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EFFECT OF PRETEST DRYING AND TESTING PROCEDURE ON ENGINEERING PROPERTIES OF BAHIR DAR RESIDUAL SOILS

Yebeltal Zerie Beju[1*] and Kumelachew Abe Sema[2]

[1]Civil Engineering Department, Institute of Technology, University of Gondar, 196, Gondar, Ethiopia

[2]Faculty of Civil and Water Resources Engineering, Bahir Dar Institute of Technology, 26, Bahir Dar, Ethiopia

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*Corresponding author's email: Yebeltal.Zerie@uog.edu.et

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Abstract — Residual soils are natural weathering products of rocks and their properties depend on the degree of weathering. These types of soils, which are found in tropical areas, are commonly used in construction, such as dams, highways, and building materials. The properties of residual soils are influenced by a variety of factors, including the original material, climate, topography, drainage, and the methods used for sampling, testing, and classification. Inadequate soil investigations can lead to inaccurate test results, which may result in flawed designs, project delays, increased construction costs, the need for post-construction repairs, and even construction failures. The engineering properties of residual soils are significantly affected by the drying process and testing procedures. This study evaluated the index properties and chemical composition of Bahir Dar residual soils to assess their suitability for various geotechnical engineering applications. The research found that the engineering properties of these soils were significantly affected by the pretest drying and testing procedures. The study recommends soaking the soil samples in water instead of drying and breaking them down with a rubber mallet, as the current standards allow. Additionally, it was observed that the specific gravity values of the residual soils change not only based on the soil texture and particle size distribution, but also on the drying methods used.

***Keywords*:** residual soil, index property, chemical property, air-dried, oven dried

1.0 INTRODUCTION

The standard testing procedures used in engineering evaluations of temperate soils may not always be suitable for evaluating tropical residual soils. In some cases, modifications of the standard tests are necessary to properly evaluate the index properties of residual soil. Residual soil (RS) is produced through in-situ weathering processes, including physical, chemical, and biological agents acting on the parent rock. It typically remains at its location of origin with little or no movement of individual soil particles. Unlike transported sedimentary soils, residual soils do not undergo systematic sorting process during erosion, transportation, and deposition, making them more heterogeneous [1]. Laterite is a soil and rock type rich in iron and aluminum, and it is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of a rusty-red color due to their high iron oxide content. Two major factors that must be taken into consideration when evaluating the behavior of in-situ laterite soils are progressive strain softening and fracture failure [2]. Poor geotechnical properties of the soils, such as high compressibility, high liquid limit, and plasticity index, are often responsible for road failures [3]. Previous research has focused on studying the engineering characteristics of tropical-weathered residual soils in Ethiopia and has found that sample preparation and testing procedures significantly affect their geotechnical properties [4–8]. However, the engineering characteristics of Bahir Dar residual soil and its suitability for use in building and road construction have not yet been investigated, despite the region's high construction activity over the last three decades. Determining the plasticity of the soil can be significantly affected by pre-test drying, mixing method, and duration [9]. Residual soils are chemically altered and sometimes bonded, rather than formed through physical sedimentation. In many cases, they are unsaturated and exhibit negative pore water pressures (soil suction). Conducting laboratory tests and interpreting test results of tropically weathered soil differ from procedures used for transported sedimentary soils.

There is limited comprehensive information about the abundance and significance of tropical residual soil in Bahir Dar compared to transported sedimentary soil. As a result, the conventional procedures developed for temperate soil zones are commonly practiced in almost all cases and soil types. A geotechnical investigation is crucial in Bahir Dar, as residual soil is the primary earthwork construction material for various geotechnical engineering projects in the city. A recent study investigated the effects of drying and sampling conditions on the engineering properties of fresh and reused soil samples. The soil samples were collected from a quarry site around Bahir Dar, which was used as fill material for road works, embankments, and building foundations. Eight disturbed samples were collected from four test pits at depths of 1.5 m and 3.0 m, and various index property tests, including chemical composition analysis, were conducted under different drying conditions for both fresh and reused residual soil samples.

2.0 LOCALITY OF STUDY AREA

The study area is located in Bahir Dar city, renowned for being home to Lake Tana, the largest lake in Ethiopia, and the Abay River, one of the world's longest rivers. The city's altitude ranges from approximately 1800 to 1970 m above sea level. The St. George Church, located on the southern shore of Lake Tana at 11°38'00" North latitude and 37°10'00" East longitude, is one of the area’s significant landmarks. The city's topography is mostly flat, with small hills on the eastern and western sides. The city is situated approximately 565 kilometers northwest of Addis Ababa, on the southern bank of Lake Tana, with mostly flat topography. Over the last 30 years, the area has experienced annual rainfall ranging from 1,076.5 mm to 1,786.6 mm and average daily temperatures ranging from 6°C to 32°C. The rainfall depth varies seasonally, with the highest recorded during winter [10]. The soil in Bahir Dar mainly comprises residual fine soils such as clays and silt-clays formed on basaltic bedrock. There are two main types of soil: red clay soil, which is widespread throughout the town and along the lakefront, and dark to dark-brown soil, predominantly found in the south and southwest of the city [11]. The study area consists of residual soil (RS) found in and around Bahir Dar city, specifically in the northwestern part near Medhaniyalem Church and Wegelsa Kebele. These soils are sourced from a local quarry and are commonly used as fill materials for road construction and building foundations. The location of the study area and test pits are shown in Figure 1.

