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Comprehensive Investigation into the Menace of Roof Collapse in Tamale and the Way Forward

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ABSTRACT

There is a perpetual problem of partial or complete roof collapse within the Tamale Metropolis and other parts of Ghana. This has become an issue of grave public concern since this menace affects both public buildings of all kinds (schools, offices, churches, mosque etc.) as well as domestic buildings.

This research sets out to conduct comprehensive investigations into the nature of roof failures, causes, and effects and then propose remedial actions towards stemming the tide.

The study employed the use of roof construction affirmation surveys, questionnaires, interviews and focus group discussions. Relevant information synthesized indicates that the roof type, construction materials, building type and environmental conditions are crucial causative factors.

Major consequences of roof failures include damage to personal belongings and exposure to inclement weather conditions, the psychological trauma victims are subjected and pressure on incomes and living conditions as a result of the cost of repair or replacement of the roofs.

It is recommended that expert advice be sought in checking maintenance requirements of existing roofs in the study area and also during the design and construction of new roofs. Tree planting programmes for this heavily deforested region should be encouraged. The use of green timber for roof construction must be replaced with well-seasoned ones. Proper construction detailing and placement openings buildings should be done so that wind flow during a windstorm is optimized.

1. Introduction

The roof is the second on the foundation as the most important component to a building. It is the part of the building that offers protection against elements of the weather. It is that component of a building which is most

associated with the concept of shelter. A homeless person is usually described as someone without a roof over his or her head ^[1].

There are incessant reports in the media year in year out on roof failures as a result of rainstorms throughout the country and Tamale in particular. The consequent

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effects on victims in the study area of Tamale is particularly prevalent at the beginning and end of the rainy seasons which spans from April to September

Generally, the design of a roof for a building should be made after due consideration to its structural function of spanning the space and helping to control the climatic conditions within it [2].

Evolution in design and construction has birthed various forms of roof typologies. Generally, roofs can classify into two types main on the basis of slope: flat and pitched roofs. Those with pitch (angles) not exceeding 10° are classified as flat, while the ones with a higher pitch (angles) are referred to as pitched. Flat roofs may be susceptible to aquaplaning, however in pitched roofs there is improved drainage thus their popularity in most climates. Pitch roofs are less prone to leakages and even where minor holes occur, the water can still easily drain over them [3].

Roofs can be affected by elements of the weather and can be subjected to failure. Roof failure refers the situation whereby a roof is no longer capable of performing any of its required functions. These failures could be either structural or environmental. The ultimate and more easily noticeable type of structural failure is roof collapse while environmental failure manifests itself in the form of reduced ability to act as barrier to heat flow from the atmosphere to the building interior” [4-6]. Other indices of roof failure include leakages, condensation and rusting or corrosion [7].

2. The Study Area

Tamale Metropolitan Area refers to the geopolitical limits of the Tamale Metropolitan Assembly of Ghana. It is the capital of Northern Region and has an area of 922 km², [9,10] as well as a total population of 371,351 [9].

The Tamale Metropolis is one of the 26 districts in the Northern Region. It is located in the central part of the Region and shares boundaries with the Sagnarigu District to the west and north, Mion District to the east, East Gonja to the south and Central Gonja to the south-west. The Metropolis has a total estimated land size of 646.90180 sqkm (GSS, 2010). Geographically, the Metropolis lies between latitude 9°16 and 9° 34 North and longitudes 0° 36 and 0° 57 West [13].

Tamale lies on 195m above sea level Tamale has a tropical climate. There are two seasons in a year: the rainy (April-September) and the dry seasons (October-March). During the dry season, (Mid November to end of January) dry winds from the Sahara blow across the region. In Tamale, the average annual temperature is 27.9 °C. While the annual precipitation records about 1111 mm / 43.7 inches per year. On the average, September is the most humid and December the least humid month. The average annual percentage of humidity is: 47.0%. The windier part of the year lasts for 8.0 months, from December 12 to August 10, with average wind speeds of more than 6.1 miles per hour. The windiest day of the year is January 14, with an average hourly wind speed of 7.7 miles per hour. The calmer time of year lasts for 4.0 months, from

