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Strength of Sway Frame Infilled with Cement Stabilized Laterite Block

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ABSTRACT- The experimental results of the strength and failure mechanism of sway frames with cement stabilized laterite block infill are presented in this study. The engineering properties of cement stabilized laterite block produced from local laterite from Rumueme, Port Harcourt, Nigeria and cement content of zero, two, four, six and eight percent are first investigated to produce blocks at optimum moisture content and then testing for strength property carried out. It was established that four percent cement stabilized laterite block, compacted at its optimum moisture content and dry density produced the best combination of physical and mechanical properties as the tensile, shear and boned strengths for the four percent cement stabilized laterite blocks meet the minimum Code specifications for sandcrete and brick blocks. This agrees with the findings of Nigerian Building and Road Research Institute (NBRRI), from a similar experiment conducted in Kano State, Nigeria. The strength of 1.13N/mm^2 achieved at 28days is higher than the Nigerian Industrial Standard (NIS) specification of IN/mm^2 for cement stabilized laterite block. The strength and failure mechanism of a one-quarter scale model reinforced concrete frame infilled with four percent cement stabilized laterite block followed the trend established for sandcrete and brick infills with the sway resistance capacity of the frame increasing by about 300%. The experimental collapse load of the frame agrees with the theoretical collapse load to about 1%. From the foregoing a wider application of cement stabilized laterite block as infill will lead to cost effective housing delivery as laterite is very available and relatively cheap.

1.0 INTRODUCTION

The need for decent, functional and affordable housing for the citizenry has formed the thrust of government policies since the 1970s. However, the issue of high cost of basic building materials and hence affordability of housing by the masses still remains topical. In an attempt to address this problem, the federal Government of Nigeria through the Nigerian Building and Road Research Institute (NBRRI) has embarked on the research, development and application of Cement Stabilized Laterite Blocks (CSLB) for affordable housing. In driving the research and development of cement stabilized laterite blocks, NBRRI embarked on collaborative research with the Ahmadu Bello University Zaria, Nigeria, using the black cotton soils of Kano. On the basis of the studies, it was established that the optimum cement content, satisfying standards for strength, durability and economy of CSLB was put averagely at four percent [1]. The compressive strength values obtained in these tests ranged from 1.50-1.68 N/mm^2. It is obvious that the optimum cement will depend on the type of larterite, varying from higher values for more sandy to lower values for the clayey lateritic soils. In view of the above, NBRRI has recommended that the required cement for local laterites should be determined from laboratory tests on trial mixes before production of CSLB. Secondly, CSLB is basically used as walling units and therefore may function as infill for structural frame. Although structural frames are generally designed to resist all lateral loads ignoring the contribution of infill, structural cracks are frequently observed on walls of buildings [2], [3]. The fact is that some loads are transferred to the infill, which must therefore, have some capacity to absorb the induced stresses and deformations [4], [5], [6]. The situation throws the second challenge, namely the need to investigate the structural load carrying capacity and failure mechanism of CSLB inflled frames. In this regard, technical literature reveals a dire paucity in available research studies.

2.0 THEORETICAL AND CONCEPTUAL FRAMEWORK OF STUDY

The study basically based on structural modeling which is an important tool in the analysis, design, and testing of prototype structures. Experiments are carried out on the model that is a reduced scale semblance of the prototype from where the behavior of the prototype is predicted. The theory of dimensional analysis that involves similitude requirements is employed in the sizing and experimentation of the model to predict the prototype behavior.

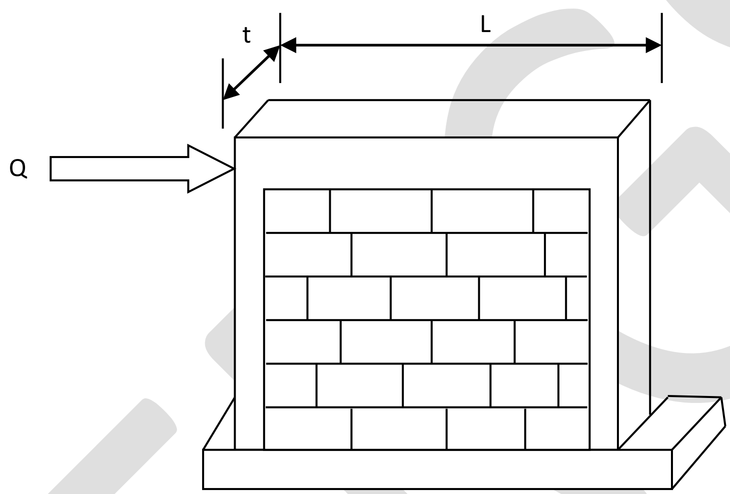

Figure 1: Infilled Frame Model

Considering the infilled frame structure in Figure 1, the following steps are considered to stimulate the physical parameters of the model.

