Mud House Failures and Mitigation Options in Bauchi, North East Nigeria

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Abstract— The use of soil materials for sustainable construction in developing countries is a viable alternative to concrete based materials. The advantages include availability of soil (earth) materials, reduction of transportation cost, saved embodied energy, reduced environmental degradation and reduced material cost. Mud house collapse is a common yearly phenomenon in Nigeria. Much of this happens during rainy seasons due to flooding generated by heavy rainfall. Whenever this happened, people were rendered homeless and became Internally Displaced Persons (IDP), with the subsequent hardships and sufferings, and sometimes casualties. Sixty seven mud houses in three locations of Bauchi town, North East of Nigeria were investigated. From observations and returns from structured questionnaires filled by house owners and tenants, about 76% of the houses had failed in form of wall collapses alone. Other data collected included age of houses, composition of wall materials and foundations. Failures were generally severe and widespread for walls of full mud houses, however those plastered with cement/sand mortar had less failure counts. Older mud houses recorded higher failures as against new constructions. Soil samples collected from borrow pits used for the investigated mud houses were tested and their soil type compositions determined in the laboratory. They slightly fell short of the specified proportional limits of clay, silt and sand considered acceptable for construction purposes except stabilized. Sample bricks made from the soils were tested for compressive strength with an average value of 0.81N/mm^2 which is far below the 2.5N/mm^2 minimum value for sandcrete blocks specified by the Nigerian Standards Organization. Lack of good quality control measures and improper stabilization procedures, among others were considered responsible for the failed resistance to the environmental factors. Cement stabilization and good urban planning are some of the recommendations.

Keywords—Mud house, Collapse, Soil, Laterite, Failure

1 INTRODUCTION

Mass collapse of residential houses made from earth as a result of climatic and environmental factors like flooding have caused a lot of human sufferings and sometimes brought about fatalities. In order to minimize this adverse environmental impact, a critical investigation of mud house failures and mitigation is imperative. According to a report from Pakistan (Shall, Khan, & Qazi, 2013), "the torrential floods 2010 in Pakistan played havoc with the people and property…. More than two million houses were damaged partly or totally. The most affected housing stock was mud houses, which were mostly collapsed leading to deaths of people and livestock".

Nigeria has a rainy season and suffers from seasonal flash floods. These flash foods are sometimes lethal, especially in the rural areas or overcrowded slums, where drainage is poor or does not exist at all. In the 2012 rainy seasonal run from July to November, 363 people were killed and over 2.1 million were displaced (Wikipedia, 2015). Major causes of rains in urban areas in Nigeria include inadequate drainage, indiscriminate waste dumps and high rate of building construction along water channels (Adetunji & Oyeleye, 2013). Still on the 2012 floods in Nigeria, the National Emergency Management Agency (NEMA) reported that 30 of Nigeria's 36 states were affected by the floods, some of the worst affected where states bordering the River Benue in the North East where Bauchi is located. The floods were termed as the worst in 40 years, and affected an estimated total of seven million people.

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The estimated damages and losses caused by the floods were worth N2.6 trillion (Approx. $9 million) (Nigeria: Worst Flooding in Decades", 2012), (Wikipedia, 2015). There were massive disruptions in food security, dislocations in living for victim returnees after the flood period and grounding of socio- economic activities (Ogbanga, 2015).

Mud houses are building structures constructed from soils (earth) with binding properties like laterites or clay. The building materials are usually presented as rammed earth or earth bricks. Rammed earth stabilized with cement have been found to develop 28 day compressive strength that is as high as 15N/mm2 (Gupta, 2014). They have been used to erect buildings of up to 2 storeys (Jayasinghe and Kamaladasab, 2007). Lateritic soils occur in the tropical and sub-tropical regions of Africa, Asia, Oceania and South America (Kasthurba et al, 2014). Investigative studies have been done in recent years on laterites as alternative building materials in hot and tropical regions (Eisazadeh, 2010). Strength and durability qualities are of importance for tropical soils like laterites because of the climatic and environmental conditions they are exposed to when used in construction, especially the harsh seasonal rains during the wet seasons. These considerations are more important for serious building and engineering structures (Latifi et al, 2013). Floods generated by rainfall usually cause failure in mud houses by any or combinations of the following: undermining of foundations, scouring/erosion at the base of the walls, scouring/erosion at the corners of structures, wiping out of structures, deposition of debris in houses, damage due to debris flow, damage due to prolong submersion of buildings in water and prolonged exposure of building to standing flood water (Shall, Khan, & Qazi, 2013). Laterites from which mud bricks were produced are available and in cheap quantities in Bauchi, Nigeria. They have been useful as road building material and used to make mud (adobe) bricks for mud house walling and roofing.

