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Geotechnical Properties of Termite Mound Soil as Construction Material

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Authors' contributions

This work was carried out in collaboration within the three authors. Author HAO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author KAA managed the analyses and author AA searches for the literature for the study. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates variation of termite mounds in relation to the control soils around our environment that are not hindered by the termites at various locations at The Polytechnic; Ibadan, Oyo State, southwest Nigeria. From the study area, five termitaria were selected at random. At the core of termitaria, soil samples were taken at a distance of 7.5m and 15m to the both side of termitaria. Twenty five (25 soil samples were collected in all and were subjected to geotechnical properties such as natural moisture content, grain size analysis, california bearing ratio (CBR) test, Atterberg's limits, and unconfined compressive strength test. The results proved that termite mound soil have better geotechnical properties compared to surrounding control soil. The betterment was attributed to the activities of termites in termitaria thus increasing the strength parameters present in the soil.

Keywords: Termitaria; California bearing ratio; geotechnical properties; Atterberg's limits.

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1. INTRODUCTION

Termites are insect that always appears between the winter and summer season, they usually affect environment most especially in the destruction of wood, farm produce etc. They build mound through the process of soil mixture, saliva and animals excreta. Termites are identified as an "ecosystem engineers" [1] since they assist in soil transfiguration by interference action. Termites gather an unprocessed material and mineral particles from distinct depths and store them in mounds, magnifying the content of organic C, clay and nutrients. An investigation of soil under termite mounds led to the conclusion that in general termites have the potential to modify soil morphology up to 6.1 m below mounds not including potentially greater depths away from these mounds [2]. Moe et al. (2009) [3] stated that termites occupied about 40%–60% biomass of the macro fauna in the tropics and an estimated of about 70–110 kg·ha^{-1} biomass in the African Savannah thereby making them the most abundant macro fauna in the soil. There have been rapid trends in publications which focus on the role of termites in ecosystem functioning over forty years [4;5;6;7].

It is clear that termites are quite active in the upper 1 m; however, it was found they may burrow deeper in search of water or moist soils [4] and in extreme cases 20–55 m in search of the water table [8;9]. As termites embark in search of moisture they bring a considerable amount of mineral material to the surface to include in their nests, potentially altering soil properties at the surface [9]. Termites also construct galleries which enlarges porosity of the soil and water penetration [10;11]. The galleries constructed may be occupied with top soil materials, with rainfall contributing to the process of deep formation, uniform Latosols (interrelated to the Oxisols in the Soil Taxonomy) [12].

Some researchers show that activity of termite is directly connected to the process of micro aggregation in Brazilian Latosols [13;12;14]. Several studies describe the nutrients concentration on termite mounds and surrounding soil [2;15;16;17;18;19]. In Nigeria, it was discovered that unconfined compressive strength of termitaria have high significance than those soils at the nearby. Besides, within and from one geological zone to another at The Polytechnic Ibadan, changes in termitaria properties were observed. In relation to the surrounding, termitaria are of high values in terms of silt and clay and of low value in terms of sand. The organic, carbon and nitrogen contents in termitaria were found at high percentage than the nearby control soils.

In Geology, soil is very important because nearly all structures are constructed in or on the surface of the earth. Therefore, the nature of the soil at locations is very vital to Geologist. The earth underneath the foundation is heterogeneous materials that are considered in design and construction of structures. Prior to foundation design, site investigation is embarked upon and the results are used in the design exercise. Since soil is heterogeneous in nature, during setting-out aspect of project construction, termitaria are seen and these structures are different from the surrounding soil by physical inspection and need to be investigated. Decision must be taken either to remove them completely or used them to level the ground. Hence the study aims at examining the variability in the geotechnical properties of termitaria and the adjacent surrounding soils as a construction material.

2. THE STUDY AREA

Samples were collected from five different termitaria locations within The Polytechnic, Ibadan, Nigeria. The study area lies between longitude 3° 52′ 44.93″E to 3° 53′ 8.62″E and latitude 7° 25′ 52.7″N and 7° 26′ 43.8″N. The five termataria points are; the main football field, student union building, main library building, Ijokodo senior staff quarters and admission office complex. Fig. 1 describes the study area.

2.1 Climatic Condition of the Study Area

The study area is characterized by tropical wet and dry season which is between November-February and the season is the period the study area experiences the harmattan. The wet seasons which is between March-October with a lull precipitation in August. The study area mean total rainfall is 1420.06 mm, falling in approximately 109 days. The rainfall is in two peaks, June and September with minimum and maximum mean temperature of 21.42°C and 26.46°C and relative humidity of 74.55%.