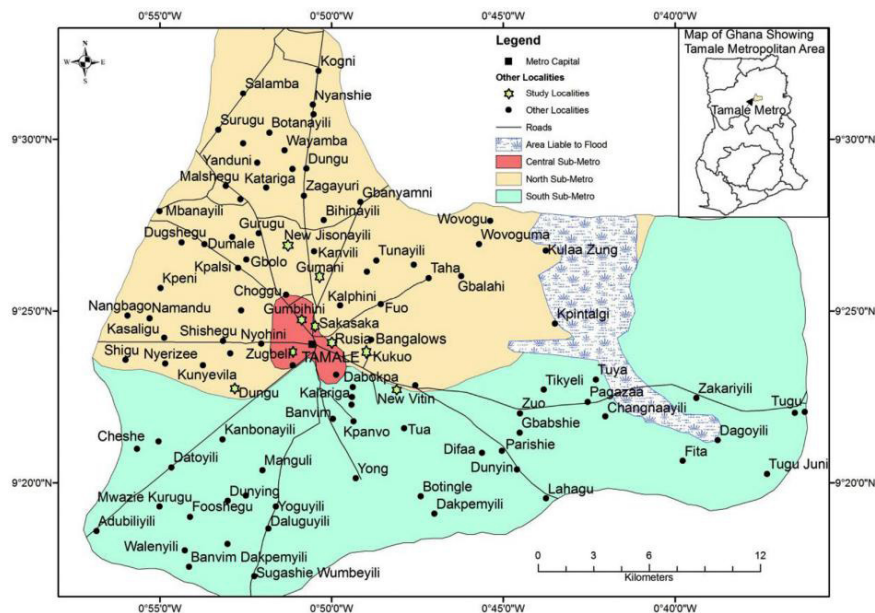


Figure 1. Map of the Tamale Metropolitan Area.

Source: Yakubu et al, 2014

August 10 to December 12. The calmest day of the year is September 23, with an average hourly wind speed of 4.6 miles per hour ^[14].

3. Literature Review

The roof is the component of the building that protects it from elements of the weather such as rain, wind and the sun. At the same time, it is also the element most subject to abuse ^[4]. Roofs are subjective to their own dead loads and live loads from winds, snow, rain etc. these loads need to be borne adequately by the structural members and covering. Contemporary design and construction methods have resulted into various techniques and roof patterns. Basically, roofs are classified according to their slope as either pitched or flat. Gradients of less than 10° are deemed flat roofs, while those above 10° pitched roofs. The susceptibility of the former to leakages is well known. The latter on the other hand offers improved drainage thus are seen as are more leakage proof. Gable roofs form the most dominant type of pitch roof.

The most determinants in the selection of roofs include, form of building, span, cost and the visual effect of the building.

The fascination with having a covering overhead any structure as shelter is as primitive as humankind. The quest for safety and security through a roof over their heads perhaps drove early man to dwell in caves and hollowed out trees ^[16]. These provided innate protection from inclement weather. Man-made roofs later evolved from natural and unnatural sources in recent times. For instance natural sources such as thatch and bamboo obtained from plant sources emerged. With technological innovation, roofs are now made from various materials including metals, clay, concrete, plastics, glass etc.

The susceptibility of roofs generally to elements of the weather and to partial or total failure is not in doubt. Failure in a roof is said to have occurred when it is no longer able to perform its designed tasks. Structural and thermal factors are the main categories of roof failures. Distinguishably total roof collapse is the most perceptible form of roof failure. Conversely, failure in terms of thermal conditions is expressed in the form of curtailed capacity of the roof to impede the entry of weather elements from the external environment into internal spaces ^[5-7]. Added indications of roof failure involve rust, sagging, leakages and decayed timber members ^[8].