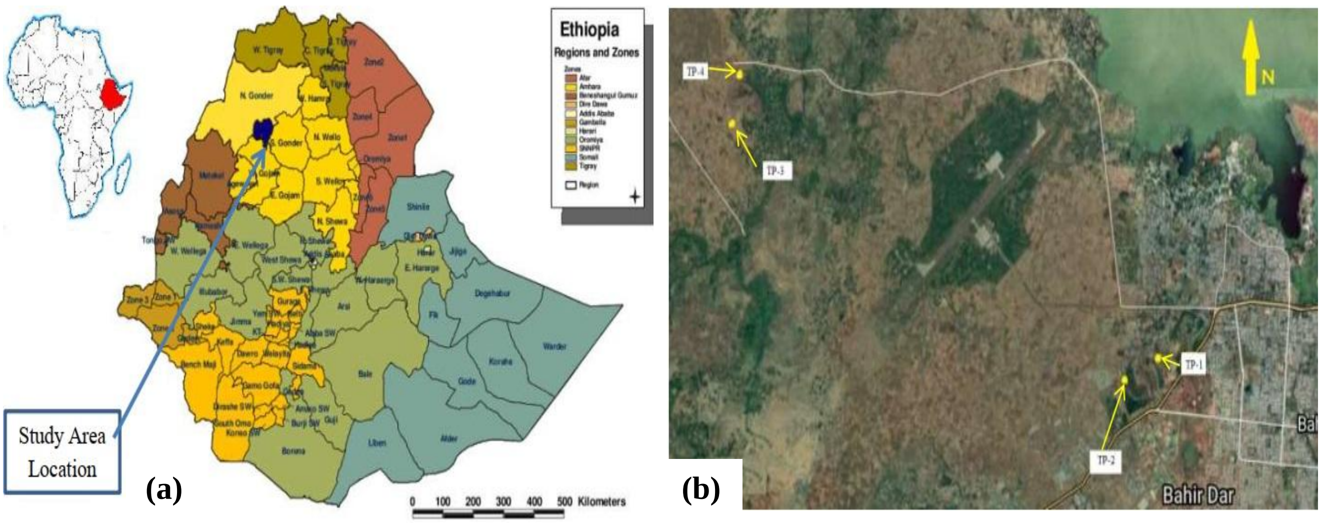

Figure 1 (a) Location of study area (b) Location of test pits

3.0 LABORATORY PROGRAM

In this study, eight disturbed soil samples were collected from four test pits in and around Bahir Dar city at depths of 1.5 and 3.0 meters. The samples were securely transported to the laboratory in sealed plastic bags to prevent moisture loss. The laboratory tests included chemical composition analysis, natural moisture content, specific gravity, Atterberg limits, and grain size distribution, performed under different drying conditions. The index property tests were performed at the Bahir Dar Institute of Technology Soil Laboratory, while the chemical composition test was conducted at the Ethiopian Geological Survey in Addis Ababa. The tests were conducted using a combination of RS and conventional ASTM test methods. The effect of temperature on the test results was evaluated by preparing soil samples under two drying conditions: air-dried (AD) at 50°C and oven-dried (OD) at 105°C. The first case, Air-Dried (AD), involved drying the soil samples in an oven at 50°C with a relative humidity not exceeding 30%, as per [12], until a constant weight was achieved. The second case, Oven-Dried (OD), involved drying the soil samples thoroughly in an oven at 105°C until a constant weight was obtained. According to standards, oven drying is conducted at two temperatures: 50°C for "special soils" and 105°C for typical soils.

Drying at 105°C is known to alter the Atterberg limits of residual soils [13]. These changes typically affect soil classification based on the plasticity chart.

3.1. Chemical Composition Test

In this study, the analytical methods used for chemical composition testing included LiBO fusion, HF attack, gravimetric, colorimetric, and AAS techniques. Chemical composition tests were conducted on soil samples from all four test pits to assess the degree of laterization. The degree of laterization was determined based on the Silica-Sesquioxides (S-S) ratio, which is the combined proportion of aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). According to classification criteria, if the S-S ratio is greater than 2, the soil is classified as non-lateritic; if it falls between 1.33 and 2, it is considered lateritic; and if it is less than 1.33, the soil is classified as true laterite [14].

3.1.1 Index properties tests

The soil's moisture content was determined immediately after sampling using the ASTM D2216-90 test method. In addition to free water, which influences soil engineering behavior, crystallized water, often present in residual soil (RS), may exist within the mineral structure and is released at temperatures between 105°C and 110°C [9]. Comparative tests were conducted on duplicate samples to determine the crystallized water content of the soil. Moisture content was measured at two drying temperatures: 105°C and 50°C. The first specimen was oven-dried at 105°C until successive weighings showed no further loss of mass, and water content was then calculated in the usual manner. The second sample was oven-dried at a maximum temperature of 50°C and a relative humidity (RH) not exceeding 30% until successive weighings showed no further loss of mass, as recommended in [14]. The results from the two drying methods were compared: if the difference in water content exceeds 4–6% of the oven-dried (105°C) measurement, this indicates the presence of structural water, which is released at high temperatures. Since this water is part of the soil solids, it should be excluded from the water content calculation. If a significant difference is detected between the two drying procedures, all subsequent water content tests, including those related to Atterberg limits, should be conducted using the lower drying temperature (either air-drying or oven-drying at 50°C with 30% relative humidity). Whenever possible, a drying temperature of 50°C should be used.