i. The diagonal tensile stress σ of the CSLB infill wall depends on the loading Q, span L, the thickness t and the modulus of elasticity E and may he represented im as;

$\theta(\sigma, Q, I, t, E) = 0$ (1)

ii. Taking, the modulus E and span L as dimensionally independent variables [7], [8], the above equation can he expressed as

$G(\sigma/E, Q/EL^2, t/L) = 0$ (2)

where

$$\sigma = \theta (Q/EL^2, t/L) \quad (3)$$

Hence

$(Q/EL^2)_P = (Q/EL^2)m$

$Q_p = Qm\ S_E\ S^2_{L,}$ Where $S_E = 1$.

iii. For the same material in model and prototype, the scale factor for material $S_E = 1$, and the prototype load $Q_P = Q_M\ S_L^2$. Where S_L is the linear scale factor.

Therefore the failure load of the prototype can be computed by multiplying that of the model by the square of the linear factor, and based on material scale factor, the model material is the same as the prototype material hence the stress is the same in model and prototype. The success of this theory reduces cost of experimentation, enhances safety and ease with which the behavior of large prototype structures are analyzed and predicted.

3.0 EXPERIMENTAL PROCEDURE

The method of research was based on structural modeling and experimental test in the laboratory. The determination of basic properties of local laterite produced is done in accordance with BS 1377, 1995- Method of Test for Civil Engineering Soils and BS 3921, (1995) and Method of Test for clay bricks and blocks, [9], [10].

The structural modeling of a previously designed frame was achieved on the assumption of a uniform scale factor for materials (laterite, cement, water, sand) and a linear scale factor of 1:4 was adopted for determination of deflections and dimensions.

3.1 Materials

The basic materials used for this study were as follows; water, local laterite from Rumueme borrow pit in Rivers State Nigeria, cement, and sand. They are described briefly in the sub-headings below.

3.1.1 Equipment

These include wooden mold conforming to 1/4 scale model dimensions of 75x37.5x37.5mm, equivalent to the prototype dimensions of 300x150x150mm, hydraulic jack, strain and dial gages, and proving ring.

3.1.2 Water

Water conforming to BS 3148 (1995); obtained from the university water supply network was used for the experiment.

3.1.3 Laterite

The laterite was obtained from a borrow pit located between Agip and Ada George Roads at Reumueme in Port Harcourt. Laterite for the construction of Ada George Road was obtained from this borrow pit. The preparation of the laterite was in accordance with BS 1377 (1995) with respect to sampling the optimum moisture content (OMC), the maximum dry density (MDD), sieve analysis, and index properties determination.

3.1.4 Cement

Portland cement complying with BS 12 (1995) obtained from Eastern Bulkcem Limited, was used in the experiment.

3.1.5 Aggregate

Aggregate conforming to fine gravel on the particle size curve was used in the production of concrete. The aggregate conformed to BS 882 (1995).

3.2 Laterite Block Production

Production of model blocks was by ramming into a wooden mold with internal dimensions 75x37.5x37.5 mm and pressing down to ensure no voids or honeycomb on block when extruded. Curing was in accordance with BS.3578. (1995). The freshly molded block were cured for 7days by covering with polythene sheets to prevent any loss of water. After 7days, the polythene sheet covering was removed. The strength of the blocks was tested at 7,14 and 28 days. The water absorption test was done at 28days for each sample at ½ hour, 1hour, 2hours and 24hours in accordance with BS 3921

3.3 Construction of Model Frame and Test Setup

The model frame was constructed after analysis of a prototype frame to determine the size of reinforcement and load capacity. Basically the prototype column section was controlled by the prototype block size of 300 x 150x150 mm. The details are set out below in Tables 1.

Table 1: Prototype and Model Frame Dimensions

Member	Prototype (mm)	1/4 Model (mm)
Frame (Full Size)	3000x3000	750x750
Column Section	150x150	37.x37.5
Beam Section	300x150	75x37.5
Block Section	300x150x150	75x37.5x37.5
Mortar thickness	12	3
Reinforcement	Y 12	Y3 (BRC wire)
Stirrup	R6	R1.5 (binding wire)
Binding wire	R1.5	R0.375 (fly screen wire)
Aggregate	12(1/2'')	3 (1/8'')
Foundation Depth	900 x 600	225x150