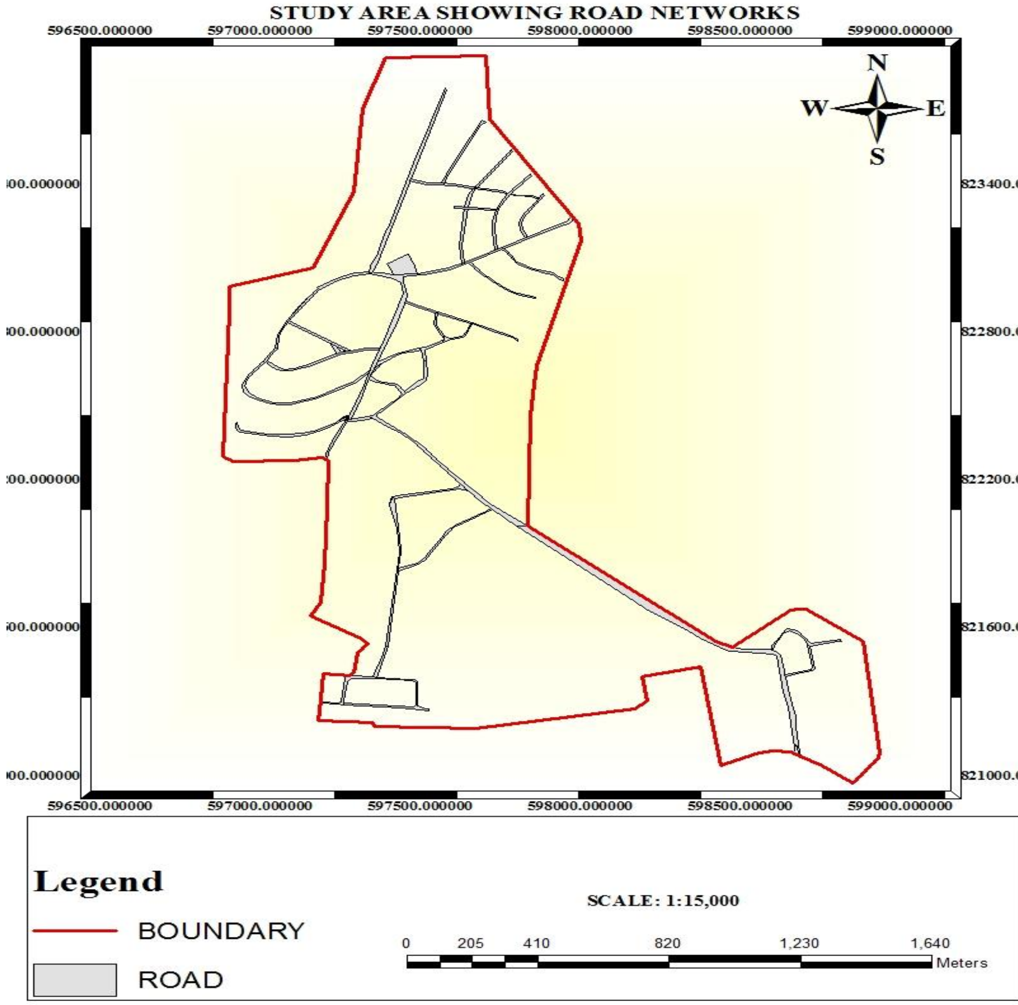


Fig. 1. Study Area Map

3. MATERIALS AND METHODS

3.1 Methods of Data Acquisition

Sample collection was done in November, 2019 during the dry season. A representative mound constructed by macrotermes bellicosus mound was chosen. The collection was at the center of termitaria and at two points adjacent to termitaria at 7.5 meters and 15 meters to both left and right side (Fig. 2). Moreover, five sample collections at each termitarium location were established making twenty five samples all together. From the Fig. 2, point A is the centre soil of termitarium where samples were collected, point B 7.5 meters away from termitarium, point C 15 meters from termitarium, point D on other side 7.5 meters from termitarium and point E 7.5 meters from point D.

All samples collected were put in a protective clean plastic bag and was sealed up so as to prevent it from exposing to the tropical weather elements. Each of the samples was labeled with letters, A, B, C, D and E for easy identification before test. During the sample collection, the depth and sampling date were written on the sheet of paper and were attached to each plastic bag. All the five samples were air-dried and were taken to the laboratory before the test was carried out. The moisture content, particle size distribution, and Atterberg limits tests were carried out to classify the soil according to British Standard 1377-2:1990 [20].

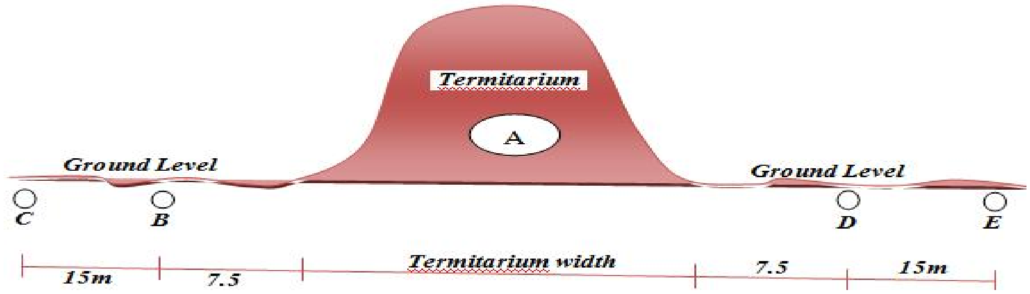


Fig. 2. Typical sampling position

Also, the sieve analysis was carried out using the ISO recommended series of sieve aperture sizes and the compaction tests were done according to BS 1377-4:1990 [21]. All these tests was carried out to determine the suitability of the soils for use as base and sub-base material using the AASHTO standard method in relation to the generation specification for construction.

3.2 Method Used in Carrying Out Test on Soil Samples

3.2.1 Sieve analysis

Soil particle size distribution was determined by performing sieve analysis. Approximately 500 g of sample representative was used for the test after washing and dried in oven. The British Standard 200 sieve was used in washing the sample. The retained air dried fraction was used for the sieve analysis. Mechanical method was used by applying an automatic sieve shakers and a set of sieves for sieving analysis. Atterberg Limits (Liquid Limit and Plastic Limit): Here, the clay content in liquid limit, plastic limit, plasticity index and shrinkage potential were determined in order to calculate the plasticity, strength and settlement characteristics of the soil sample. Liquid limit were determined by passing the soil sample through 425um sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. Casangrade's apparatus cup with a grove was used to collect the paste and the number of blows to close it was recorded. However, plastic limit were determined by passing the soil sample through 425 µm test sieve, weighing 200 g and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. Then, the plastic limit was determined by placing the 3 mm diameter in the oven at 105°C.

3.2.2 Moisture content

The ratio of the weight of the water in a soil specimen to the dry weight of the specimen is known as Moisture content. The moisture content of soil can be influenced by the mineralogy and formation environment influenced the moisture content of the soil.