The specific gravity test was performed according to ASTM D854-14. To examine the effect of pretest drying on specific gravity results, both air-dried and oven-dried samples were tested. In the first case, the mass of the air-dried soil specimen at its natural moisture content (NMC) was measured. Huat et al. (2009) [9] proposed that the specific gravity test for residual soil (RS) should be conducted at its NMC. In the second case, specific gravity was determined using oven-dried soil specimens following the standard procedure, with the dry mass measured after oven drying. Atterberg limit tests were conducted to determine the liquid and plastic limits of fine-grained soil samples based on ASTM D4318-00. In this study, five specimens were mixed with water to obtain a range of water contents suitable for liquid and plastic limit determinations. The mixed specimens were stored in sealed containers for 24 hours to allow the water content to equilibrate with the solids before testing. A higher plasticity index indicates greater engineering challenges when using the soil as a construction material, particularly for foundation support in residential buildings and road subgrades. During the Atterberg limit test, mixing times of 3, 5, 7, and 10 minutes were used to assess the effect of mixing duration on the test results for RS.

Sieve analysis tests were performed on soil samples collected at different depths of the test pits. The samples were sieved using a series of sieves following ASTM D422-98. First, specific gravity tests were conducted separately for fine- and coarse-grained particles. If a significant difference in results was observed, the grading was adjusted by modifying the mass proportions for analysis [15]. The soil samples collected from the field were first air-dried and oven-dried, with each set sieved separately. The mass of soil passing through different sieve sizes was recorded. Wet preparation was conducted on moist (as-received) samples without pretest drying. The samples were soaked until the coating material was fully softened, ensuring the removal of fine particles adhering to coarser ones while preventing the fracturing of weak coarse particles [15]. Wet preparation methods are used when coarse-grained particles in a sample are soft and prone to pulverization or when fine particles are highly cohesive and resist separation from coarse particles [13]. The soaked samples were washed using 2.00 mm and 0.075 mm sieves. In this study, almost all soil samples passing through sieve No. 200 were found to be less than 20%, so hydrometer analysis was not performed for all test pits and depths. Aggregations were thoroughly broken down using a rubber mallet before sieving the samples. The test samples were then separated into two portions by sieving with a 2.00 mm sieve, with the retained particles used for coarse sieve analysis.

3.2. Soils Classification

The effects of sample preparation and testing procedures on soil classification have been examined. The applicability of the Unified Soil Classification System (ASTM D2487-11) and AASHTO Soil Classification System (AASHTO M145-87) has been explored. Soil grouping based on mineralogical composition proposed by [1] and the genetic basis and soil-forming factors French pedological classification system proposed by [16] have also been investigated.

4.0 RESULTS AND DISCUSSION

A chemical composition test was conducted at the Ethiopian Geological Survey in Addis Ababa to determine the soil's chemical composition and its lateralization. The results from the test pits in Table 1 showed that the S-S ratios for all four test pits were less than 1.33, indicating that they are true lateritic soils, specifically categorized as RS. This means that the study area is covered by true lateritic soil [14]. Additionally, the annual rainfall in the area indicates a ferruginous soil type. The Bahir Dar area's laterite soils are known for their high concentrations of Sesqueoxide.

Table 1 Chemical Composition Test Results of Soil

Compound	Test Pit Designation			
	TP-1	TP-2	TP-3	TP-4
	Experimental Result (%)			
SiO_2	40.96	37.4	41.54	39.24
Al_2O_3	25.40	22.02	21.52	21.61
Fe_2O_3	13.16	14.56	12.06	16.16
CaO	1.48	1.80	4.72	0.90
MgO	2.04	4.16	5.06	2.04
Na_2O	0.52	0.32	0.92	0.32
K_2O	< 0.01	< 0.01	< 0.01	< 0.01
MnO	0.24	0.24	0.26	0.20
P_2O_5	0.13	0.25	0.36	0.17
TiO_2	0.94	0.96	0.83	1.03
H_2O	4.86	6.66	4.65	6.32
LoI	11.14	10.35	7.14	11.85
S-S	1.06	1.02	1.23	1.04

4.1. Natural Moisture Content

The natural moisture content (NMC) of the soil samples was determined according to the guidelines provided by ASTM D2216. Three trials were conducted for each sample, and the average value was calculated. The samples were first air-dried (AD) until no further weight loss was observed. Subsequently, the same samples were oven-dried (OD) at 105°C until a constant mass was achieved. The NMC test results for both air-dried and oven-dried samples are presented in Table 2. As shown in Table 2, the difference in water content between OD and AD ranges from 0.9% to 5.6%. The moisture content was found to be greater than 4% for all depths of TP-4 and TP-3, as well as at a depth of 3.0 m for TP-2. Therefore, these test pits contain a significant amount of structural water. High temperatures during oven drying remove structural water, whether or not it was pre-oven-dried. To ensure accurate results for this study area, moisture content tests should be conducted using either air drying or oven drying at 50°C. However, for other test pits, air drying is preferable to prevent the removal of structural water at high temperatures. Additionally, for all depths of TP-1 and at 1.5 meters for TP-2, the natural moisture content difference is below 4%, indicating a minimal amount of structural water in the soil. Thus, the conventional drying method is suitable for testing TP-1 and TP-2. To obtain the most accurate results, duplicate samples (as received, air-dried, and oven-dried) should be used, and a weighted average should be calculated.

