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Analysis of the Effects of Biological Activities on some Structures in Cross River State and the Federal Capital Territory, Abuja, 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

Engineering structures are constantly subject to damage caused by biological activities such as the action of insects, penetration of roots and fluids. Because of this, we conducted a critical study on how these activities contribute to the collapse of these structures in Nigeria. The damage caused by biological activities was evaluated in fifteen buildings in Cross River State, of these buildings six showed damage caused by termites, two of the failed engineering structures were linked to development of roots of plants, and the remaining seven were linked to poor quality building materials, poor compaction, lack of supervision, poor engineering design. Others ten structurally failed buildings were examined in the Federal Capital Territory Abuja, Nigeria, of these four were linked to biological activities of termites, with subsurface porosity showing evidence of surface

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water discharge zones, two of the failed structures were linked to the growth activities of roots of trees, and four to poor construction design. The road that links Cross River State to Abuja had more than 80 points of failure, the majority of which were linked to poor compaction of road foundation, root of plants and fluid interference. Such damage could be prevented through: thorough investigation of biological activities existing and likely to exist around the environment before the establishment of the engineering structure and over the years; use of bio-resistant materials, such as nano materials incorporated coatings with novel functionalities should be used in the construction of structures; protection of engineering structures from fluid penetration into foundations; and engineering structures must follow the global best practices guide lines, provided by 'Society of Structural Engineers'.

Keywords: Termites; animals; plants; environment; porosity; roots.

1. INTRODUCTION

Failure of engineering structures is more common in the developing countries, and the magnitude of losses in terms of lives and properties is becoming very alarming [1]. According to [2] building failure occurs when the building loses its ability to perform its intended design function. Basirat, et al. [3] noted that the recurrent building collapse in Nigeria has led to the loss of lives and properties, and has become a great concern to all. Oluwatobi [4] further observed that the magnitude of building collapse in Nigeria has also led to the loss of many lives and properties, and if contentment measures are not taken, there could be more serious cases of devastating challenges in the future. Although most of these failures are attributed to poor engineering construction and quality materials, biological activities of plants and insects like termites have also contributed greatly to failure of some of these structures. Ghaly and Edwards [5] pointed out that termites are essential members of the soil ecosystem and are found throughout the world; and in their natural environment, they improve the soil pH and organic carbon content. However, they can also negatively impact human welfare by causing damage to some engineering structures like unprotected timber structures, underground cables, earthen dams, etc; and this can lead to serious economic cost. Although effort has been made to ensure quality construction of engineering structures within the recent years, very little attention has been paid to the effects of biological activities of plants and insects on these structures. According to Debelo and Degaga [6] termites problem on rural houses is a neglected area regardless of the intensity of the problem which at times results to total collapse of newly constructed houses. And it is estimated that the annual economic cost of structural damage to buildings from termites in urban areas is about $15-29 Billion Dollars worldwide (Geer, 2005; [5,7]). Rakesh (2019) noted that between 2001 and 2015, an average of 7 people die per day in collapsed structures including buildings in India, and about 38, 363 people have lost their lives due to collapse of various structures including residential houses in India between 2001-2015. Similarly, biological activities of roots of trees also contribute to collapse of buildings as they exert serious pressure on the foundations of structures. For Mercer et al. [8] subsidence damage to buildings is often caused by trees. Olabosipo and Adedamola [9] pointed out that while it is certain that buildings are prone to deterioration, it is important that the rate of collapse and associated loss should be greatly reduced. According to Davis and Reynolds [10], the Griffith Criteria of brittle deformation explains that a structure that experiences increase porosity and fluid interference at the subsurface will likely go to failure. This paper therefore takes a critical analysis of the effects of biological activities on buildings in Cross River State and the Federal Capital Territory, Abuja, Nigeria. The main objectives are to highlight the possible failure of engineering structures as a result of biological activities, and to proffer solutions that will prevent failure of these structures as a result of these biological activities.