3.2.3 Compaction test

The soil densification using mechanical equipment rearranged the soil particles and compact them together and the compactness resulted in an increase in the ratio of horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight of the soil and thereby increasing the bearing capacity foundation of road, stability slopes, controls changes in the volume not required and stop unwanted settlement of structures. 25 blows of a 4.5 rammer were used to fill and compact mould with soil.

3.2.4 California bearing ratio

The California bearing ratio (CBR) test was carried out to assess the mechanical strength of a sub-base/base course material in the soil. It measures the controlled density, shearing resistance, and moisture content of the soil. In carrying out CBR test, soaked and unsoaked method was conducted to characterize the soil for use as a base or subbase material. A portion of the evaporated soil sample was mixed with about 5% of its weight of water. In the test carried out five (5) layers of which each of the layers were compacted with 55 blows using 2.5 kg hammer at drop of 450 mm (standard proctor test) was put in CBR mould. The soil that was compacted and the mould was weighed and placed under CBR machine and approximately load of 4.5 kg was applied.

Table 1. Spatial location coordinates of the five termitaria points

Location	Easting (m)	Northing (m)	Height (m)
Main Football Field	823019.529	597211.541	193.798
Student Union Building	822941.749	597013.357	205.389
Main Library	821865.013	597741.732	213.001
Ijokodo Staff Quarters	821450.673	597395.534	191.197
Admission Office	822715.393	597459.841	205.701

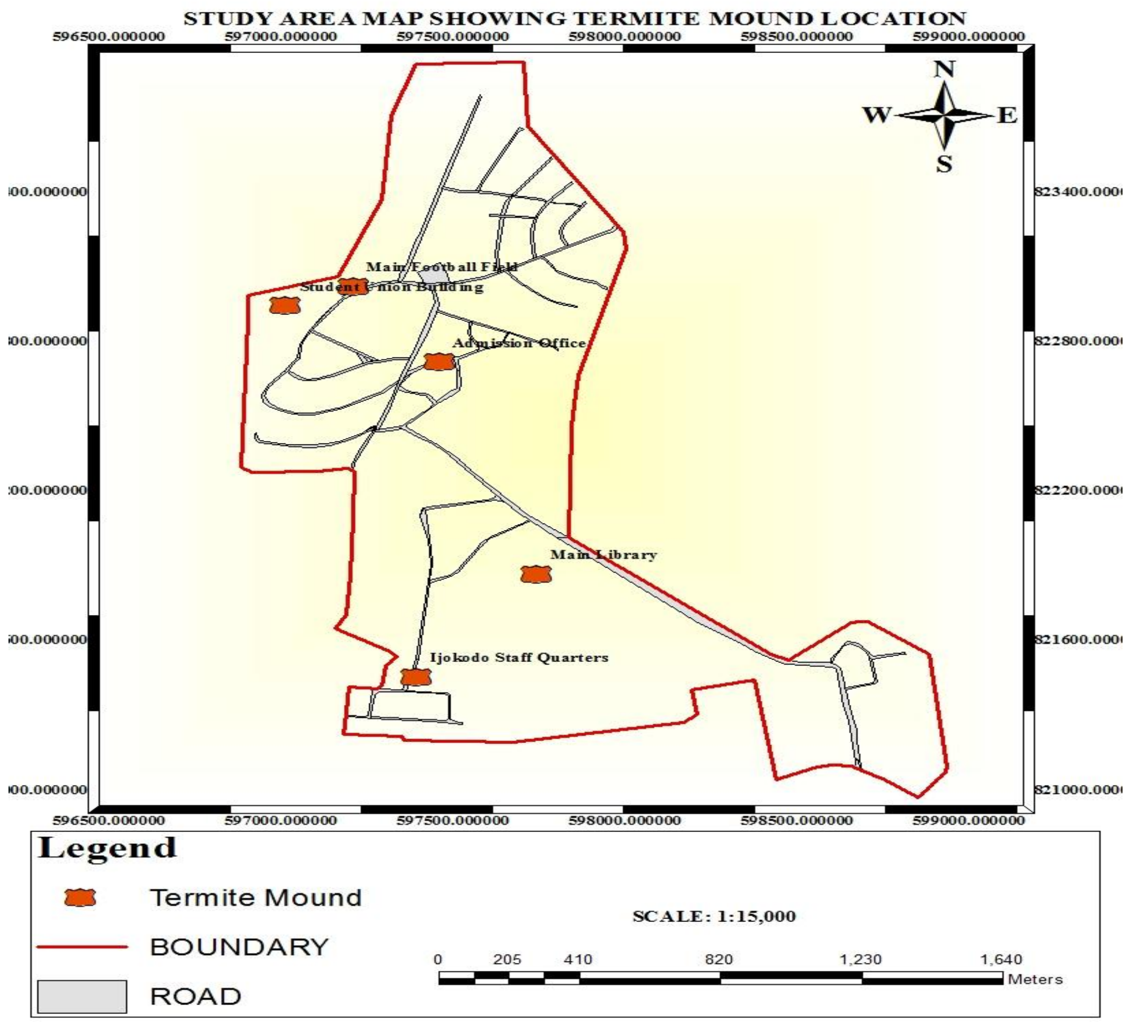


Fig. 3. Study area road map and termite mound location

4. EXPERIMENTAL RESULTS AND DISCUSSION

The results from the process data were presented in form of fig. and Tables. Fig. 3 shows the location of termite mound within the study area. Fig. 4 describes the results of the test of particle size distribution; Fig. 5 shows the percentage of natural moisture content present and Fig. 6a shows percentage of liquid limit and Plastic limit from Mound Soil and Control Soil, while 6b shows comparison of consistency limits for Mound and Control Soil. Fig. 7 presents the percentage of California Bearing Ratio (CBR) Test. Table 1 presents the spatial coordinates of the five termitaria locations. Table 2 presents geotechnical properties of termite mounds and their surrounding soils.