Table 2 Natural Moisture Content Values Variations with Drying Temperature

Drying Condition	Natural Moisture Content (%)							
	TP-1		TP-2		TP-3		TP-4	
	1.5 m	3.0 m	1.5 m	3.0 m	1.5 m	3.0 m	1.5 m	3.0 m
OD (105^0C)	27.1	28	26.7	27.4	27.8	28	25.8	26.2
AD (50^0C, RH = 30%)	26.2	25.8	23.9	21.8	23.4	23.7	21.7	21.6
Difference	0.9	2.2	2.8	5.6	4.4	4.3	4.1	4.6

4.2. Specific Gravity of Soil Particles

To determine the specific gravity of the soil, three test trials were conducted, and the average value was used. The specific gravity test results for residual soils under air-dried (AD) and oven-dried (OD) conditions are presented in Table 3. The specific gravity of air-dried (AD) samples was higher than that of oven-dried (OD) samples, suggesting that specific gravity is significantly affected by drying before testing. The data indicates that specific gravity varies not only with soil texture but also with drying conditions. The specific gravity values for the study area range from 2.6 to 3.14, which exceed typical ranges, suggesting a high iron oxide content. Some residual soils have shown unusually high or low specific gravity values, as reported by Huat et al. (2009) [9]. Townsend (1985) [13] reported that lateritic soils have high specific gravity values ranging from 2.7 to 3.5. Therefore, measuring the specific gravity of residual soils (RS) is essential rather than assuming a standard value, as tropical residual soils exhibit highly variable particle densities. The variation in specific gravity between air-dried (AD) and oven-dried (OD) soils is shown in Figure 2.

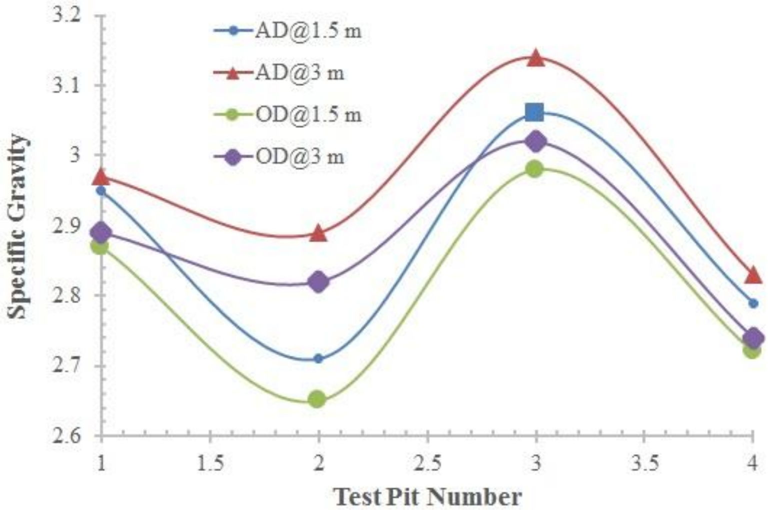

Figure 2 Variation of specific gravity of AD and OD soils

4.3. Atterberg Limits

The results of the Atterberg limit test for soil samples under different drying conditions are presented in Table 3. The test results indicate that pretest drying significantly affects the Atterberg limits of the soils. The differences in liquid limit (LL), plastic limit (PL), and plasticity index (PI) between the air-dried (AD) and oven-dried (OD) samples ranged from 0.12% to 5.17%, 1.08% to 7.57%, and 0.17% to 4.76%, respectively, across all test pits. Tropical residual soils are highly sensitive to mixing duration and drying, as these factors can alter their physical and chemical properties. Figure 3 shows the effect of mixing time on the liquid and plastic limits of residual soils under different drying conditions. An oven-drying temperature of 105°C may not be suitable for all soil types in Atterberg limit tests. Over-drying should be avoided, as soils do not typically experience such high temperatures in the field. Therefore, air-dried conditions are recommended for this study area. Furthermore, mixing duration significantly affects the Atterberg limit test results of residual soils. Air-dried soil samples should be used for plasticity index tests, with mixing time limited to a maximum of 5 minutes. Pretest drying, mixing duration, and mixing method significantly affect moisture content, Atterberg limits, optimum moisture content (OMC), and maximum dry density (MDD) in residual soil tests [8, 14].

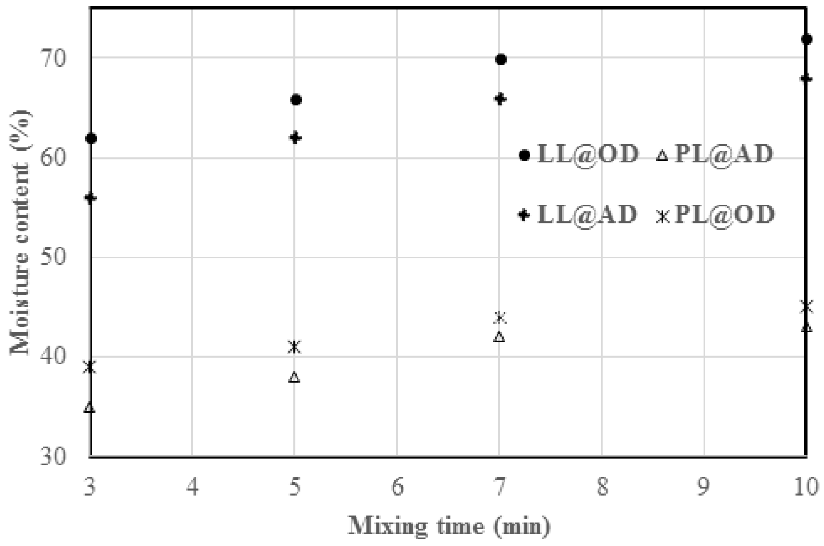

Figure 3 Effect of mixing time on the liquid and plastic limit values of residual soil

