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Indigenous earth building construction technology in Ota, Nigeria

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This paper documents the earth construction techniques used in Ota in order to preserve the earth construction heritage of the Ota people while checking the suitability of the earth materials used, using soil classification tests. Interviews of earth constructors in six villages in Ota were conducted to determine their material selection criteria, material processing and construction techniques. Colour and texture of soil samples were determined and *in-situ* tests such as biscuit, cigar, hand-wash and adhesion tests were performed on soil samples used for earth building construction at three of the villages. Natural moisture content, sieve and hydrometer analyses, and Atterberg limits test were performed in the laboratory, on soil samples taken from these three locations. It was revealed from the interview sessions that cob construction technique is widely used and that earth building construction is becoming less-appealing to the youths in these locations. The soil samples at the three locations were classified as clayey sand and were ascertained to be suitable for earth building construction. Earth constructors in Ota perceive that earth buildings are more economical and energy-conserving. Earth buildings are a potential solution to the global housing crisis experienced, especially in developing countries.

Keywords: Earth building, Eco-efficient construction, Low-income housing, Mud, Sustainable housing

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Despite cement being an essential material used for today's infrastructural developments, there is increasing awareness to consider alternative construction materials and techniques that are more environment-friendly, affordable; and that will cut-down on our energy consumption[1-4]. Most of the research works on construction materials focused on their mechanical properties with little or no consideration of their environmental impact[5].

It is estimated that about one-third of the world's population and about half of the people living in developing countries live in earth buildings[6,7]. The most commonly used traditional building materials in the world are, undoubtedly, earth-based. This is because they are cheap[8], locally-available, environment-friendly[8] and are of low-embodied energy[8-10]. They are traditionally used in various forms, depending on the processing techniques adopted or the materials combined with the earth for construction. Cob, earth or adobe bricks, rammed earth and wattle and daub are some examples of these forms. However, the traditional use of earth materials is not receiving the required attention it deserves despite global concerns about sustainable development issues in today's building industry and the current worldwide housing crisis. There is still poor understanding of the selection and use of these materials, especially among scientists, architects and engineers[11] but we can learn from the past.

Akinwumi[12] investigated the earth building construction materials and techniques used by earth builders in three villages in the ancient Benin City of Nigeria. He investigated the earth material selection and construction techniques used by the Benin people and classified the soil samples used using standard soil classification schemes. He found out that the interplay between the tradition of the Benin people and their earth construction procedures is unique and represents their cultural building heritage.

The objectives of this study are to identify the earth-building construction materials, their selection criteria, their processing and the construction techniques used in the ancient town of Ota; to identify the challenges encountered by those living in earth-buildings that favour the increasing demand by many people for cement-based materials for

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building construction; and to provide standard engineering classification of the earth materials used in Ota, while benchmarking with known earth material selection criteria.

Study area and methods

Ota is a town in Nigeria at latitude 06 °41′ North and longitude 03 °41′ East. It is the headquarters of Ado-odo/Ota Local Government Area (LGA), one of the nineteen (19) LGAs in Ogun State in Southwest Nigeria. It borders on metropolitan Lagos to its South, Ifo LGA to its North and it is about 329 km (by road) away from Benin City – where a similar study was previously undertaken (Fig. 1). According to the Ogun state Government[13], the mean annual rainfall in Ota is 1280 mm and its average monthly temperature ranges from 23-32°C. Rainy season in Ota starts in March and ends in November, yearly. The villages in Ota, where this study was carried out, are Tisha, Atan, Iju, Ilewo-alaga, Onilado-isaga and Iyesi.

Earth constructors (10 each per selected village) were orally interviewed, utilizing Yoruba language. The interviews were conducted to determine the various criteria for material selection and the material processing techniques used by each of them while constructing earth buildings.