4.1 Discussion of Comparison of Mound Soil and Control Soil

4.1.1 Particle size distribution analysis

The particle analysis results revealed that mound soil (termitaria) contain high content of clay and silt than the nearby soils (control soil) because there is higher concentration of fine particles in sieve No 200 (75um) than the surrounding soil, and which is found to have exceeded the 35% standard requirement. In termite mounds, clay content is usually 20% greater than in the nearby soils, but incomprehensible either termite choose particles, or soil experiences a physical breakdown across their guts [4;22;23]. From Fig. 4, silt from termataria samples 3-5 (a-e) have the highest percentage test values from the soil test carried out while in the first termataria sample point, sand has the highest particle size distribution at sample 1c and lowest at sample 1a. Clause 6201 of Federal Ministry of Works and Housing 1972 specify certain requirement for a sample to use for sub-grade and base material which the sieve No 200 (75um) in percentage by weight passing shall be less than but not greater than 35%. Hence the soils are in the Silty-Clay group and are classified not excellent construction materials.

4.1.2 Natural moisture content

According to the British Standard International (BSI), soils with existing moisture content greater than 16% are belief to be a saturated soil and of low quality construction materials, while soil with moisture content less than 16% quality as sub-grade materials for construction. The range of Natural moisture content of 5.8% to 13.2% for soils in the study area (Table 2) displayed Natural moisture content within the required limit of 16% indicating that the soil is very good for subgarde material for construction.

4.1.3 Consistency limits

Water content in the soil influenced the fine grained soil consistency largely. It is observed from the results that the termite mound soil have high consistency limits than the control soil, which indicated that termite soil have good clay fraction than control soil. Liquid limit results of the mound soils ranged from 39% to 44% and the surrounding soils (control soils) ranged from 26% to 35% (Table 2). According to the British Standard International (BSI) guideline, for the construction material to be appropriate for use, the liquid limit should not be greater than 35%. From the result of fig. 6a &6b, it shows that the liquid limit has the highest value in percentage in both the mound soil and control soil. The higher values recorded in the mound soils could further serve as clear evidence that termite' activities in their habitat encouraged the forces of attraction and adhesion among the soil particles of termitaria.

4.1.4 Compaction test

Dry density/moisture content is used to show the association of soil under experimental condition that can be differentiated with field requirements [24]. The soils examined exhibited qualities of fair graded material. The termite mound soils when compacted in the laboratory had a Maximum dry density (MDD) ranges from 1.09–2.21 g/cm3, corresponding to an Optimum moisture content (OMC) from 9.0 % - 14.9 % (Table 2). The Maximum dry density (MDD) measured in a control soil ranges from 1.09-2.17 g/cm3 and corresponding to Optimum moisture content (OMC) from 9%-14% (Table 2). The samples characterized with low contents are best suitable for use as construction materials.

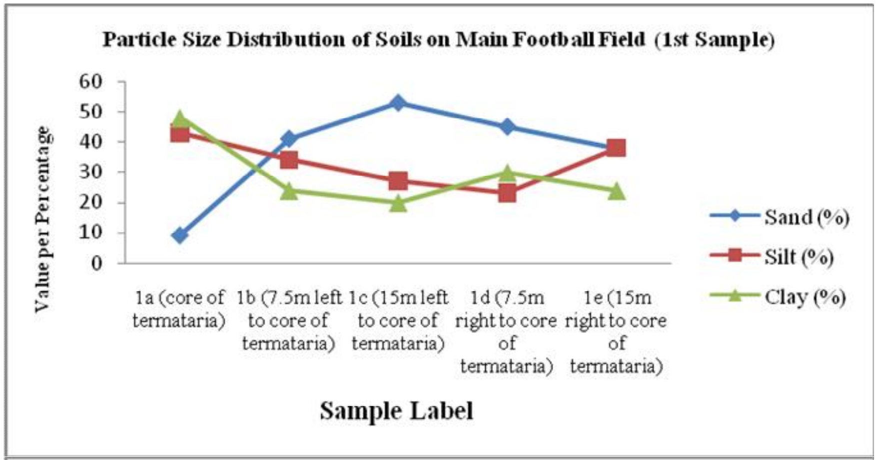
4.1.5 California Bearing Ratio (CBR) test

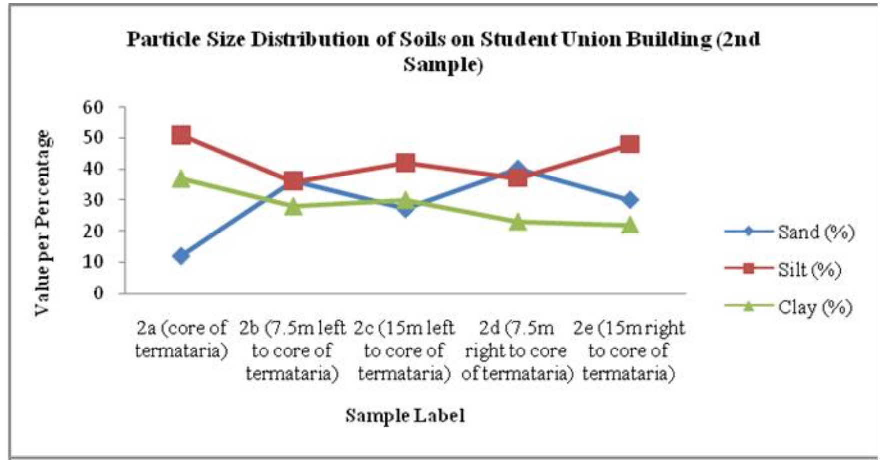
The California Bearing Ratio (CBR) supply information about the mechanical strength and good estimate of the bearing capacity of construction materials. It is clear from the tests results that the CBR values of termite mound soils were higher than the surrounding soils but below the specified requirement range of 15% to 30%. The result of the CBR test from Fig. 5 shows that the core of the termataria has the highest value in all five samples (a-e) tested (Table 2). The high values of CBR recorded with termite mound soils were related to activities of termites in the termitaria. From specification CBR value greater than 15% belongs to the strong sub-grade classification.