Table 3 Index Properties of Soils using Different Sample Preparation Methods

Test Pit	Test Pit Depth (m)	Drying method	NMC (%)	Gs	LL (%)	PL (%)	PI (%)
TP-1	1.5	AD	26.23	2.95	61.36	38.61	22.75
		OD	27.13	2.87	61.48	37.41	24.07
	3.0	AD	25.8	2.97	62.88	37.54	25.34
		OD	28.02	2.89	63.78	38.61	25.17
TP-2	1.5	AD	23.87	2.71	61.29	35.31	25.98
		OD	26.71	2.65	63.98	42.88	21.1
	3.0	AD	21.82	2.89	67.28	42.3	24.98
		OD	27.41	2.82	69.43	41.8	27.62
TP-3	1.5	AD	23.44	3.06	63.02	42.63	20.38
		OD	27.8	2.98	62.36	37.21	25.15
	3.0	AD	23.67	3.14	58.83	35.09	23.74
		OD	27.98	3.02	64	41.88	22.13
TP-4	1.5	AD	21.73	2.79	66.23	43.8	22.43
		OD	25.83	2.72	68.85	44.57	24.28
	3.0	AD	21.64	2.83	61.06	39.43	21.63
		OD	26.17	2.74	62.28	35.73	26.55

4.4. Particle Size Distribution (PSD)

The results of the gradation tests indicate that most soil particles in the study area are sand. The soil classification presented in Table 4, based on ASTM D2487 and AASHTO M145, shows that all test pit soils are sandy soils. The percentage of soil passing through a 4.75 mm sieve and retained on a 0.75 mm sieve ranged from 45.47% to 64.55% under both drying conditions. Furthermore, the percentage of soil retained on the 75 µm sieve exceeds 50%, classifying it as coarse-grained soil. The oven-dried lateritic soils contained a lower clay fraction than the air-dried samples. The Unified Soil Classification System (USCS) classification remained the same for both air-dried and oven-dried soils. TP-1 and TP-2 were classified as SC and SP-SC, respectively, at both depths, regardless of the sample preparation method. Additionally, TP-3 and TP-4 were classified as SP-SC at 1.5 meters, but at 3.0 meters, they were classified as SP-SM and SW-SM, respectively. The particle size distribution of residual soil may be influenced by sample preparation, as weak particles in lateritic soil can impact grading analysis. To ensure an accurate representation of the source material, coarse particles should not be fractured, and fine particles should remain adhered to the coarse particles. Wet sieving should be conducted, and a closed-system washing method should be maintained to prevent material loss. Any tendency of coarse particles to fracture should be documented in the test reports.

Table 4 Grain Size Distribution and Classification for Air and Oven Dried Soil Samples

Soil Property		Test Pits Designation and Sample Location Depth							
		TP-1		TP-2		TP-3		TP-4	
		1.5 m	3.0 m	1.5 m	3.0 m	1.5 m	3.0 m	1.5 m	3.0 m
Fine (< 0.075 mm) (%)	AD	17.33	14.65	7.13	6.9	24.53	14.64	23.13	10.07
	OD	16.98	11.72	7.70	5.28	19.12	16.20	22.13	8.20
Sand (2.00–0.075 mm) (%)	AD	54.52	47.78	52.81	52.92	45.47	58.82	51.51	50.7
	OD	55.01	54.12	57.95	50.24	47.66	64.55	49.10	46.32
Gravel (> 4.75 mm) (%)	AD	28.15	37.56	40.06	40.18	30.00	26.54	25.36	39.22
	OD	28.01	34.16	34.35	44.49	33.22	19.24	28.77	45.47
LL (%)	AD	61.36	62.88	61.29	67.28	63.02	58.83	66.23	61.06
	OD	61.48	63.78	63.98	69.43	62.36	64	68.85	62.28
PL (%)	AD	38.61	37.54	35.31	42.3	42.63	35.09	43.8	39.43
	OD	37.41	38.61	42.88	41.8	37.21	41.88	44.57	35.73
PI (%)	AD	22.75	25.34	25.98	24.98	20.38	23.74	22.43	21.63
	OD	24.07	25.17	21.1	27.62	25.15	22.13	24.28	26.55
D_{10}	AD			0.09	0.09				0.08
	OD		0.08	0.09	0.10				0.09
D_{30}	AD			0.54	0.42				0.30
	OD		0.35	0.36	1.07				0.45
D_{60}	AD			4.75	4.82				4.75
	OD		3.25	3.43	6.67				9.50
C_u	AD			55.23	54.10				63.33
	OD		43.31	38.07	65.35				105.56
C_c	AD			0.70	0.41				0.26
	OD		0.51	0.41	1.70				0.24
ASTM D2487 classification	AD & OD	SC	SC	SP-SC	SP-SC	SP-SC	SP-SM	SP-SC	SW-SM
AASHTO M145	AD & OD	A-2-7	A-2-7	A-2-7	A-2-7	A-2-7	A-2-7	A-2-7	A-2-7

Note: SC = clayey sands, SP-SC = poorly graded sands with clay, SP-SM = poorly graded sands with silt, SW-SM = well graded sand with silt.