The interview approach was favoured because most of the respondents were old and could not read nor write in both English and Yoruba languages. A random sampling method that ensured that the interviewees are dispersedly-distributed in the study area was used while selecting those to interview. The questions asked during each of the interviews include: when the earth buildings in which the respondents' live were constructed; how they identified suitable soil types for earth building construction; their source(s) of suitable soil; their soil processing technique(s); their construction processes; their efforts at passing the knowledge of earth construction to the next generation; and their perception about living in earth buildings.

Fig. 1—Ota in Ogun state, Southwest Nigeria[14]

A nonrandom sampling method was used while collecting soil samples used for earth building construction in the study area. Ilewo-alaga, Onilado-isaga and Iyesi were selected as locations for disturbed soil samples collection. Disturbed soil samples were collected because these samples were only needed for soil classification purpose. In these locations, samples were collected from earth building construction sites with the aid of digger, shovel and watertight bags.

Soil samples collected from Onilado-isaga, Iyesi and Ilewo-alaga were denoted as samples A, B and C, respectively. *In-situ* tests, which comprised colour, texture, biscuit, cigar, hand-wash and adhesion tests, were conducted on the collected samples. Colours of the soil samples were identified. Small quantities of each of the soil samples were rubbed on the palm, when dried and after being moistened, to feel their texture. Biscuit, hand-washing, cigar and adhesion tests were performed in accordance with Achinomy[15] and Baker[16]. The gravel-sized particles were removed, using a sieve with 2.36 mm openings, before performing these tests.

Biscuit test: After the soil was moistened, it was formed into a biscuit shape of 3 cm diameter and 1 cm thick and allowed to dry thoroughly in the sun. The dry biscuit was then broken, while carefully observing it from the drying to breaking processes, in order to determine their suitability or otherwise.

Hand-wash test: Moist sample of the soil was prepared and worked on with bare hands, until the hands became soiled. They were, afterwards, washed until they were clean. Observation of this process helps to fairly determine which soil type predominates.

Cigar test: Moist sample of the soil was rolled, using the palms of the hands, into a shape similar to that of a cigar or sausage of about 6 mm diameter. Rolled soil was then held within one palm, squeezed and pushed out of it through a small opening between the thumb and forefinger. The length of the soil squeezed out of the palm, before it broke-off and fell to the ground, was measured. This was used to determine whether there is a good blend of sand, silt and clay in the samples.

Adhesion test: Moist sample of the soil was rolled into a spherical (ball-like) shape. Knife was used to pierce the moulded soil and removed. The sticking of the soil or otherwise to the knife was used to roughly describe the plasticity of the soil samples.

Laboratory tests

To classify the soil, *in-situ* moisture content, sieve analysis, hydrometer analysis and Atterberg limits tests were conducted on the samples at the Geotechnical Engineering Laboratory of Covenant University.

Gradation tests, comprising of sieve analysis and hydrometer analysis, were carried out on the soil samples to determine their particle size distribution. Soil moisture content determinations were carried out using the oven drying method. Liquid, plastic and shrinkage limits tests were the Atterberg limits tests conducted. They were performed on the samples in order to characterize their in-situ states or conditions, based on their water content. These tests were conducted in accordance with the requirements of BSI[17].

Results

Outcome of interviews

Of the sixty villagers (who live in earth buildings and are also earth building constructors) interviewed, 15, 33 and 12 respondents reported that their earth buildings were constructed within the last 30 yrs, between 30 and 50 yrs ago, and over 50 yrs ago, respectively. The few number of earth buildings constructed within the last 30 yrs suggests that earth building construction is becoming less-appealing in Ota. This was ascribed, by respondents, to the recent increase in the number of educated people residing in these villages, most of who found it cheaper to acquire land and construct modern buildings in these villages than in Lagos, where they earn their living.