2. METHODOLOGY

Study of the effects of biological activities on buildings was carried out in Cross River State, Nigeria, situated within the Niger Delta region in the tropical rain forest belt, which lies between latitude 5o321 and 4o271 North and longitude 7o501 and 9o281 East, with temperature ranging between 15oc – 30oc and annual rainfall between 1300 – 3000mm, through a 900km road to the Federal Capital Territory, Abuja, Nigeria, which lies between the GPS coordinate of 90 4120. 1504 N and 70 291 28.6872 E, with an average annual temperature of 25.7o, and 1389 mm inch of precipitation falls [11]. Defective engineering structures linked to biological activities were visited and the cause of the damage was classified according to the underground porosity due to termite activity, presence of lines of ants on the surfaces of the walls around the structures, presence of faults and fractures in the structures, presence of deeply penetrating holes around the structures, physical damage to wooden support structures by termites, distortion of the orientation of the structures due to faults, presence of spirogyra showing evidence of bioactivity and moisture. The termites were subterranean in nature both in Cross River State and FCT, Abuja. The structural strength of the buildings were tested using Schmidt Hammer Test. To measure porosity, the bulk volume of samples minus the volume of decompacted sample. Most of the structures after failure showed evidence of strike slip faulting. From Calabar to Odukpani in Cross River State (CRS), 10 road failed spots; from Udukpani to Ugep in CRS, 14 road failed spot; from Ugep in CRS to Abaji in FCT, Abuja, 58 road failed spot, and from Abaji to FCT Abuja, 2 road failed spots, mostly attributed to poor soil compaction, plants roots interference and erosional activities resulting to faulting. Fig. 1, is map of Nigeria showing the distribution of the structures in the study areas, that is, FCT, Abuja, Nigeria, and Cross River State, Nigeria.

3. RESULTS

The damage caused by biological activities was evaluated in fifteen buildings in Cross River State, of these buildings six showed damage caused by termites, two of the failed engineering structures were linked to development of roots of plants, and the remaining seven were linked to poor quality building materials, poor compaction, lack of supervision, poor engineering design. Others ten structurally failed buildings were examined in the Federal Capital Territory Abuja, Nigeria; of these four were linked to biological activities of termites, with subsurface porosity showing evidence of surface water discharge zones, two of the failed structures were linked to the growth activities of roots of trees, and four to poor construction design. The road that links Cross River State to Abuja had more than 80 points of failure, the majority of which were linked to poor compaction of road foundation, root of plants and fluid interference. Tables 1 and 2 below show the structures, causes and their years of failures:

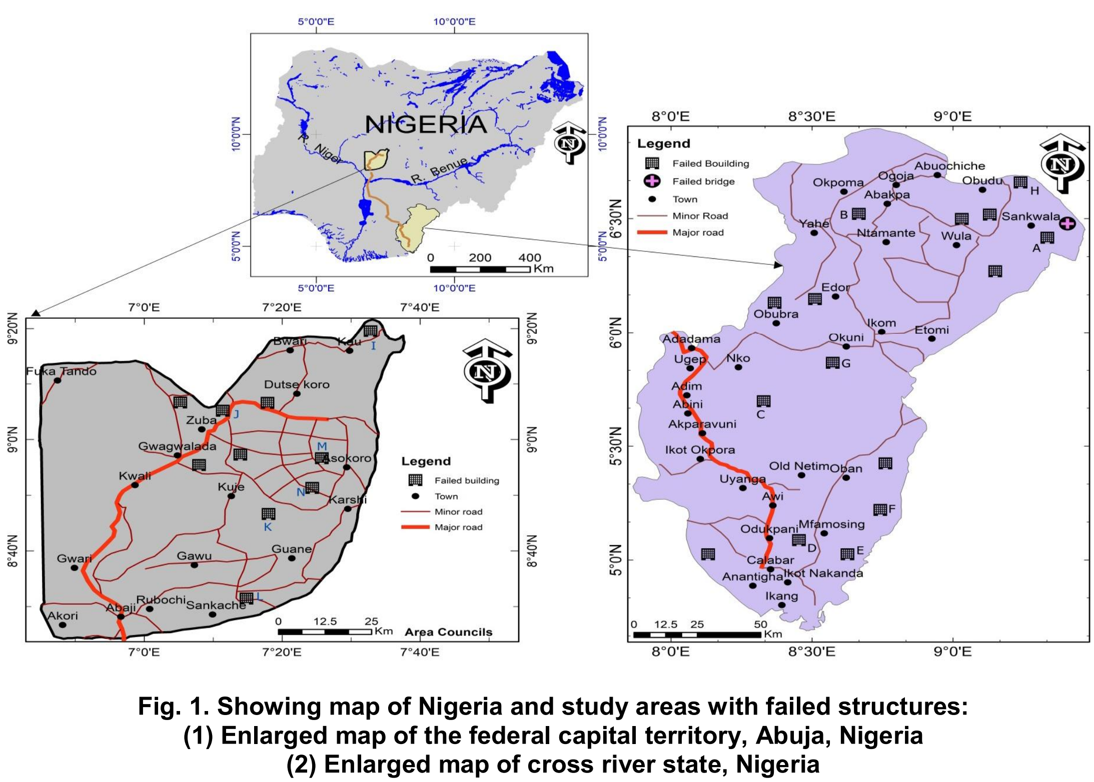

Fig. 1. Showing map of Nigeria and study areas with failed structures: (1) Enlarged map of the federal capital territory, Abuja, Nigeria (2) Enlarged map of cross river state, Nigeria