The grain size distribution curves for all test pits under different drying conditions are shown in Figure 4. Figures 3(a) and 3(b) show that as test pit depth increases, the percentage of finer material decreases. This may be due to the greater laterization of the upper soil layer compared to the lower layer. Figure 3(c) compares the grain size distribution curves for TP-1 under air-dried (AD) and oven-dried (OD) conditions. A higher percentage of clay-sized particles was observed in the layer just below the lateritic soil layer [17]. Properties like grain size, mineral composition, organic matter content, and soil plasticity are more suitable for classification than moisture content, density, and shear strength [18]. Thus, tests using disturbed samples are preferred. Particle size distribution (PSD) is a key characteristic of lateritic soil that influences various properties. Several factors influence laterite soil gradation, including the parent rock type, formation process, degree of weathering (e.g., decomposition, desiccation, or laterization), sample position within the topography, and soil depth in the profile. Besides their naturally poor grading, lateritic PSDs are significantly affected by sample preparation methods, including pretest drying, chemical pre-treatment, flocculation issues in hydrometer analysis, and the presence or absence of dispersing agents. Standard laboratory procedures often break down silt and clay aggregates formed by iron oxides, a process that does not occur in construction, leading to test results that may not accurately represent as-built conditions [14]. For materials with weak gravel-sized aggregate particles, achieving an optimal particle size distribution (PSD) maximizes grain-to-grain contact and minimizes void spaces. This arrangement improves aggregate support, reduces internal stresses, and enhances load-bearing capacity, minimizing the risk of fracturing.

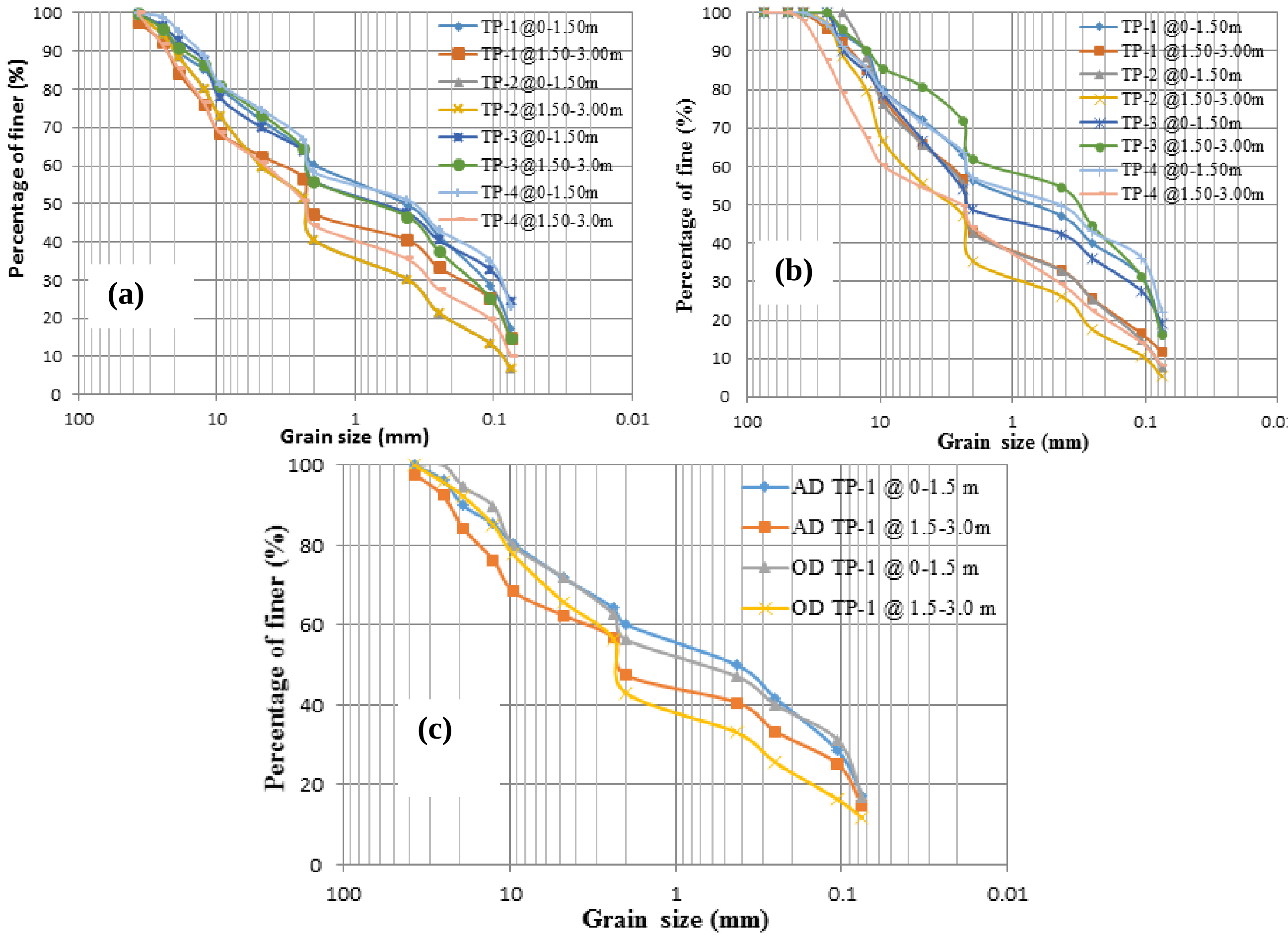

Figure 4 Grain size distribution curves of soil (a) AD (b) OD (c) AD and OD

The plasticity charts for both air-dried (AD) and oven-dried (OD) soils, as per ASTM D2487-11, are shown in Figure 5. The percentage of soil passing through the 75 µm sieve is less than 50% in both AD and OD cases for all test pits, classifying them as coarse-grained soils. Most soil samples passed through the 75 µm sieve at a rate of 5–12%, with a coefficient of uniformity (Cu) greater than 6 and a curvature coefficient (Cc) outside the 1–3 range in both AD and OD cases. Exceptions include TP-2 at 3.0 meters (OD), TP-1 and TP-4 at 3.0 meters, and TP-2 at 1.5 meters, which are classified as poorly graded sandy soils. Additionally, TP-2 at 3.0 meters (OD) is classified as well-graded sand, as 5–12% of the soil passed through the 75 µm sieve, and both Cu and Cc meet the specified criteria. The chemical composition test results (Table 1) indicate that test pits with highly laterized soils contain a greater percentage of fine soils in both AD and OD cases.