When asked how they identified suitable soil types for their construction, most of the respondents said that this is done after visual inspection and by textural identification of the material. Reddish brown, light brown and yellowish brown colours were described as the predominant coloration of most of the suitable soil types. Some of the respondents described the textural identification procedure as involving: the addition of small quantity of water to a handful of the sample; moulding the moist sample to form a ball; releasing it to fall freely to the ground; and observing whether the sample crumbled, or some of its particles got stuck to one another, or it rolled-off like a ball. Soil samples suitable for earth building construction are expected to retain cohesion within some of its particle after falling to the ground. Eighty five per cent of the respondents said that suitable soils, most times, were a stone's throw away from their construction sites. All the respondents stated that they do not add any cementitious material before use of the soils in these locations.

The frequently used construction technique in the study locations was described as consisting of the following: preparation of a stone foundation; chopping of straw into small length; thorough mixing of the soil with straw (to a proportion of about 3:2, by volume) and water to achieve a sticky consistency; placing the mixture on top of the foundation to form wall; compacting the mixture by treading and beating it; once this layer becomes firm, another layer is placed on it; openings for windows and doors are formed, and lintels are placed as the wall is raised.

By observation, it was discovered that some residents used cement mortar to surface-finish their interior and / or exterior walls (Fig. 2). Some use the cement mortar only to protect the unstabilised earth materials, close to the ground, from rain splashes. It was also noted that most of the earth buildings in these locations were single-storied. There was consensus by the respondents that earth building constructions were preferably carried out during the dry season of the year, except a temporary structure that will protect the construction from rain is erected.

Many of the respondents revealed that youths in their community were not interested in knowing how to construct earth buildings because they believe that living in earth buildings connote poverty. These respondents, however, stated that the internal temperature within their houses get automatically regulated against the prevailing outdoor temperature. They reported that these houses also have high fire

Fig. 2—An earth building in Ota with its protective cement coating on wall already falling off

resistance and are soundproof. Also, 40% of the respondents believe that the total cost incurred by them during the construction of their earth buildings should be about 10% of the amount they would have required to build a house (of similar size) using cement blocks, mortar and concrete.

***In-situ* test results**

The results of in-situ tests on the soil samples collected from the three villages are shown in Table 1. Reddish brown colour of the soil sample B shows that the soil is rich in iron. It was suspected that sample C contains organic matter that resulted in its dark coloration. The texture of soil Sample C shows that it has the highest gravel-sized particles.

The gritty and smooth texture of samples A and B suggests that it is comprised of a mixture of sand, silt and clay. On sun-drying, the moulded biscuits of all the samples kept their form and did not crumble when picked. It also required significant effort to make the samples crumble. These show that a fraction of the soil is cohesive. The texture of the moist samples was gritty and slippery, and it took some time to wash it off the hands. These results and that of the adhesion test show that the clay fraction of the soil samples was significant enough to influence their physical properties. The result of cigar test on all the soil samples shows that the length of soil pushed out of the palm before it broke-off ranged from 50-150 mm, indicating that the soil samples are suitable for earth building construction.

Laboratory test results

The natural moisture contents of the samples were generally low and their mean values ranged from 9-15%. The average of the results of the tests for the determination of liquid, plastic and shrinkage limits; and the plasticity index, for each of the three soil samples are presented in Fig. 3. For each of the liquid, plastic and shrinkage limits; and plasticity indices of the samples, their mean values ranged from 23.5-28.6%, 7-12%, 3.6-7.1% and 12.5-21.6%, respectively. These results indicate that the soil samples collected from the three villages are of low plasticity and, thus, workable. Due to the dark brown colour of sample C, it was necessary to check whether it is an organic soil. Consequently, liquid limits test for sample C was performed for both oven-dried and not-dried soil conditions. The ratio of the liquid limit of the oven-dried condition to that of the not-dried condition was determined to be 0.89. This result indicates that sample C is inorganic, since this ratio is greater than 0.75. The liquidity index for samples A, B and C was determined to be 0.28, -0.15 and