Four different models were constructed at the premises of the structural engineering laboratory, Rivers State University of science and Technology Port Harcourt, Rivers State, Nigeria. Each frame foundation was made very rigid to avoid over turning effect during testing. The frame starter reinforcement was fixed and cast in-situ with the foundation. The entire foundation was covered and flushed with the ground level and compacted to represent true site situation. The experiment was carried out in dry season when the ground was dry and strong enough to resist the racky load.. The frames were loaded using a hydraulic jack as shown in Figure 2. The laboratory stanchions provided the reactant action for the jack. The strain gages tagged GI, G2,G3 and G4 are 100mm gages. Gages G1 and G3 measured strain on the compression diagonal while G5 and G4 measured strain on the tension diagonal. The dial gage, G5 measured displacement in the sway direction. The hydraulic jack connected to the proving ring assembly, exerted horizontal force on the frame. The load was applied in steps of 0.50KN and maintained for 5 minutes to allow for stabilization of the frame under the load and observation of cracks which may develop. The load at which crack appeared on the infill was recorded as the collapse load.

3.4 Loading Scheme

The horizontal sway load capacity of the prototype and model frame was calculated as 23.81KN and 1.48KN respectively and the loading scheme for the frame was carried out in accordance with BS 5628: part: 1995. The load values were read on the proving ring. The readings of strain gages G1, G2, G3,G4 and G5 were recorded at each loading cycle, until the infill frame showed cracks on the infill panel. The load at which the cracks appeared on the infill was recorded as the maximum load capacity of the frame. The strain gages G1, G2, G3 and G4 recorded internal strains on the infill, while dial gage G5 recorded the horizontal away of the frame. The frame deflection, stress/strain profiles were plotted to show the infill behavior during loading up to failure.

4.0 RESULTS AND DISCUSSION

This chapter presents the result obtained in the experimental investigation conducted in this study. The results are analyzed with the Table and graphs provided. The discussion of the results is done with comparison with the code provisions and the result of similar researches conducted by researchers in other locations. The graph of deflections and stress- strain behavior of the infill frame are shown, and deflection values calculated. Model horizontal load was applied to the frames and deflections/strains induced on the frames were measured. The mode of failure of each frame was noted and photographed. The average resistance of the infill in the three frames with infill was used in calculating the stresses on captured as would be seen in the figures below.

4.1 Failure Mechanism of the Frames

The failure mechanisms of the frames are shown in the figures below. Figure 2 shows the collapsed mechanisms of the rigid frame (MF0) with hinge formation on the joint of the columns, while figure 3 to 5 shows the collapse mechanisms of infilled frames MFI, MF2, and MF3, respectively with the crack formations at critical sections

Figure 2: Failure Mode of MF0 Frame

Figure 3: Failure Mode of MF1 Frame

Figure 4: Failure Mode of MF2 Frame

Figure 5: Failure Mode of MF3 Frame

The failure of the rigid frame was observed to be by formation of hinges at the upper and lower portions of the two columns, wile the failure of the infill frame was by formation of diagonal cracks starting from the load application point running parallel to the loading diagonal. The crack width ranged between 2 and 3mm. Separation of infill panel from the column near the application of the load as well as, separation of the infill panel from the ground beam was also observed. There were also micro cracks initiating from point of application of the load mainly due to corner crushing mode of the infilled frame. Generally, it was observed that the infill increased the resistance of the frame as would be seen from the readings and the reduced and corresponding calculation from the proving ring and dial gauge.

4.2 Critical Loads on Model Frame.

The critical loads are the loads at which first cracks are initiated on the frames without further increase on the proving ring readings. These loads are shown on the Table 2 below. These loads are used to predict the prototype sway load for the infilled frame.

Table 2: Critical Sway Loads

Frame type	Height (mm)	Span (mm)	Infill Type	Load (kN)
MF0	“	750	“	750
MF1	“	“	CSLB infill	5.00
MF2	“	“	“	3.50
MF3	“	“	“	4.50

From the foregoing the critical load on the prototype model can be predicted as follows:

Critical load on frame MF0 load through experimental modeling = 1.5KN

Predicted load from analysis =1.49KN

Accuracy of predication = 1.5/1.49 = 1.0067

Critical prototype Load, $= 1.5S^2$ (from similitude requirement) $= 1.5x4^2 = 24$kN

It is possible to determine the prototype infill frame sway loads based on the model result by applying the scale factor as also seen in Table 2.