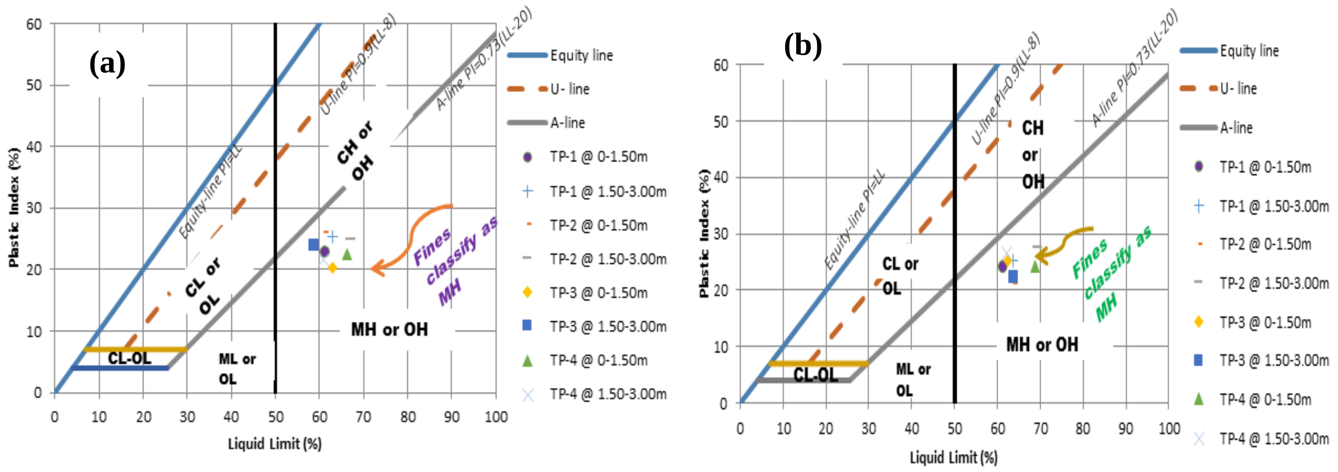

Figure 5 Plasticity chart of soil for different sample preparation methods (a) AD (b) OD

According to the AASHTO classification system, most soils are granular (silty/clayey gravel and sand) and fall under subgroup A-2-7, with a group index of less than 3. Their subgrade material rating ranges from excellent to good, and the classification of all test pits remains consistent across both test procedures and depths. Under the French pedological classification system, the Geological Society classifies these soils based on the Silica-Sesquioxide Ratio (SSR) as ferralitic or ferruginous [19]. Soils with an SSR of less than 2.0 are classified as intensely weathered ferralitic soils, whereas an SSR greater than 2.0 indicates less intensely weathered ferruginous soils.

$$SSR = \frac{(SiO_2/60)}{(Al_2O_3/102) + (Fe_2O_3/160)} \tag{1}$$

Based on the SSR values (Equation 1) for all TP soils (2.061, 2.031, 2.418, and 2.090 for TP-1, TP-2, TP-3, and TP-4, respectively), the study area soil is classified as ferruginous. The study area's average annual rainfall over the past 20 years ranges from 1,076.5 mm to 1,786.6 mm, classifying the soil as ferruginous based on a classification system, since the rainfall is below 1,830 mm [16]. Additionally, according to [1], all test pits in the study area are classified as Group C in the major division and sub-grouped as (c), resulting in a final classification of C(c), since they fall under true laterite. Table 5 presents a comparison of test results from different sample preparation methods with previously published results, showing reasonable agreement. The plastic limit value was found to be high despite the small percentage of fines, possibly due to the handling of sensitive samples. In-situ soils may not exhibit such high plastic limit values. Furthermore, the index properties of residual soils vary by depth within a layer and should not be used to generalize soil conditions at other layers. Misrepresentation of soil properties may lead to inaccurate designs and potential failure under the first applied load [17].

Table 5 Comparison of Sample Preparation Methods of Soils with Earlier Studies

Author	Drying Condition	NMC (%)	Gs	Atterberg Limits			Grain Size Distribution (%)		
				LL (%)	PL (%)	PI (%)	Gravel (> 4.75 mm)	Sand (2.00–0.075 mm)	Fine (< 0.075 mm)
[20]	AD	–	2.53–2.82	35.2–57	21–33.9	8.5–23.1	2.2–33	31.5–71.5	18.8–50.5
	OD	–	2.44–2.78	27.2–55.1	20.6–38.8	6.4–17.6	1.8–32.5	30.4–70.5	19.6–52.4
	Difference	–	0.09–0.04	8–1.9	0.4–4.9	2.1–5.5	0.4–0.5	1.1–1	0.8–1.9
[7]	AD	14.9–40.4	2.42–2.74	46.4–62.5	27.3–38.4	18.2–25.2	–	28.3–5.2	71.7–94.8
	OD	15.5–43.4	2.4–2.76	48.9–59.7	29.1–38.2	18.1–21.6	–	7.6–2.4	92.4–97.4
	Difference	0.1–3	0.02–0.02	2.5–2.8	1.8–0.2	0.1–3.6	–	20.7–2.8	20.7–3.4
This study	AD	21.6–26.2	2.71–3.14	58.8–67.3	35.1–43.8	20.4–26	25.4–40.2	45.5–58.8	6.9–24.5
	OD	25.8–28	2.65–3.02	61.5–69.4	35.7–44.6	21.1–28	19.2–45.5	46.3–64.6	5.3–22.1
	Difference	4.19–1.79	0.06–0.12	2.7–2.2	0.6–0.8	0.7–1.6	6.1–5.3	0.9–5.7	1.6–2.4