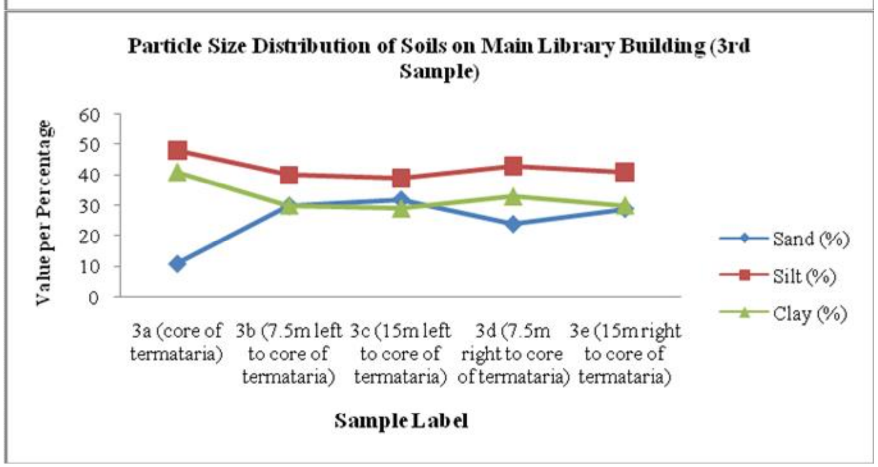
Table 2. Geotechnical properties of termite mounds and their surrounding soils

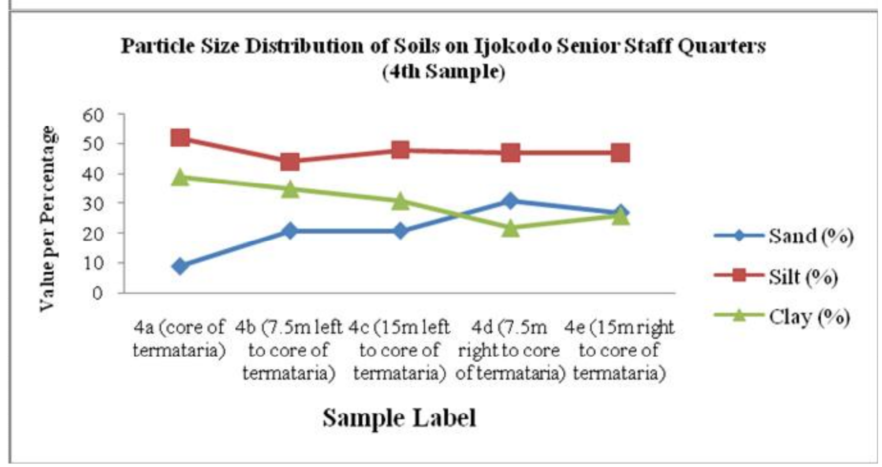
Sample Location	Sample Label	NMC %	SG %	Particle size distribution			Atterberg limit			CBR value (%)	STD protector properties	
				Sand %	Silt %	Clay%	LL (%)	PL (%)	PI (%)		MDD%	OMC%
Main football field	1A (Core of Termitarium)	8.2	2.13	9	43	48	39	24	15	7.4	1.91	13.8
	1B (7.5m Left to core of Termitarium)	12.1	2.26	41	34	24	32	23	09	2.9	1.5	11.7
	1C (15m Left to core of Termitarium)	12.8	2.3	53	27	20	26	15	11	2.4	1.42	12.0
	1D (7.5m Right to core of Termitarium)	12.4	2.24	45	23	30	34	24	10	2.6	1.53	12.2
	1E (15m Right to core of Termitarium)	13.2	2.26	38	38	24	27	18	09	2.6	1.72	12.6
Student union building	2A (Core of Termitarium)	6.8	2.1	12	51	37	41	25	16	6.2	2.21	14
	2B (7.5m Left of core of Termitarium)	10.6	2.16	36	36	28	29	22	7	2.4	1.09	10.7
	2C (15m Left of core of Termitarium)	11.1	2.23	27	42	30	34	24	10	2.1	1.57	13.1
	2D (7.5m Right of core of Termitarium)	9.6	2.23	40	37	23	31	23	8	2.1	1.91	12.9
	2E (15m Right of core of Termitarium)	9.1	2.22	30	48	22	34	22	12	2.0	1.74	11.8
Main library building	3A (Core of Termitarium)	5.8	1.9	11	48	41	44	28	16	8.1	2.17	14.9
	3B (7.5m Left of core of Termitarium)	8.0	2.43	30	40	30	35	27	8	2.9	1.4	12.8
	3C (15m Left of core of Termitarium)	7.8	2.31	32	39	29	31	21	10	2.3	1.52	13.6
	3D (7.5m Right of core of Termitarium)	7.1	2.2	24	43	33	29	20	9	2.6	1.81	14.0
	3E (15m Right of core of Termitarium)	6.9	2.4	29	41	30	32	24	8	2.4	1.64	12.8
Ijokodo senior staff quarters	4A (Core of Termitarium)	7.8	2.08	9	52	39	44	24	20	7.9	2.03	13.7
	4B (7.5m Left of core of Termitarium)	11.3	2.31	21	44	35	35	24	11	2.6	1.64	10.5
	4C (15m Left of core of Termitarium)	9.6	2.2	21	48	31	32	23.5	8.5	3.1	1.69	9.1
	4D (7.5m Right of core of Termitarium)	9.1	2.32	31	47	22	26	18.6	7.4	2.8	1.50	9.0
	4E (15M Right of core of Termitarium	8.9	2.28	27	47	26	29	18	11	3.6	1.61	11.1
Admission office complex	5A (Core of Termitarium)	6.4	2.0	12	49	39	40	26	14	7.9	1.78	13.6
	5B (7.5m Left of core of Termitarium)	9.3	2.6	25	42	33	34	24	10	3.2	1.34	12.0
	5C (15m Left of core of Termitarium)	9.6	2.4	24	46	30	27	19.8	3.2	2.8	1.6	12.7
	5D (7.5m Right of core of Termitarium)	7.8	2.4	28	43	29	31	23	8.0	2.9	1.5	10.9
	5E (15m Right of core of Termitarium)	8.2	2.3	30	44	26	33	23	8.0	2.6	1.5	11.4

