12
SITE 2	12.55	12
SITE 3	11.84	12
SITE 4	11.71	12
SITE 5	12.2	12

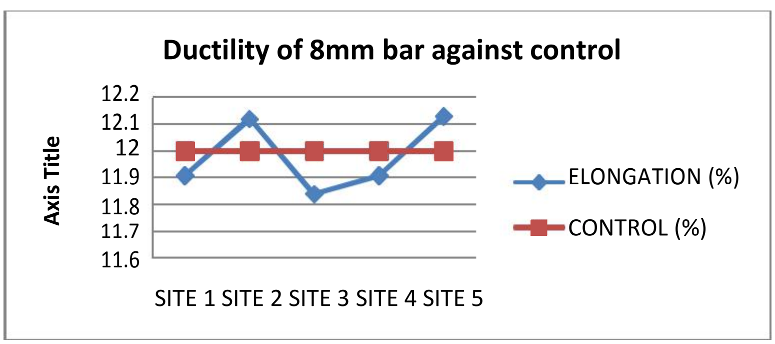

Fig. 7. Ductility of 8 mm bar against control

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Table 10. Tensile Strength Result of 8mm Reinforcement Site 1, 2, 3, 4 AND SITE 5.

	YIELD STRESS (N/mm^2)	YIELD CONTROL (N/mm^2)	ULTIMATE STRESS (N/mm^2)	ULTIMATE CONTROL (N/mm^2)
SITE 1	300.76	410	608.22	460
SITE 2	407.57	410	540.23	460
SITE 3	425.87	410	530.23	460
SITE 4	456.89	410	513.06	460
SITE 5	375.84	410	420.45	460

Fig. 8 depicts a graph of strength of 8mm bar against the control

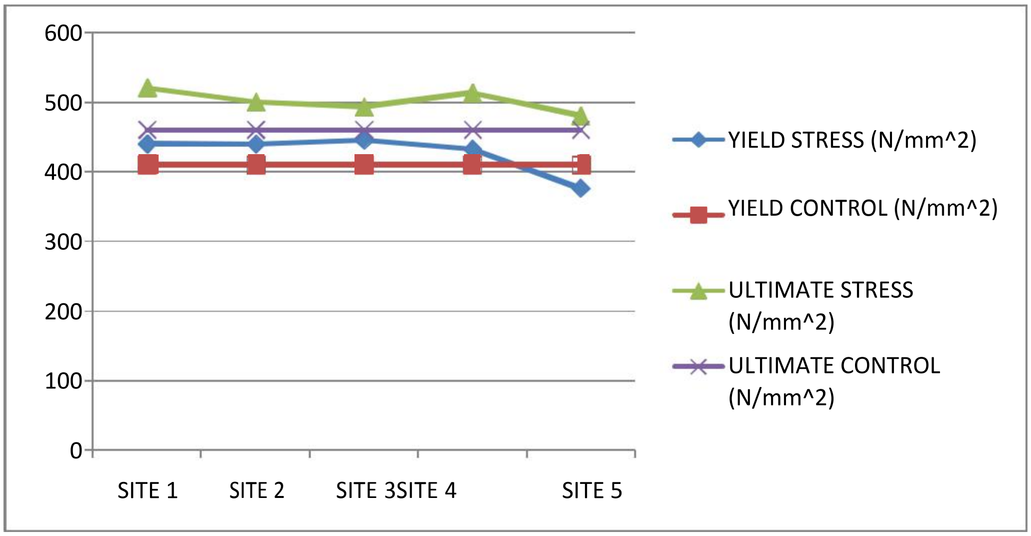

Fig.8. Strength of 8mm bar against the control

Table . Comparing 8mm bar ductility of site 1, site 2, site 3, site 4 and site 5.