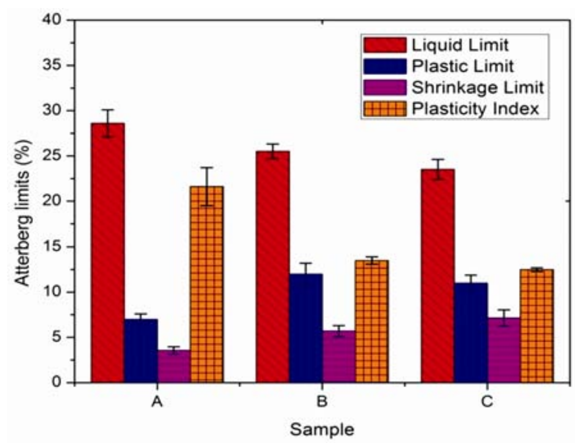

Fig. 3—Results of Atterberg limits tests

Table 1—*In-situ* test results of soil samples from the three villages

Test	Sample A	Sample B	Sample C
Colour	Light brown	Reddish brown	Dark Brown
Texture (dry)	Gritty and smooth	Gritty and smooth	Rough due to presence of gravel
Biscuit (After sun-drying)	Kept the form of a biscuit and did not crumble after being picked	Kept the form of a biscuit and did not crumble after being picked	Kept the form of a biscuit and did not crumble after being picked
Biscuit (On breaking)	Required significant effort to crumble it	Required significant effort to crumble it	Required significant effort to crumble it
Moist soil (Worked-on with bare hands)	Felt both gritty and slippery	Felt both gritty and slippery	Felt both gritty and slippery
Hand-wash	Soapy and took some time to get hands cleaned	Soapy and took some time to get hands cleaned	Soapy but took lesser time to get hands cleaned
Cigar	Pushed out 137 mm length of soil before it broke-off	Pushed out 115 mm length of soil before it broke-off	Pushed out 103 mm length of soil before it broke-off
Adhesion	Some particles of the soil got stuck to the knife	Some particles of the soil got stuck to the knife	Some particles of the soil got stuck to the knife

0.24, respectively. This indicates that samples A and C were in their plastic states while sample B was in its semisolid state, when they were taken from the locations. Fig. 4 presents the results of sieve and hydrometer analyses for the three samples.

The percentage of soil particles finer than the sieve with 0.075 mm opening, for the 3 samples, were less than 35%. This indicates that the three samples are coarse-grained.

Samples A and B were classified as clayey sand (SC) while sample C was classified as clayey sand with gravel (SC), according to the Unified Soil Classification System (USCS). The three samples were classified as A-2-6, according to American Association of State Highway and Transportation Officials (AASHTO) system.

Aside the particle size distribution curves for the samples, a ternary plot of the percent of clay, silt and sand (Fig. 5) show the predominance of sand in all the samples. A triangle embedded within the ternary plot was used to indicate where plots for the ideal soil-types mix for earth building materials should fall; as proposed by North and Kanuka-Fuchs[18]. Sample C falls within this triangle while samples A and B are on the boundary of the triangle (Fig. 5). Consequently, all the samples are suitable for earth building construction.