*NMC = Natural Moisture Content, **CBR** = California Bearing Ratio, MDD = Maximum dry density, OMC = Optimum moisture content, LL = Liquid Limit (%), PL = Plastic Limit (%) and PI = Plastic Index (%)*


Particle Size Distribution of Soils on Main Football Field (1st Sample)
Value per Percentage
60
50
40
30
20
10
0
1a (core of termataria)
1b (7.5m left to core of termataria)
1c (15m left to core of termataria)
1d (7.5m right to core of termataria)
1e (15m right to core of termataria)
Sample Label
Sand (%)
Silt (%)
Clay (%)


Particle Size Distribution of Soils on Student Union Building (2nd Sample)
Value per Percentage
60
50
40
30
20
10
0
2a (core of termataria)
2b (7.5m left to core of termataria)
2c (15m left to core of termataria)
2d (7.5m right to core of termataria)
2e (15m right to core of termataria)
Sample Label
Sand (%)
Silt (%)
Clay (%)


Particle Size Distribution of Soils on Main Library Building (3rd Sample)
Value per Percentage
60
50
40
30
20
10
0
3a (core of termataria)
3b (7.5m left to core of termataria)
3c (15m left to core of termataria)
3d (7.5m right to core of termataria)
3e (15m right to core of termataria)
Sample Label
Sand (%)
Silt (%)
Clay (%)


Particle Size Distribution of Soils on Ijokodo Senior Staff Quarters (4th Sample)
Value per Percentage
60
50
40
30
20
10
0
4a (core of termataria)
4b (7.5m left to core of termataria)
4c (15m left to core of termataria)
4d (7.5m right to core of termataria)
4e (15m right to core of termataria)
Sample Label
Sand (%)
Silt (%)
Clay (%)

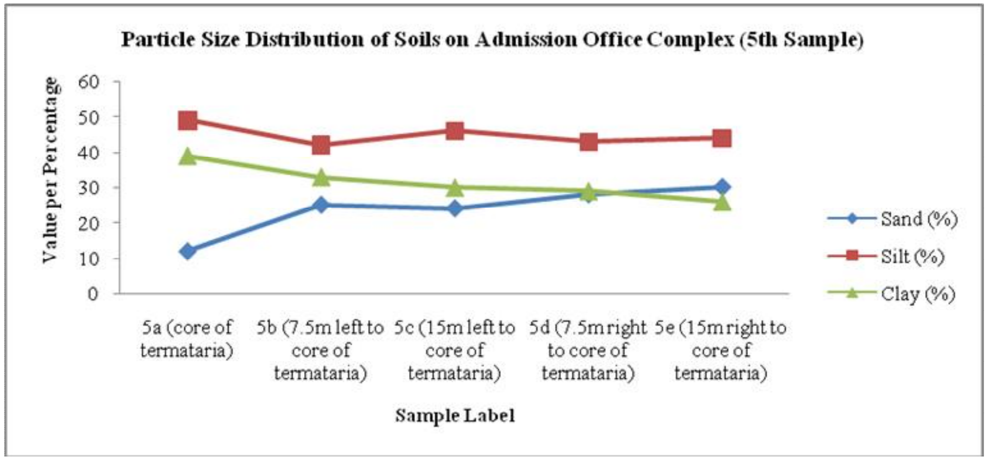


Fig. 4. Chart showing particle size distribution of soils for sample 1-5 (a-e)