The mud houses investigated were built from Plain Mud Bricks (PMB) and Straw Stabilized Mud Bricks (SSMB). They represent the materials used by the most economically vulnerable in the study area. The mud walls were in some instances plastered with cement-sand mortar. This trend is gaining ground among low income developers. Structural failures in mud houses are rampant and of grave concern in Bauchi. It is an open fact that over the years, every rainy season left a trail of wall collapses and more roof leaking points. This is in addition to the multiple cracks often observed throughout the year. Most building collapse in Nigeria have been attributed to the following:

(a) Complete absence of professional Engineers from the design/construction/supervision teams.
(b) Fraudulent dealings between project sponsors and the relevant planning authorities.
(c) Incompetent Builders
(d) Use of poor materials
(e) Unacceptable low standard of workmanship.
(f) Absence of Supervision
(g) Basic ignorance of the frailties of soil as a foundation material (Akintunde, 1997).

To investigate mud house failures in Bauchi North East Nigeria, 100 questionnaires were distributed to residents in 3 locations of Gwallameji, Birshi and Yelwa but 67 were retrieved by the deadline. Some of the information required included building material type, crack and collapse history, age of house and roofing type. In carrying out the investigation, three approaches were employed, they were:

(a) Administration of structured questionnaires to residents and developers of the three study areas.The information collected from the questionnaires were analyzed and presented.
(b) Touring of the study areas to collect firsthand information through visual observations. This included visiting of laterite borrow pits, observing mud block manufacturing exercises, mud house construction and failure forms, namely, wall cracks, wall collapses and roof leakage.
(c) Collection of soil samples from borrow pits used by local mud brick makers for laboratory tests.

The objective of this investigation is to highlight the extent of failure, present the causes and proffer remedies to the menace. Results of the investigation show that the incidence and level of structural failure is rampant and very high. Reasons for structural failures included poor or incompetent building practice, use of poor materials, low standard of workmanship, absence of supervision, basic ignorance of the frailties of soil as a foundation material and lack of adequate quality control in the production process of bricks. These deficiencies easily succumbed to flooding and thunderstorms during every rainy season with the resultant wall collapses, foundation wash – out and multiple cracking of the walls.

2 METHODOLOGY

2.1 Field Work

One hundred questionnaires were distributed randomly to residents and developers in the three study areas of Gwallameji, Yelwa and Birshi. Respondents were given between three and ten days to answer the questions. Sixty seven completed questionnaires were considered eligible for this paper and subsequently compiled after submissions by various respondents. A sample is attached as Appendix. Further oral interviews were conducted to verify and authenticate written responses where they were not made clear. One of the problems encountered was that of meeting illiterate respondents. In such situations, the questionnaires were completed by the researchers after taking dictations from the respondents. Another problem was the loss of some questionnaires by potential respondents.

2.2 Sites Observations

According to Ehiorobo & Ogirigbo (2013), visual inspection is usually the first step in the investigation of the causes, nature and extent of deterioration in structures. Borrow pits, brick making sites and mud houses in the investigated places were visited and activities observed. It was observed that earth used for PMB were not tested to ascertain their engineering properties and suitability for construction. Compaction was too brief and inadequate. Lumps of wet soil mortar were thrown into wooden molds and briefly shaken, all by hand and then left to set and cure. Where they were used, the straw in SSMB were not chopped to sizes which is required to minimize segregation during mixing process and improve strength (Ndububa, 1995), even though the mixing appeared thorough. The quantities of straw used were chosen arbitrarily. Bricks were generally cured in open air. Past results have shown that curing done under the shade produced stronger bricks (Ndububa, 1996).

Transportation of blocks were either by hand, wheel barrows or pick-up vans depending on the distance and quantity of blocks. A lot of carefulness was observed during transporting and handling of blocks. Block damage while in transit was minimal. Construction procedures were not unusual. There were no tests on materials, no working drawings and soils were not usually investigated for proper foundation design and construction. Foundation laying was casual with little emphasis on its importance. The cracks exceeding 2mm in width were considered for reporting. Another failure parameter was wall collapse and where any section of a house wall collapsed, the mud house was considered to have failed.