Durability and the efficacy of a roof are the criteria used to evaluate its capability and capacity. Majority of failures in roofs happen around connection points such as nailed or bolted joints. These deficiencies during the construction stage are further aggravated by gradual

depreciation of the components. Lack of consideration for details like factors of safety and tolerance could result in failures in roofs. The influence of winds, improper maintenance, fire, deficient quality components and poor works superintendence practices in roof failures deserve mention. Subsequently grave socio - economic ramifications including loss of lives and property usually ensue from roof failures ^[15,16].

Reports are rife in both the traditional and social media every year in Tamale about roof failures. This imposes severe suffering and deprivation on a community that is plagued with poverty and need. Therefore strenuous attempts should be made in order to ameliorate this situation.

4. Information (Data) and Procedures

The Roof Construction Affirmation Process

The roof design affirmation process involved undertaking random surveys on the media reported and unreported cases of collapsed and ripped off roofing systems in the Metropolis, peri-urban and rural parts of the study area over a two year period (2018-2020). The outcome of these studies suggested that the persisting roof failure does not only affect aged roofs but also the recently constructed.

The investigations also divulged that the unending roof failures affect all manner of buildings e.g. single and multistory residential buildings, schools, offices, churches, mosques and warehouses.

Total collapsed or partial rip off was recorded in most of the roof systems. Pitched roofs with sawn timber as rafters and purlins mostly formed the structural unit. Roof coverings were many and varied including corrugated galvanized or aluminum sheet (pigmented and non-pigmented) and thatched roofs.

Other methods employed in the data gathering comprise structured questionnaires, interviews and focus group discussions. Relevant data sought included construction materials of roofs, materials used for structural members, regularity of maintenance, roof age, culture of maintenance and possible causes of failure. The attendant ramifications on the lives and livelihoods of victims were also interrogated.

In total, 260 buildings across the Metropolis were surveyed. These comprised of domestic (75%) academic institutions (10%) religious (5%) warehouses (3%) and others (7%).

The age distribution varied from the recently built to a peak of (fifty) 50years. Buildings surveyed also

constituted the ones in good condition and the rest that suffered some partial or complete collapsed. The affected buildings with defects were investigated and included in the analysis of results. However, the unaffected were repudiated.

Table 1. Characteristics of buildings surveyed

Type of building	Roofing members and covering	Age of building	Purpose	Sample size
Domestic	Timber rafter and purlins with pigmented and non-pigmented galvanized or aluminum sheets and thatch roofs with off-cut timber/tree branches	From 6 months-50 years	Residential, with some commercial functions	75%
Academic	Timber rafter and purlins with galvanized and aluminum sheets	From 1- 30 years	Teaching, learning and research	10%
Religious	Timber rafter and purlins. In some cases metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 6 months-50 years	Worship	5%
Warehouses	Mostly metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 1- 10 years	Storing manufactured goods and farm produce	3%
Others	Timber rafter and purlins, metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 6 months-50 years	Offices, commercial buildings, small scale industries guest houses and hotels.	7%

5. Results and Discussion

5.1 Results of Quantitative Study

The types of failures observed during this study can be broadly divided into two, collapse and non-collapse. Collapse entails the complete removal of the entire roof from the building, while in non-collapse failure the roof is still in place but may suffer one problem or the other that inhibits it from maximum performance. Such failures include corrosion, leakage, exposed laps, tearing off of sheets, rafter damage, detached nails, rotten timber, bowing and disfigured roofs. The results of the study are shown in Figure 2.

Form the results of the roof construction affirmation

process and the other methods employed i.e. structured questionnaires, interviews and focus group discussions, it is now known that the recurring roof failures affect all building typologies comprising domestic dwellings, academic, offices, warehouses and others.

The foremost mainspring of roof rip off is wind emanating from storms. This is exasperated by substandard materials and components as well as bad artisanship. In a lot of instances, infirm bands of steel were applied as ties between walls and the timber structural roof frame. The irregular surface of the walls on which the timber plates sit coupled with the infirm steel bands exposes the structure to much stress. Additional stresses/ loads from storms for example can easily cause failure of these roofs.