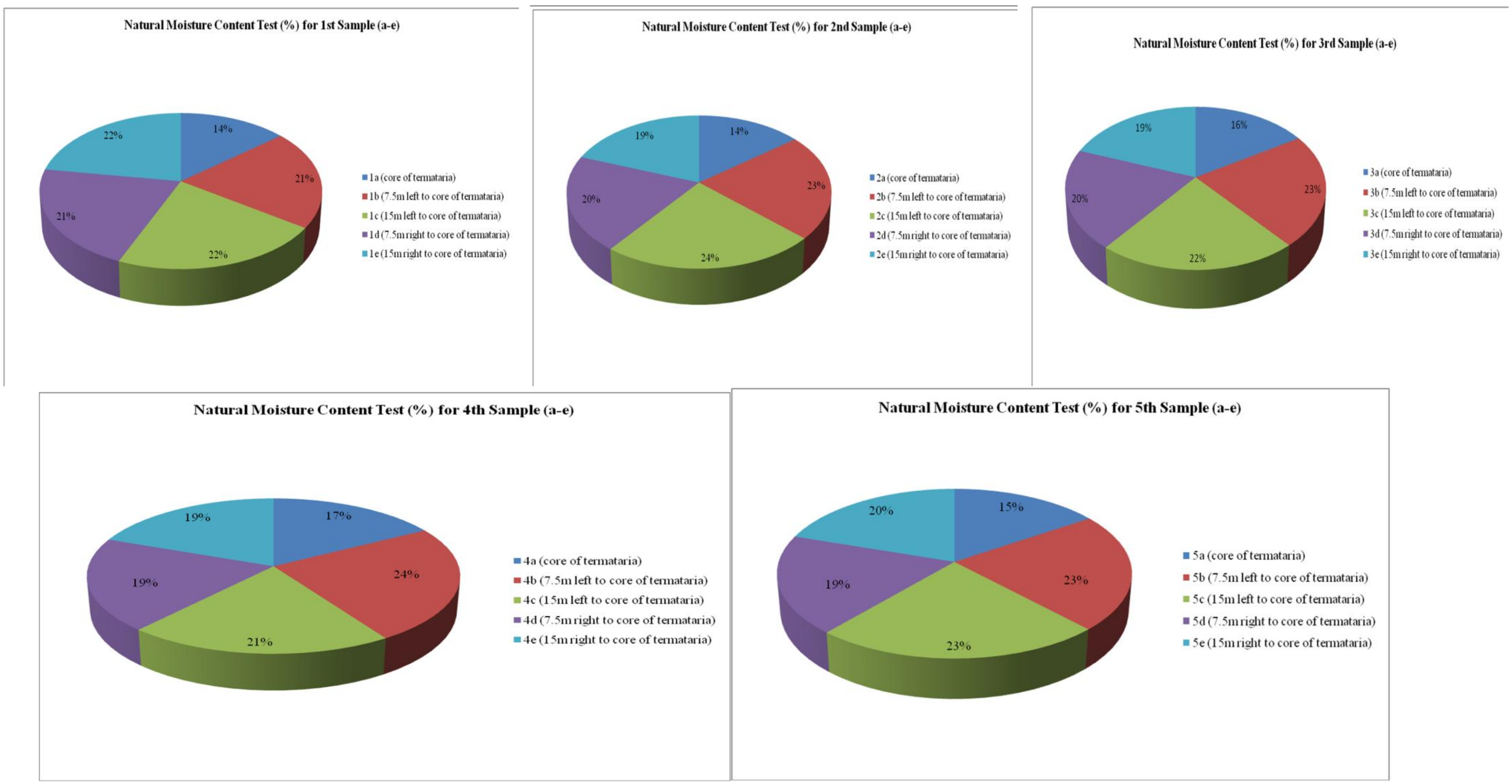


Fig. 5. Showing percentage of natural moisture content for samples 1-5 (a-e)

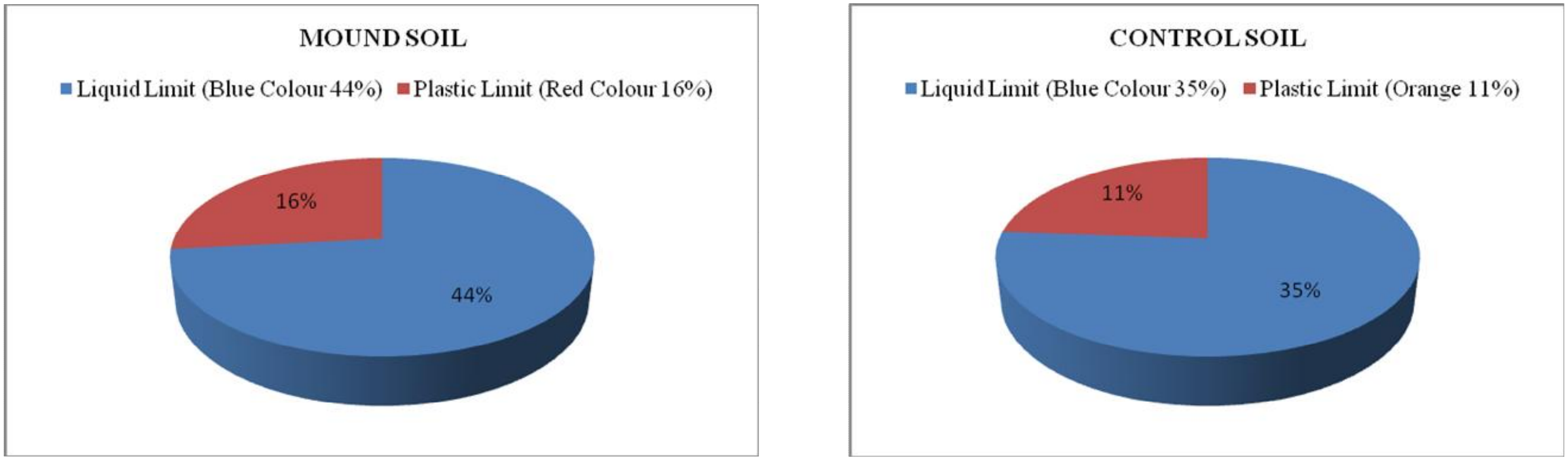


Fig. 6a. Percentage of liquid limit and plastic limit from mound soil and control soil