2.3 Laboratory Tests

Soil samples from different borrow pits and mud bricks that local mud brick makers used were collected and taken for laboratory tests to ascertain their viability as building materials. Hydrometer tests were conducted on the samples to ascertain the relative proportions of sand, silt and clay for the purpose of comparing with acceptable limits. Compressive strength tests on PMB samples were also done. The samples were molded into 150mm cubes and cured under laboratory conditions before crushing. British Standards (BS) 1983 was adopted.

3 RESULTS AND DISCUSSION

In Table 1, it is shown that the mud houses generally failed from multiple cracks and wall collapses. 62% of PMB with cement mortar rendering experienced wall collapsed as against 100% collapses with those without rendering. This is likely due to the protection rendered by the cement mortar to mud walls which served as barrier to moisture from rainfall and flooding.

Flooding generated by rainstorms is the most prominent agent of wall collapse failure and sometimes in concert with strong winds. The strong winds are known to precede rainfall during the early parts of the rainy season. They also had the highest cracking situation. It must be noted that not all the cracks extended deep beyond the cement mortar plaster as they seemed to peel off from the mud walls due to poor bonding. The result however shows that building mud houses without rendering constitute very high danger to life under flooding, storms and other environmental vagaries. It is noted that SSMB houses slightly improved in collapse failure at 90% compared to PMB with soil rendering at 94%. However the later had least crack problem.

The higher crack percent of SSMB over PMB with soil rendering may be due to the poor quality control measures employed in the production of SSMB as earlier explained; straw chopping was not done thereby adversely affecting bond between earth and straw.

Table 1: Failure of different Wall Types

Wall Type	No of Houses investigated	Crack Count (>2mm width)	Wall Collapse Count	% of cracks to No. of Houses	% of Wall collapse to No. of Houses
PMB with soil rendering	18	31	17	172	94
PMB with cement mortar rendering	34	123	21	362	62
PMB with no rendering	4	15	4	375	100
SSMB	10	21	9	210	90

Table 2 shows that mud houses with concrete foundations experienced no wall collapses and least percent of cracks. Those with sandcrete blocks at 55% wall collapse were better secured compared to those built on rammed earth which was 100%. The reason for this is attributed to the impact of floods after heavy rainfalls which eroded foundations, causing collapse. The floods usually supply soaking water to the walls from the bottom up which weaken them and when in combination with winds induced overturning moments on the walls thereby causing collapse. Concrete foundations were able to withstand the impact of the floods. The results in Table 2 clearly show that mud house failures are principally attributed to weak foundations.

Table 2: Failure Based on Foundation Materials used

Foundation Material	No of Houses Investigated	Crack Count	Wall Collapse Count	% of Cracks	% of Wall Collapse
Concrete	10	6	0	60	0
Sandcrete Blocks	31	109	17	351	55
Rammed Earth	22	86	22	391	100

Table 3 shows what can be considered as a natural trend, which is that mud houses deteriorated with age. The cracks increased with age. The only surprise is that there was no difference in percent of wall collapses for all houses below 10 years of age. However crack and wall collapse failures increased drastically in houses with ages above 10 years. It may therefore be deducted that the lifespan of mud houses in Bauchi is 10 years. In a Report from India, unstabilized rammed earth was reported to have shown structural durability for up to 20 years (Buia, Morela, & Ghayada, 2009).

Table 3: Failure Based on Ages of Mud Houses

Age of Houses (Years)	No of Houses Investigated	Crack Count	Wall Collapse Count	% of Cracks	% of Wall Collapse
1-5	10	15	5	150	50
6-10	20	53	10	265	50
10 and above	31	128	28	413	90

Table 4 shows that straw stabilized mud roofs leaked most at 500%, but the few number of respondents with this type of roof make proper assessment inadvisable. However galvanized corrugated iron (gci) roofing sheets leaked more than straw roofs. Possible reasons adduced for this include poor quality gci sheets in use, high susceptibility of gci sheets to rust and continuous use of gci sheets beyond their life spans which is not common with straw roof users. They changed theirs more frequently (average 1½ years).