These failures manifest as partial (74%) or complete (26%) failures. They can also be classified into rainstorm damaged (23%) and those that suffer gradual deterioration as a result of poor maintenance (76%). Pitched/gable roofs with timber structural members and pigmented and non-pigmented galvanized iron and aluminum coverings constituted the majority (94%). A small percentage of (4%) thatch roofs and about (2%) made of composite roofs i.e. concrete clay tiles, shingles etc. were also recorded.

Factors that were identified as the main causes of partial collapse included the following corrosion (15%), opening of exposed laps (7.8%), leakage (18%), rotten timber (11.3%), and damage to rafters (8.8%), detached nails (10.8%), bowing (10.1%) and the disfigured roofs (7.2%).

5.2 Construction Materials for Roofing

A total of 91% of the roofs under this study were constructed with timber structural frame covered with pigmented and non-pigmented galvanized iron and aluminum sheets, (4%) thatch roofs, (3%) concrete and, the rest including clay tiles and shingles account for up to (2%).

Though thatch roofs have been used historically in this location as a result of their suitability for the climate and availability, they are currently restricted to rural parts of the Metropolis. Bush poles (planted at the central point in the space as well as framing for the conical shaped rooms) are predominantly used. Concrete roofs which usually form a composite with the timber framed roofs as verandahs, water tank towers, roof terraces etc. also exist. The casting methods of these concrete roofs render them highly liable to leakages. The high heat conduction capacity of aluminium may be considered unsuitable for this climate; however its equally high resistance to corrosion makes it a preferred choice.

Timber is the material most frequently used for rafters and roof trusses. In the case of small to medium spans it is considered comparatively cheaper and very familiar to artisans and workmen. The spans and altitude of large buildings such as warehouses require higher strength and stability hence steel trusses are applied.

Details of this distribution are illustrated in Figure 2:

5.3 Identification of Potential Causes

5.3.1 Roof Construction Affirmation Process

Diligent examination through the roof construction affirmation process unveils major causative factors of the recurrent menace of roof collapse in the area of study.

5.3.2 Ecological Damage

The difficulty with the incessant pulling-off of roofs can largely be associated with the ecological damage. Trees and vegetation in the vicinity of majority of buildings struck by this menace were largely bare. As a result roof surfaces take the full impact of wind loads; more often than not they are unable to withstand the wind pressure and eventually collapse. In most cases these trees which act as windbreaks were removed to make way for the new construction. It would have been prudent to restore the vegetation with rapid growth varieties. The surveys however revealed otherwise.

5.3.3 Roof Layout Issues

Results of the random surveys of roof construction affirmation process, carried out by this study reveals that more than 95% of roofs construction are predominantly executed based on experiential knowledge of artisans,

instinct and commonsensical methods instead of being based on the scientific approach.

- Deficient erection was noted to be one of the principal causative factors of roof failures in the random surveys. For instance, artisans determine the size of structural timber members without recourse to codes and structural calculations.

- Additionally, owing to the prohibitive prices of adequate grade timber members for the structural frame, prospective builders resort to lower grade and undersized structural timber members.

- The roof structures formed from these timbers are usually not built to standard design details and in such situations the whole construction is left to the discretion of the carpenter to decide on the design solutions. The tiny structural lumber sizes renders these roofs vulnerable to destruction through forces of suction as a result of wind storms.

- The concept of rigidity of the triangular form in structures was not very apparent. Timber studs which could otherwise be used as straps to hold back the outspread at the base of rafters however were fastened to wall plates at uneven intervals thus making the entire structure of the roof prone to lifting during windstorms.