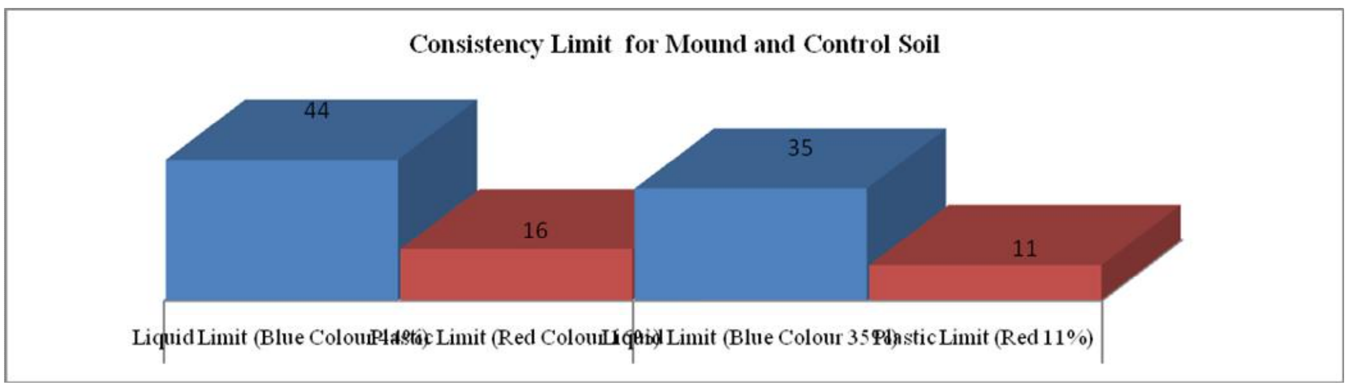


Fig. 6b. Diagram showing comparison of consistency limits for mound and control soil in category

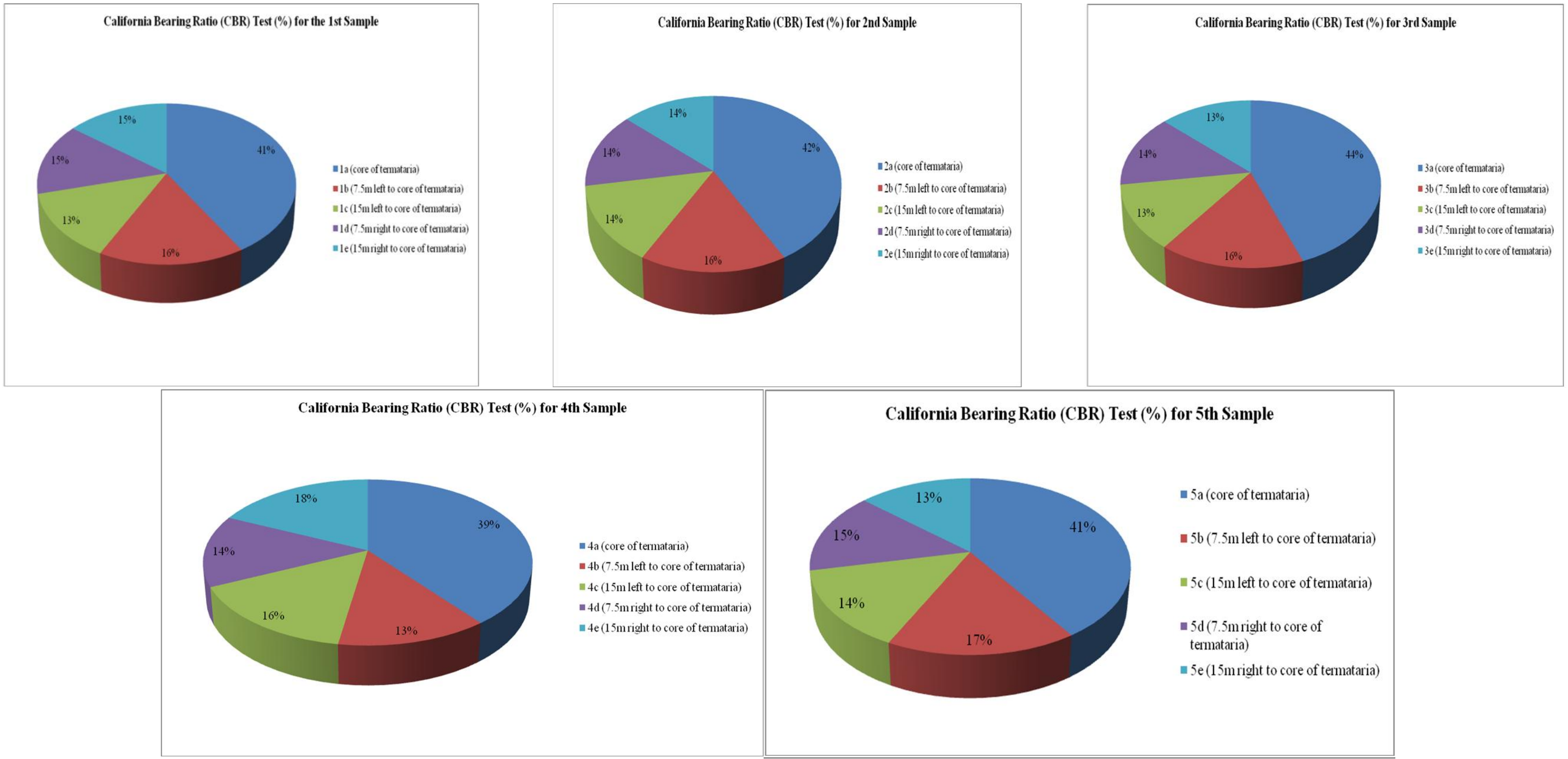


Fig. 7. Showing Percentage of California Bearing Ratio (CBR) Test for Sample 1-5 (a-e)

5. CONCLUSIONS

This study has investigated the geotechnical properties of termite mound and control soil. Mound soil has better properties than the surrounding control soil. From the five locations where sample were taken, it revealed that the activities of termites in their termitaria promoted adhesive, friction force and cohesive properties of soils of the area. The analysis from the particle size showed that the mound soils containing fines particles are more than the required 35% of the soil passing through sieve No 200 (75um). However, the result of the plasticity index (PI) categorized the soils as majorly silty-clay and is rated as fair to poor construction materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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