Table 4: Failure Rating Based on Roofing Materials used

Roofing Materials	No of Houses Investigated	Roof Leaking Count	Roof Leakage %
Straw	16	5	31
Straw Stabilized Mud	2	10	500
Galvanized Corrugated Iron Sheets	40	173	433

Table 5 shows the results obtained from hydrometer (wet sieving) test. It shows that while sand exceeded recommended proportion limits for building soil blocks, silt barely fell within the range and clay slightly fell below the limits (Norton, 1986). This shows that local mud house builders inadvertently have been using inadequately graded soil for the purpose of mud house walling. The clay content is the binding material. The relatively low clay content in the soil must have contributed to poor performance of both PMB and SSMB. The average sand fraction content of 76.49% is higher than the acceptable and recommended 75% limits. This must have affected bonding properties of the bricks especially as some of them were stabilized with straw. Straw will bind better with more clay. Even the straw used for stabilization purposes were picked arbitrarily and were generally in excess of the recommended 3-5% fraction content (Ndububa, 1995). They were also not cut to short lengths of between15-40cm to minimize segregation and 'balling effect' during mixing. Though the mixing processes were fairly done as observed, compaction was not adequate and the open air curing method rather than under-shade curing could not have maximized strength development (Uzomaka, 1978).

Figures 1 and 2 show the results of the density and compressive strength tests on bricks molded from earth collected from the borrow pits. The 28day density and compressive strengths were 1966 Kg/mm3 and 0.81N/mm2 respectively. The result for density shows that the cubes reduced in density by 4% between the 7 and 28days of curing and that made the walls lighter each passing day. The compressive strength as expected increased with age, though the values were inadequate for load bearing. The minimum specified value for sandcrete blocks in Nigeria is 2.5 N/mm² (NSO, 1975).

Table 5: Percentage Proportions of Soil Samples from the three locations as given from Hydrometer Soil Tests.

Location of Borrow pit	Sand Fraction (0.06-2.00mm) %	silt Fraction (0.002-0.06mm) %	Clay Fraction (0.002mm) %	Total %
Gwallameji	78.4	10.2	11.4	100
Yelwa	75.3	11.2	13.5	100
Birshi	76.6	8.9	14.8	100
Average %	76.8	10.1	13.1	100
Specified Fractions (Norton, 1986)	40-75	10-30	15-30	

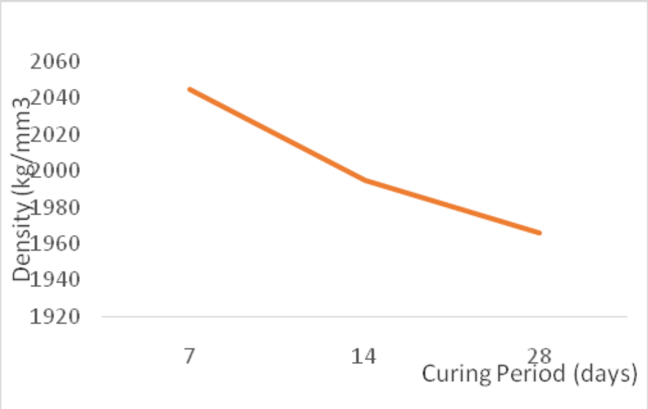

Fig. 1. Density of PMB cubes

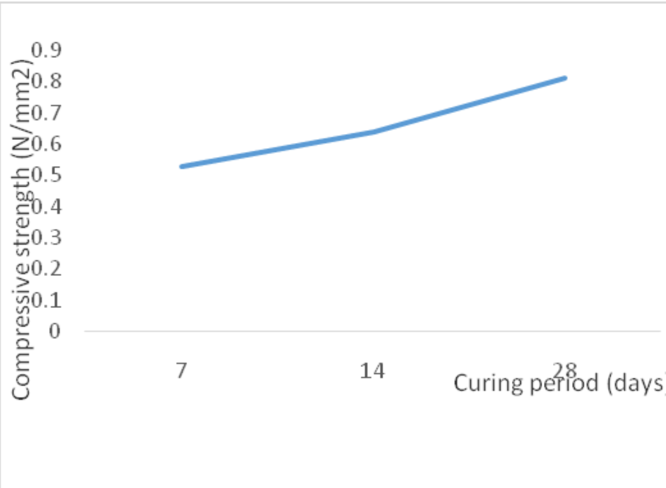

Fig. 2.Compressive Strength of PMB Cubes

4 CONCLUSION

From the various results and discussions, the failure of mud houses in Bauchi is high and flooding occasioned by rainfall is the major cause. Flooding and other climatic conditions were able to do the havoc due to the following reasons: Poor grading of soils used to make mud blocks for building purposes with sand in excess and lower clay content thereby possessing poor bonding properties, the high incidence of the use of rammed earth as foundation materials which in structural sense is a no-foundation situation, the use of mud houses beyond their life spans with lack of adequate maintenance, the non plastering of mud walls in some buildings and lack of adequate quality control measures during construction. With the compressive strength of bricks at 0.81N/mm2, the bricks were too weak to withstand loads imposed by climatic forces.