4.3 Deflection of Infilled Frame Model

The deflection of the frames was monitored by dial gage seen in the test set-up in the sway direction. Generally it was observed that the introduction of the cement stabilized Laterite Block with acted as an infill panel reduced the horizontal defection of the frame by 67% as can be seen in the comparison with the load-displacement profile of the rigid frame model tagged MF0. The MF0 model which is without infill, was swayed through 18.5mm before collapse by a horizontal load of 1.5kN, as recorded by the dial gage. The infilled frame models tagged MF1, MF2 and MF3 were displaced through, 11.6mm 3.6mm and 3.08mm respectively by horizontal load of 4.4, 3.5 and 5kN acting on the frame respectively. The load-displacement diagram is shown in Figure 6 where it is clearly seen that the introduction of infill reduced the sway of the frames at increased load before collapse by stiffening the frame.

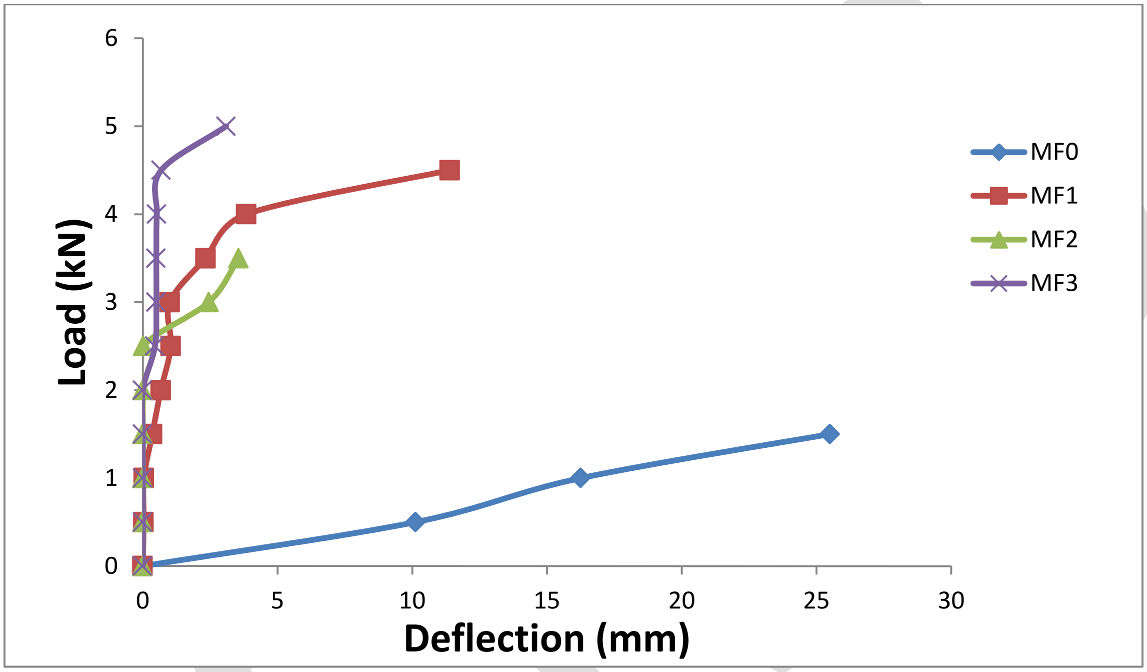

Figure 6: Load-Displacement Profile for Structural Models MF0, MF1, MF2 and MF3

4.4 Streets-Strain Characteristics of Infilled Frame Model

The estimation of the linear strain in the infill was monitored at increased load and measured as points G1, G2, G3, and G4, using strain gages and the values recorded. Diagonal cracks and separation of infill from the frames through a length of about 600mm on each frame were observed, as well as separation from the foundation through the entire length of 750mm as shown in Figure 2 to 5. This could be attributed to the frames bearing pressure on the infill while being acted upon by the external horizontal load and the foundation providing the counter thrust to the horizontal force. The end action was that frame and infill were crushed under the two opposing force leading to the collapse of the frame and infill. Strain gages G1 G3 measured strain in same direction but opposite to strain gages G2, G4 which were placed on the other side of the infill panel measuring strain in same direction. The net strain is given by [19] as G0 = G1 + G2 – G3+ G4 with the stress-strain profile given in Figure 7.