Column1	ELONGATION (%)	CONTROL (%)
SITE 1	12.12	12
SITE 2	12.13	12
SITE 3	12.1	12
SITE 4	12.13	12
SITE 5	12.12	12

Fig. 9 depicts the plot of ductility of 8mm bar as against the control

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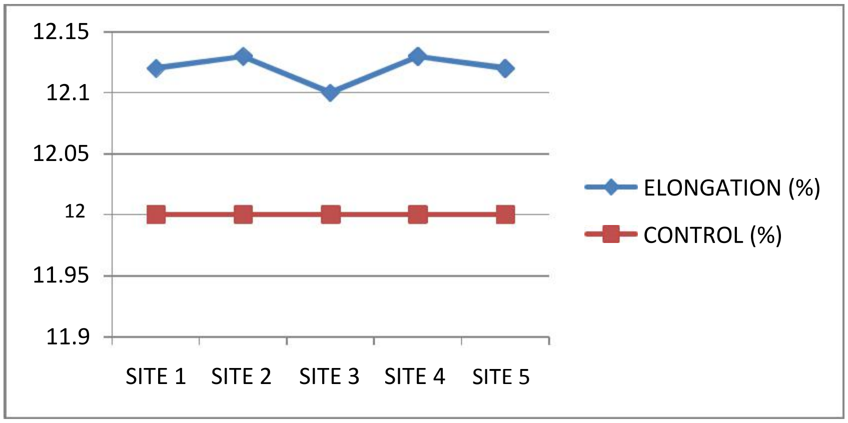

Fig. 9. Ductility of 8mm bar as against the control

From the destructive and non destructive test conducted the following inference was derived using sensitivity analysis. The graph shows the degree of contribution of the various parameters on the collapse of the five building sites visited.

The sensitivity analysis was computed using the equation $Z = X^2 + Y^2$.

Fig. 10 depicts the sensitivity graph for the different contributors to building collapse.