Table 1. Showing numbers of failed engineering structures, years of failure and causes, in cross river state, Nigeria

S/N	Type of structure/building	Numbers of buildings failure	Year of failure	Location	Suspected cause(S) of failure
1	Residential	6	2018	Calabar, Cross River State	Biological activities of termites.
2	Residential	2	2019	Calabar, Cross River State	Development of roots of plants.
3	Residential	7	2020	Calabar, Cross River State	Poor quality building materials, poor compaction, and poor engineering design.
4	Wooden Bridge	1	2018	Cross River State	Termites activities
5	900 km road from Cross River State to Abuja	80 spots of road failure identified	2018	From Calabar – FCT, Abuja.	Poor compaction of road foundation, Plants roots activities and fluid interference.

Table 2. Showing numbers of failed engineering structures, years of failure, and causes in FCT, Abuja, Nigeria

S/N	Type of structure/building	Numbers of buildings failure	Year of failure	Location	Suspected cause(s) of failure
1	Residential	4	2020	FCT, Abuja	Biological activities of termites, with subsurface porosity showing evidence of surface water discharge zones.
2	Residential	2	2018	FCT, Abuja	Growth activities of roots of trees.
3	Residential	4	2020	FCT, Abuja	Poor construction design.

Interaction with most of the building contractors also showed that, there have been no pre-investigation of sites for the presence of biological activities within the surface and subsurface. Failed engineering structures linked to biological activities are characterized by the presence of the following:

(1) Subsurface porosity as a result of termites activities.
(2) The presence of ants-lines on wall surfaces and around the structures.
(3) The presence of faults and fractures on the structures.
(4) The presence of deeply penetrating holes around the structures.
(5) Physical damage of wood supporting structures by termites.
(6) Distortion in orientation of structures due to faulting.
(7) The presence of spirogyra in some areas showing evidence of bioactivities and moisture.

4. DISCUSSION

There are different types of biological activities that are capable of causing failures to engineering structures. In our study, we identified these biological activities as a result of plant development, termite establishment and fluids penetration. In addition to these biological activities, we also find damage resulting from human failure in the construction process. We also present the reasons for the occurrence of these failures and present solutions. From this study we intend to provide data to guide decision makers, engineers and people in general in the construction of buildings so that there is no unnecessary expense, loss of life and constraints due to biological activities. Most termites failed structures had indicators of termite lines covered with clay soil around and within the structures, for the mobility of the termites, and sometimes the appearance of closed range termites hills, known as termiterium. The presence of termites may be evidence of decompaction of the subsurface [12]. This decompaction creates the subsurface porosity that gives way to fluid easy penetration in structures [13]. Engineering structures rest on compacted soils; and when porosities are created, this gives way to fluid penetration, and further weakens the engineering structure foundation, as the activities of these termites continue, the structure will likely go to failure [14]. Apart from subsurface porosity creators, termites also destroy wood supporting engineering structures resulting to failure of engineering structures [15] in some cases, destruction occurs quietly within the structure [16]. It is important to note that, temperature at the subsurface of engineering structures are lower than exposed surfaces, and as such, termites prefer their colonies below engineering structures where temperature is favorable, and in the establishment process initiate subsurface porosities [17]. In addition, termite-affected structures have remained uninhabited for many years, providing a peaceful environment for termite activities [18]. Plants have different types of root system; some are surface runners and others subsurface runner. Some plants have root systems that can grow to very long distances away from the original location of the plant, and can gradually penetrate engineering structures and foundations, resulting to faults and fractures [19]. Examples of such plants include 'Shepherd's Tree' (Boscia Albitrunca), known to have very deep penetrating roots system with about 70m or 230 feet deep; and the Kapok Tree (Ceiba Pentandra) which is also known to have long distance root penetrating system [20] Once faults and fractures are created, propagation is very eminent and the likely tendency of fluid intrusion, and these activities will create porosity and weaken the strength of the foundation at the subsurface, and in some cases the fault system may be visible at the surface exposure of the engineering structures [21]. The roots of the plants were one of the main causes of damage to the built roads, however, such damage could be controlled if the trees were made far away from the road before the establishment of the roads, in addition to their regular maintenance [22]. The roots gradually penetrate the structure, initially a fracture develops which makes provision for fluid penetration, and then a system of fault which may result to displacement of the structure, and then failure [23]. In addition, it is important to highlight that investment in quality roads contributes to the maintenance of properties close to them and reduces the possibility of accidents that constantly claim lives [24]. Fluid penetrations weaken the strength of engineering structures and can result in failure of the structures [25]. The biological activities of plants and insects require fluids and consequently result in the initiation of porosity causes for fluid penetration [26]. The presence of fluids increase porosity, reduces compaction and in general weakens the resistance of the foundation, generating cracks that hinder construction, as suggested by the Theory of Fragile Structural Fractures that a crack will propagate when the reduction of potential energy that occurs due to crack growth is greater than or equal to the increase in surface energy due to the creation of new surfaces [27]. To avoid such damages, some steps can be taken before starting the establishment of engineering structures to contain the failures resulting from biological activity, starting from a thorough investigation and analysis of the site including biological aspects; having competent professionals from different areas of study in charge of the constructions, so that attention is paid to all aspects that may interfere with the quality of the engineering structure; bio-resistant materials, such as nano materials incorporated coatings with novel functionalities should be used in the construction of structures; and protection of engineering structures from fluid penetration into foundations [28]. In order to guarantee the maintenance of the quality of engineering structures, it is important that there is regular monitoring and checks for the presence of fault and fracture in engineering structures; engineering structures such as buildings should not be constructed and abandoned, they should be used for the purpose there was constructed for; in addition to regular checking and monitoring of engineering structures, to guide against biological activities destruction [29]. As we have seen, one of the causes of damage to engineering structures comprises human error, when using low quality materials or even not doing a good planning job, although this condition facilitates the involvement of engineering structures by biological activity, it is important to highlight that even engineering structures that were built with all the necessary precautions such as good quality building materials, good architectural design, good supervision, excellent foundation, good sand, cement and gravel ratio, can still fail, if such foundation structure is in contact with active root system of plants that can cause biological weathering [30].