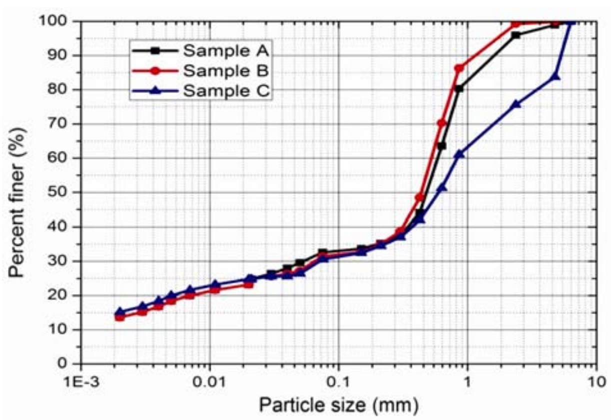

Fig. 4—Particle size distribution for each of the samples

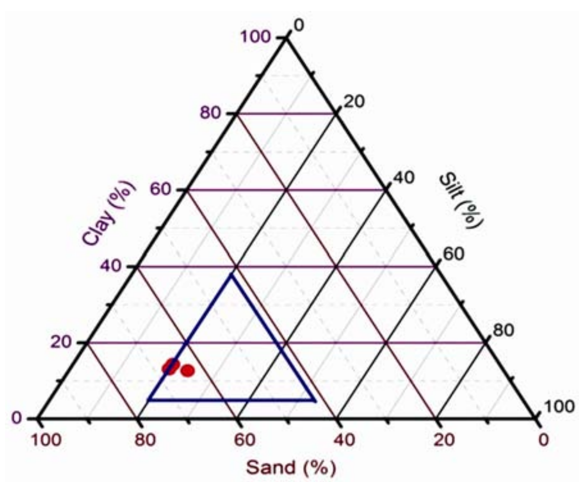

Fig. 5—Ternary plot of clay, silt and sand for each of the samples

Discussion

Earth building construction is no longer attractive in Ota, despite earth being more environment-friendly. This is, however, not peculiar to Ota or Nigeria. Delgado &-Guerrero[19] reported that earth buildings are ignored and underestimated in Spain, partly because people are more attracted to modern building materials such as concrete and steel. Niroumand *et al*.[20] conducted an online survey to determine the interest level and involvement of respondents living in Australia, India, Iran, Malaysia, United Kingdom(UK) and United States of America in earth buildings. They reported a greater interest in Iran and the UK, and a generally low involvement of the respondents in earth buildings. Modernizing earth building to make them aesthetically-pleasing is a potential way of increasing people's interest and involvement in earth building construction. The importance of this research work is highlighted by a statement by Sameh[8] that "the preservation of the local knowledge and cultural patterns previously used in earth buildings is very important to assure its proper development".

People living in earth buildings where this study was undertaken stated that the internal temperature within their houses gets automatically regulated against the prevailing outdoor temperature. Nematchoua *et al*.[21], after analyzing the responds of people who live in 500 modern and traditional buildings during a long rainy season and a short dry season in Cameroon, found out that inhabitants of traditional (earth) buildings experienced more thermal comfort during the two seasons than those who live in modern buildings.

One important process before the construction of unstabilised earth buildings is the selection of suitable soil. There is currently no national standard for selection of suitable soil for earth building construction in Nigeria. Delgado and Guerrero[22], after reviewing over 20 technical documents (including some national standards) for the selection of suitable soils for construction of unstabilised earth buildings, found out that particle size distribution was the most common property for the selection of suitable soils.

Conclusion

Earth buildings in Ota were reported to be soundproof; have high fire resistance and have the capability of improving their internal ambience. Earth building construction is becoming less-appealing to people living in these study areas, despite being more economical, environment-friendly and energy-conserving. This was attributed to society's perception that there is a correlation between living in earth building and poverty.

The results of the *in-situ* tests show that the soil samples at Onilado-isaga, Iyesi and Ilewo-alaga are suitable for earth building construction. However, it is considered necessary that selection of suitable soil should not be based only on *in-situ* tests without their engineering classification. This is because the outcome of in-situ tests is usually non-quantitative and subjective. Soil samples at Onilado- isaga and Iyesi were classified as clayey sand (SC) while that of Ilewo-alaga was classified as clayey sand with gravel (SC), according to USCS. According to AASHTO system, all the samples were classified as A-2-6. Their liquid, plastic and shrinkage limits; and plasticity indices ranged between 23.5-28.6%, 7-12%, 3.6-7.1% and 12.5-21.6%. The samples were found to be inorganic. The soil samples fell within the acceptable gradation triangle (for suitable soils for earth building construction), proposed by North and Kanuka-Fuchs[18] and defined within the ternary plot for clay, silt and sand.

There is a need to find cheap ways of making earth buildings aesthetically-pleasing (modernized) and attractive to the youths; waterproof (to permit construction during wet seasons); and to improve the mechanical properties of earth materials, preferably using wastes such as steel slag[23], reclaimed asphalt pavement[24], etc., without using Portland cement.

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