5 RECOMMENDATIONS

The following recommendations are hereby made to mitigate the impact of Mud house failures:

1. Adequate soil tests be conducted before using soil for mud house construction.
2. If developers insist on PMB, then re-grading the soils by sieving away sands above 1.25mm diameter is suggested. An earlier work showed that blocks made from such soils but stabilized with vegetable materials (SSMB) experienced enhanced performance (Ndububa, 1996).
3. Another option is to stabilize the soils in the area with Ordinary Portland Cement (OPC) without regrading. This will suit the soil in view of the relatively high sand content (Ogunsusi & Kolawole, 1994).
4. Training on quality control measures in building constructions should be offered to local mud house developers.
5. Governments and other stakeholders need to focus on improving livelihood conditions of the people in the flood ravaged communities (Ogbanga, 2015). Urban planning with adequate drainage and flood controlmeasures must be considered as imperative in our communities.

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APPENDIX: SAMPLE OF STRUCTURED QUESTIONNAIRE

DEPARTMENT OF CIVIL ENGINEERING
QUESTIONNAIRE FORM ON RESEARCH PROJECT

TOPIC: STRUCTURAL FAILURE OF MUD HOUSE WALLS IN BAUCHI (BIRSHI, GWALLAMEJI AND YELWA CASE STUDIES)

Please all information in this questionnaire will be treated with strict confidence.

1. Age of Respondent:...
2. Occupation:...
3. Marital Status:...
4. Number of Household Members:..
5. Estimated Monthly Income N..K
6. What Year Did Construction Start:..
7. What Year Did Construction End:...
8. Estimated Cost of House N:...K
9. Did you procure Loan to Complete the House (tick) Yes:................../No..............
10. If yes, From What sources (Tick) (a) Bank:.......... (b) Thrift, Cooperative or Building Society:.......................... (c) Friends/Relations:........ (d) Others (Mention):.................
11. What Materials Were Used to Build the Walls (Tick): (a) Plain Mud Blocks:............... (b) Mud Block with Straw:............ (c)Soil Block with Cement Blocks:.........(d) Sandcrete Blocks:.............(e) Mud Blocks Plastered with Sand/Cement Mortar:.......(f) Others (Mention)
12. How were the Materials Above Obtained (Tick): (a) Purchase:.....................(b) Site production:..
13. Briefly Explain the Material Production Process (Optional):...
14. Briefly Explain the Wall Construction Process (Optional):...
15. What Type of foundation Was Used (Tick): (a) Isolated Base:...................... (b) Combine Base:........................ (c) Strip Footing:.........................(d) Others:.............................
16. Estimated Depth of Foundation:...
17. Type of Material for foundation: (a) Concrete:................. (b) Sandcrete:.....................
 (c) Laterite............ (d) Ordinary soil:.................. (e) None:..............Others:..............
18. What DPC Material Was Used:...
19. Mention Material Used for roofing: (a) corrugated Steel Sheets:........... (b) Straw:.......
 (C) Mud:.............. (d) Asbestos sheets:.............. (e) Alluminium:..........(f) Others:........
20. What year was the first Major Crack Observed in the Wall:...
21. How Many Major Cracks are Presently in the Building:..................
22. Has Any Wall Portion Ever Collapsed: Yes............./No................
23. If Yes, When?..
24. Does the Roof Lick? Yes............/No..............
25. If yes, At How Many Points:..
26. If Any Wall Portion Ever Collapsed Before, Under What Conditions did It happen? (a) strong Wind:..................... (b) Rainfall:................. (c) Under Construction:................. (d) Flooding:.................. (e)Normal conditions:............ (f) Others (Mention)..................
27. Does the House Experience Occasional flooding: Yes/No:................
28. If Yes, for about How Many Days Within a Year?:...........................
29. If Yes What Are the Plastering Materials: (a) Sand/Cement Mortar:........... (b) Clay/Mud:............ (c) Others:.................................
30. Any Other Informations:..

Thank you.