The following therefore is required for the establishment of engineering structures:

- Recommended depth of foundation by Civil and Structural Engineering Society, for the type of engineering structure.
- Recommended mixing ratio for cement, sand, and gravel as approved by Structural and Civil Engineering Society.
- The size, quantity and quality of rods (irons) must be in line with engineering recommendations for the type of structure.
- Soil compaction must be properly done with depth depending on the type of engineering structure as recommended by the Society of Civil and structural Engineers.
- Investigation of biological activities in the site before construction of the engineering structure, and constant monitoring by qualified persons after construction.
- Qualified site workers and engineers, such as civil engineers, structural engineers, geophysicists, biosafety officers, microbiologists, etc, should be part of the site investigation team.
- Proper supervision during construction of the engineering structures.
- The use of Bio-resistant materials, such as nano materials incorporated coatings with novel functionalities should be used in the construction of structures [31].
- Protection of engineering structures from fluid penetration into foundations. Fluids are also basic requirement for most “bioactivities” to proceed.
- The use of Ground Penetrating Reader (GPR) in scanning roads, building, bridges, etc is encouraged. GPR is a sensor and software designed for inspection of buildings, bridges, concrete foundations. Different types of GPR are recommended, example LMX 200 Tm Utility locator, LMX100 Tm Utility locator, Density Profiler (PDP), Rescue Radar Tm, etc [32].
- Engineering structures such as buildings should not be constructed and abandoned. They should be habited and used for the purpose there were constructed for.
- Trees should not be allowed to grow closed to engineering structures.

It is important to note that, temperature at the subsurface of engineering structures are lower than exposed surfaces, and as such, termites prefer their colonies below engineering structures where the temperature is favourable, and in the process initiate subsurface porosities [33]. According to Zehnder [34] the Griffith Theory states that a crack will propagate when the reduction in potential energy that occurs due to crack growth is greater than or equal to the increase surface energy due to the creation of new free surfaces.

However, there were also challenges encountered during the research such as: lack of photographic access in some failed engineering structures, while physical observation was allowed, due to restriction by security agents within the structures; lack of efficient subsurface foundation monitoring devices like the Ground Penetrating Radar (GPR); and Lack of adequate logistics/finance.

5. CONCLUSION

While poor quality materials and engineering design have contributed over time to the collapse of some engineering structure, it is also important to note that biological activities of plants, insects, and animals have also contributed greatly to the failure of engineering structures. Hence, the need for biological investigation of such activities during and after the construction of any engineering structures be considered. Most of the engineering structures that failed due to biological activities of plants, showed evidence of faults and fractures that were penetrative, thus trees should not be closed to engineering structures as their roots systems may affect the strength of the structures.

Structures that failed as a result of termites infestation showed termites lines of clay soil within and around the structure and other evidence of presence of anthill around the structure, this suggests the presence of subsurface decompaction that will likely affect the strength of the engineering structure. The presence of borrows and surface water channels into engineering structures should be checked and properly controlled to prevent increase in porosity and fluid interference with foundation of structures. Much sensitization on the effects of biological activities is really needed, as the research work shows that most building engineers are yet to take into consideration the effects of biological activities on engineering structures. According to Olaniyi abd Olalekan [35], failure along Nigerian roads affects both the road users and the vehicles, leading to increase in insecurity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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