5.3.4 Faulty Erection and Works Superintendence Methods

The random surveys in the roof construction affirmation process further unveiled the following:

- Inadequate knowledge on the part of artisans e.g. instances were observed in which the timber structural frame was structurally sound, however owing to bad erection such as poor/inadequate fastening of the timber structural frame to the blockwork/concretework of

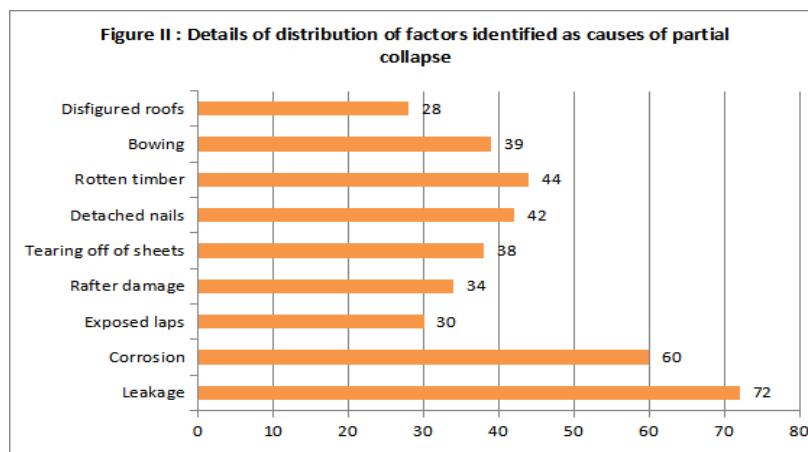


Figure 2. Details of distribution of factors identified as causes of partial collapse

buildings. The roofs are thereby rendered deficient and can become vulnerable to windstorms.

- Purlins not adequately fastened to rafters and top chords of trusses. Purlins were observed to be pulled off inclusive of metal coverings while the remainder of the roof structure was still intact. Rafters were not also adequately fastened to wall plates. Some ripped off roofs with wall plates intact were also observed. Poor fastening techniques of sheet coverings especially at high risk joints and junctions of roof planes exposed these coverings to being pulled off. Nailing of joints in the course of construction of roofs with no due regard to the margins renders the nails not deeply rooted enough to prevent the roofs from being lifted off during windstorms

- The expanse of laps at the ends of roof coverings was also found to be rather insufficient. This allows driving rain to bring in moisture to timber structural members causing their decay and subsequent leaking and damage of the entire roof structure.

- There is total absence of superintendence by consultants and professionals. Prospective builders prefer to deal directly with artisans due to the poor building controls. Majority of erected roofs of this kind are defective in many regards and are highly prone to damage. Roof coverings are mostly manufactured by industrial processes. However the requirements and instructions of these manufactures are usually not complied with. Not complying with the recommended gradients and gauges of coverings result in deficiencies such as deterioration of roofing members hence leakages.

5.3.5 Poor Culture of Maintenance

The poor culture of maintenance in the study area is well known. The roofing regimen is not spared this menace. Prolonged exposure to inclement weather brings about decay and damage to roofing members and coverings leading to leakages and crumbling of roofs. Without a proper maintenance regimen, repercussions of gradual decay and coincidental damage to roofs give rise to the eventual damage.

5.3.6 Economic Implications of Roof Collapse

The projected cost of construction of new roofs is normally estimated to be up to 20% of the entire cost of construction. On the other hand, replacement cost of damaged roofs can reach up to 40%^[17]. Considerable losses take place with the occurrence of failures in roofs. Firstly, the cost of replacement and also the cost of damage to items within the buildings such as stationery, furniture and other prized possessions. This has profound

implications on the quality of life, education and livelihoods in general.

Information on the quantum of losses to victims is not easy to come by. This is as a result of the fact that most victims do not keep records of their losses. Also, low property and other insurance product uptake renders the availability of these records very challenging. In some instances Government intervention through the National Disaster Management Organization (NADMO) is not indexed to the quantum of loss.

In qualitative terms, the collapse of roofs subjects the affected people to vagaries of the weather. The burden associated with cost of replacement constitutes a huge financial burden on them. Furthermore, the hazards and perils to their health and psychological wellbeing cannot be over emphasized.

In view of this, the study will venture into estimating the quantum of losses to victims of roof collapse.

Assume

- a yearly rate of roof collapse of 0.5 buildings per 1000

- total number of houses 965,000

- 94% of the total number of houses typical angled roofs

Hence

- On a yearly basis, up to about 325 buildings experience roof collapse.

Assume

- Current estimated cost of replacement (structure and covering) is GHS¢ 20,000.