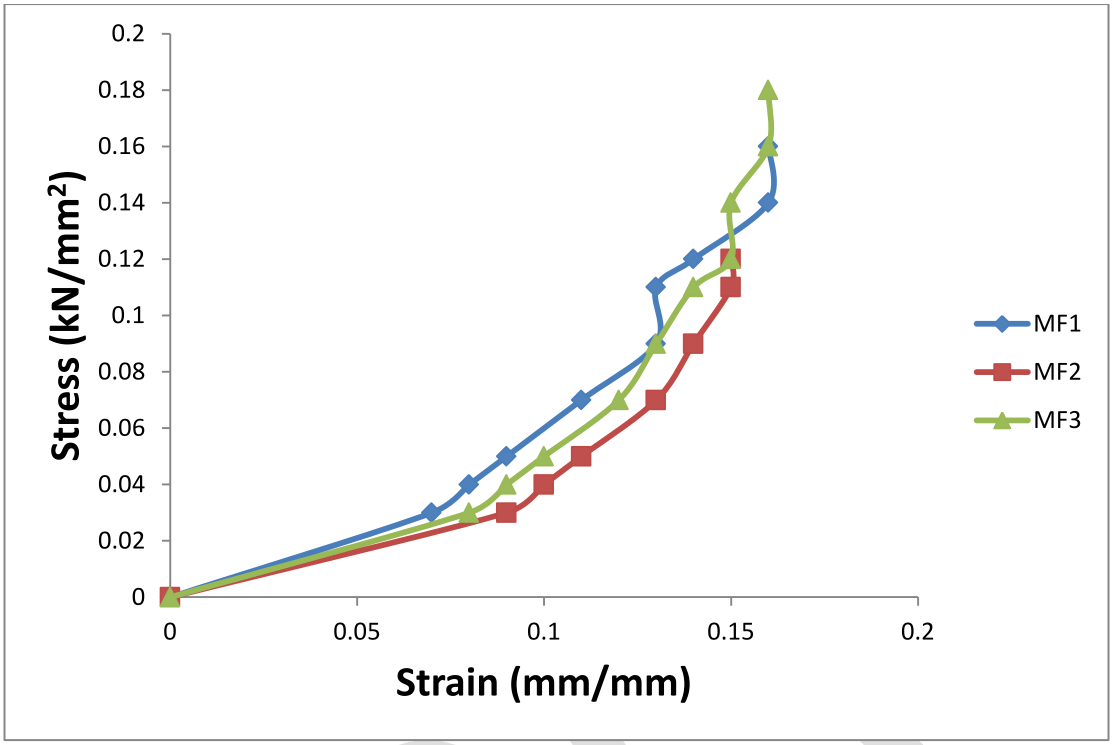

Figure 7: Stress-Strain Profile of Infilled Frame Models, MFI, MF2, MF3

Crack formation on the infill was visible and it is attributed to the limit of shell buckling, which is the point at which failure of the interior web of the infill starts [8],[11]. This behavior is attributed to the failure of each member of the composite even though it still contributes to the overall resistance of the composite frame till collapse mechanisms, thus confirming that the high in-plane rigidity of the masonry wall significantly stiffens the otherwise relatively flexible frame, while the ductile frame contains the brittle masonry after cracking, up to critical sway load. The tensile stress which corresponds to the maximum tensile strain [12], is obtained as 0.09N/mm and it compares favorably with the codes specification [9], [10] for sandcete blocks and clay bricks.

5.0 CONCLUSION

This study the strength of sway frame using cement stabilized literite block unit as structural infill has been presented. From the analysis of the results obtained in the study, the following conclusions are arrived at.

1. Four percent Cement Stabilized Leterite Blocks, produced at optimum moisture content and maximum dry density presents the best combination of physical and mechanical properties. The strength of 1.13 N/mm^2 achieved in

28days is within the Nigerian Industrial Standards (NIS) specification for cement stabilized laterite blocks. This also confirms the applicability of four percent cement content recommended by NBRRI to Niger Delta laterite soil.

2. The strength and failure mechanism of a ¼ scale model reinforced concrete frame, with the four percent CSLB as infill, followed the trend established for sandcrete and burnt brick block infills and the sway resistance capacity increased from 1.5kN to 4.5kN, suggesting an average of 300%

3. The experimental failure load compares favorably with the theoretical failure load from the model collapse load.

4. The tensile, shear and bond stresses for the CSLB are within the code specification for infill material. The values obtained for four percent cement stabilized infill constitute respectively, 0.09N/mm^2, 0.22N/mm^2 and 0.21Nmm^2.

5. The CSLB is cost effective and competitive over sandcrete and burnt brick in terms of strength; thus a wider use of CSLB as infill will lead to cost effective housing delivery in the country.

5.1 RECOMMENDATIONS

1. The CSLB from Rumueme laterite is recommended for the state mass housing project.

2. The effort of Nigerian Building and Road Research Institute should cover the entire nation by collaborating with all the universities in research on the local laterite, to establish the economic cement mix for production of cement stabilized laterite block for the locality in order to help local people in housing.

3. Further research on the carrying capacity of CSLB infill and resistance to both racky and gravity loads is recommended.

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