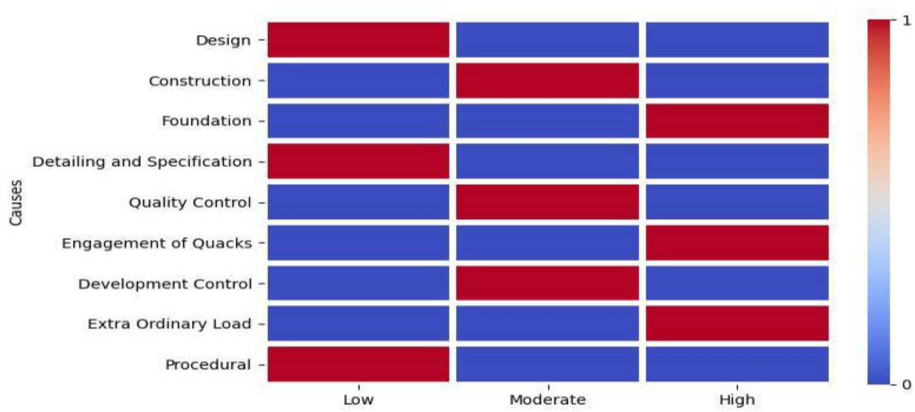

Fig. 10. Sensitive graph for the different contributors to building collapse

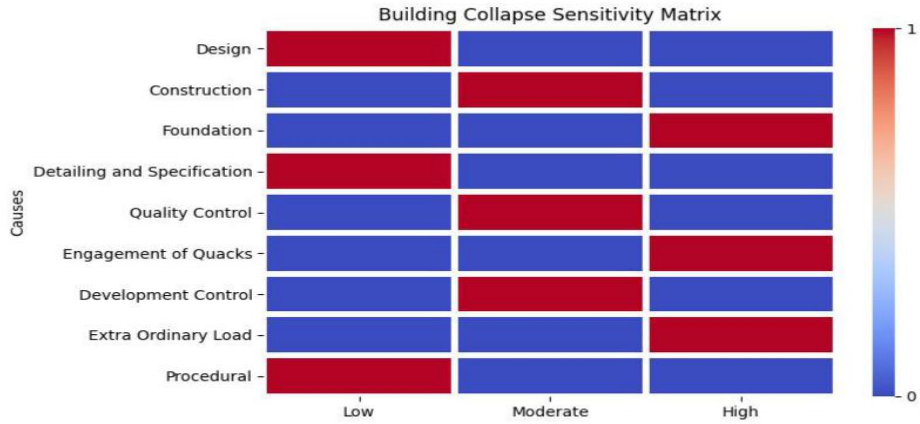

Fig. 11. Building collapse sensitivity matrix

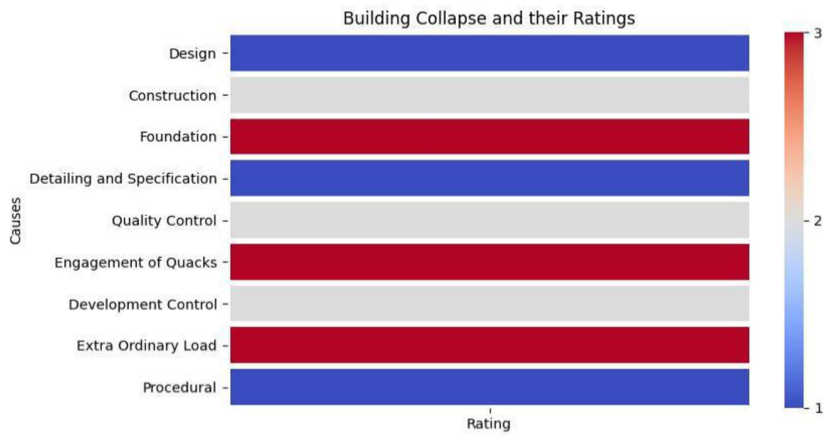

Fig. 12. Building collapse and their ratings

V. CONCLUSION

From the destructive and non destructive test carried out, and even the sensitivity analysis, it can be inferred that the major causes of the failure in site 1, site 2, site 3, site 4 and site 5 tallies. In site 1, the primary cause of the building collapse is the loss of vertical load carrying capacity in critical building components leading to cascading vertical collapse. The use of poor quality building materials was another critical factor leading to the collapse. Inadequate foundation on expansive subsoil under saturated conditions may have contributed to the imminent collapse of the building. In site 2 the use of poor quality concrete mix and substandard building materials are the other critical factors that must have led to the building collapse. Again, the probable cause(s) of building collapse to wrong foundation method on expansive soil, poor workmanship, poor quality concrete mixed-use of substandard materials. In site 3, the imminent and probable causes of building collapse to poor foundation structures, structural defects, poor quality building material, poor concrete mix and inadequate reinforcement. Also in site 4 Again, the imminent and probable causes of building collapse to inadequate foundations (type and depth), poor quality concrete mix, and poor construction met. Finally site 5, the primary cause of the building collapse is the loss of vertical load carrying capacity in critical building components leading to cascading vertical collapse. Inadequate foundation works resulting from lack of geotechnical investigation for appropriate foundation design, thereby leading to wrong construction method. In all the five sites studied, the ductility of the reinforcement contributed to the collapse on only two sites while in the other three sites, the ductility of the reinforcement did not contribute to the failure. This shows that the sensitivity of the reinforcement detail is fair. From the feed investigation conducted at the five site it was observed the concrete compressive strength varies from 0.1N/mm^2 to 7N/mm^2. This shows that the sensitivity of construction method is very high.

However, from evidence and samples collected on site, it was obvious that concrete quality and mix were extremely low and compromised. The quality of the reinforcement bars used for construction was inadequate as well. The above evidence may have adversely affected the framed structure integrity. Progressive collapse of a structure takes place when the structure has its loading pattern or boundary conditions tampered with or changed such that the structural elements are loaded beyond their ultimate capacities. It is a dynamic process, usually accompanied by large deformations. It is therefore very likely that the structural elements were subjected to loads beyond their ultimate capacities resulting to failure and subsequent building collapse.

Use of wrong construction methods, substandard materials, inadequate reinforcement, poor quality concrete mix, and poor workmanship may have therefore contributed as probable cause(s) of collapse From the field investigations, it was observed that the geotechnical properties of the soil, wrong choice of foundation types contribute to foundation failure of the building. The implication is the sensitivity of the foundation type is very high. Moreover, the field investigation during the site visit and interaction, there was no evidence that a professional participated in the supervision of the project, sowing that the sensitivity of using quacks is very high. Upon investigation, it was observed that the approval was given from development agency (ANSSIP) and (ACTDA) but there was no certification for the different stages of the work thus the sensitivity of development control cause is very high. Upon investigations, there were no adequate site preparations to secure and make sure that the materials are kept in good environment to avoid impurity. Thus the sensitivity is fair. From the report, it cannot be attained that detailing and specification were major problems on the cause the building collapse. Thus, the sensitivity is low. Upon detailed investigation from the site visit, it was discovered that proper construction methods was not followed and could as well may have led to the collapsed of the various building sites visited. Thus the sensitivity is fair.

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