Then

- Total cost of replacement equals GHS¢ 6,650,000 yearly. This constitutes an enormous financial burden in an area where incomes and earnings are relatively very low.

- Estimated work days of up to 65,000 in total are lost. This works out to around 90 work days for every replacement job.

- The environmental consequences in terms of the number of trees cut for replacement of the structural frames of these buildings can also be considered as dire. More than 700 logs from forests in southern Ghana are harvested for this purpose.

6. Conclusions

By way of the roof construction affirmation investigation coupled with quantitative and qualitative surveys, it was found that various kinds of roofs including flat roofs, gable/hipped etc. are all found in the study area. However hipped roofs dominate.

Factors such as span, strength and durability, cost and

aesthetics among others are the principal reasons for the selection of roof type. Timber framed structures with pigmented and non-pigmented galvanized/aluminium coverings are the main construction materials. Roof collapse can also be categorized as partial and complete. The partial variant is expressed in the form of rust/corrosion, sagging, disfigurement and leakages.

Ecological factors like the absence of trees and vegetation as well as design and construction issues, poor works superintendence, poor artisanship and weather elements can be attributed to the gradual decay and deterioration in partial roof collapse.

Notwithstanding the fact that the exact cost implications of roof failures are not easily known, attempts have been in this investigation to estimate the monetary, labor and other implications such as the hazards and perils on victims health and psychological wellbeing.

7. Recommendations

The recommendations are structured as follows:

- General recommendations
- Particular recommendations of deficient construction practices

7.1 General Recommendations

We recommend that existing roofs be checked for maintenance issues such as rotten timber, open lapped ends, leakages torn parts in the coverings. This will ensure that problems are detected early enough and building owners alerted to take action. This enforcement measure could be taken up by District engineers and their teams. Appropriate maintenance culture should also be initiated, cultivated and enforced by local authorities and even the security and disaster management bodies.

The study area is replete with depletion of forests and trees at building sites without replanting. It is therefore recommended that rapid growing local trees like acacia and neem be applied in a massive replanting drive generally and at building sites in particular.

Application of well cured timber in roofing should be encouraged. Where this is not available, fresh cut timber must be allowed periods of at 30 days to achieve sufficient curing before the covering materials are placed.

The necessity of proper fastening of the roof to the concrete/blockwork structure is crucial. Currently artisans apply 6 mm diameter mild steel cords. It is recommended that these fasteners should measure up to 7.5 mm diameter and be spaced at least 600 mm centre to centre. Connections and junctions that are subject to the most stress and strain including ridgelines, overhangs and

valleys should also receive the 75 mm steel bands at even more closer intervals of 450 mm.

Proper artisanship is pertinent to the right functioning of any roof. Enforcement of building codes and by-laws should be taken seriously by local authorities. Their Building control function needs to be stepped up. This will ensure that artisans and prospective building owners are held to the codes and building regulations. Consequently disasters relating to roofs will be stemmed. Artisans should also receive re-training so that they can unlearn their obnoxious methods and relearn current best practices.

Table 2. Recommendations of deficient construction practices

Item	Deficiency identification	Recommendation
1	Uncoupling of rafter, wall plate and ceiling joist.	These members must be tied together to form one fixed triangular rigid frame.
2	Rafter length increasing connections using timber off cuts	Mild steel plates of at least 10mm thickness should be used instead of off-cuts.
3	Rafters and bottom chords of trusses fastened to protruding reinforcement bars	These should be done right-angled mild steel plates connected with bolts and nuts
4	Off-centre pattern of timber structural members in trusses and rafters	Well-proportioned and balanced grid like patterns are encouraged
5	Gable ends of walls grooved and purlins fixed with concrete /mortar grout	Purlins should be fastened to walls by horse-shoe shaped metal clips of about 750 mm thickness.
6	Attachment of purlins to rafters and top chords of trusses without provision against slippage.	Provision of angular shaped timber cuttings to the underside of these attachments to act against slippage.
7	Joined rafters at the ridge not strengthened in the triangular shape underneath	Introduction of vertical and cross bracing between rafters recommended

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