4.5. Existence of Structural Water in Lateral Soil Samples

Structural water is water bound within the mineral structure of a material and is not considered part of free water in the typical engineering sense, as shown in Figure 6(a) [21]. Drying temperature plays a crucial role in the accuracy of moisture content measurements in laterite soils. Previous studies have examined the effect of drying temperature on structural water content in laterite soils, considering various air- and oven-drying conditions [7, 8, 12, 13]. These studies suggest that if the moisture content difference between drying at 105°C and 50°C exceeds 4% and is confirmed through repeated testing, the oven-drying temperature should be adjusted in future tests to account for structural water. Alternatively, efforts should be made to reduce moisture content discrepancies in conventional measurement methods. Some researchers have previously reported that Ethiopian laterite soils contain minimal structural water, leading to irreversible changes during drying [7, 8]. However, results from Bahir Dar residual soils (see Table 2 and Figure 6(b)) indicate the presence of structural water, resulting in irreversible changes upon drying. This may be due to mineralogical composition, internal structure, moisture conditions, environmental factors, and clay mineral content, among other factors.

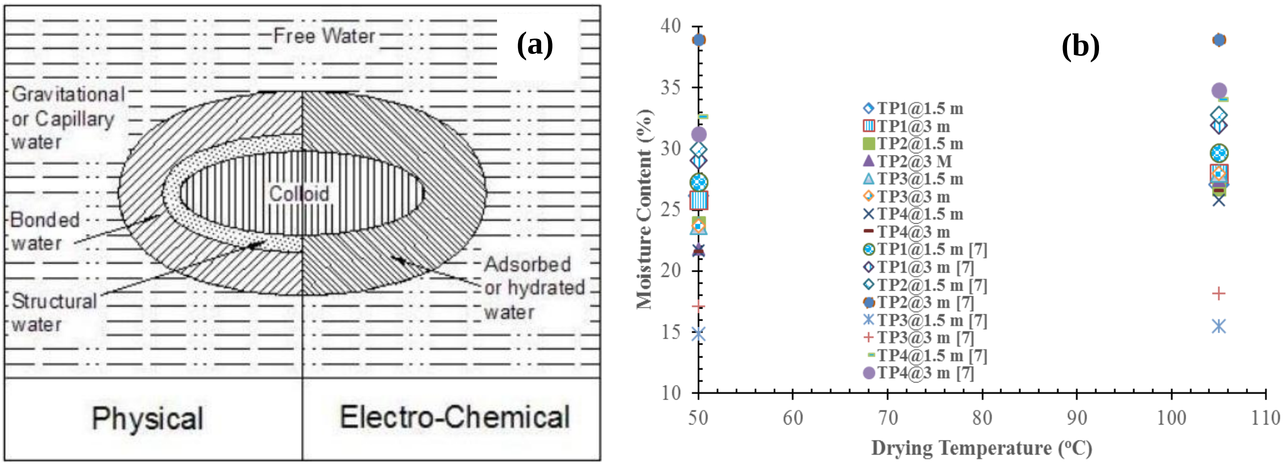

Figure 6 (a) Types of soil moisture [21] (b) Moisture content variation with drying temperature

4.6. Effect of Organic Content on Engineering Properties of Lateral Soils

Many researchers have reported that soil organic content significantly affects its properties. Loss on Ignition (LoI) is one of the most widely used methods for measuring organic matter content in soils; however, it lacks a universal standard protocol. Several factors influence its accuracy, including furnace type, sample mass, ignition duration and temperature, and clay content [22]. According to ASTM C618, the maximum allowable LoI values for raw or calcined natural pozzolans (Class N), Class F fly ash, and Class C fly ash are 10%, 6%, and 6%, respectively. In this study (see Table 1), the LoI values for TP-1, TP-2, TP-3, and TP-4 were 11.14%, 10.35%, 7.14%, and 11.85%, respectively. This suggests that organic content minimally affects the basic soil properties of the study area.

Organic matter content affects the specific gravity and void ratio of clay in a linear manner. In contrast, moisture content, Atterberg limits, and shear strength parameters exhibit nonlinear changes with increasing organic matter content [23]. According to ASTM D2487, organic clay and organic silt are classified based on whether their liquid limit after oven drying is less than 75% of the liquid limit measured before oven drying. As shown in Table 3, the ratio of the liquid limit (LL) after oven drying to LL after air drying is less than 75%. This indicates that organic content minimally affects the engineering properties of residual soils in the study area. An increase in plasticity index due to higher organic content enhances the soil's expansion and contraction capacity. These fluctuations can pose significant challenges for buildings constructed on such soils. Additionally, a higher coefficient of permeability due to increased organic matter suggests a greater number of voids between soil particles. This change may limit the suitability of the soil as an impermeable material in certain civil engineering projects. Furthermore, organic matter in clay soils significantly reduces shear strength values [24]. Further research is needed to assess the impact of organic content on the engineering properties of residual soils by testing varying organic matter proportions.

5.0 CONCLUSIONS

The sampling method, pretest drying, and testing procedure significantly affected the index properties of the residual soils. The conclusions drawn from the test results are as follows:

- The chemical composition test showed that most of the test pit soils were high in lateritic content, classified as group C and sub-grouped in (c).
- With an increase in the pretest drying temperature, the moisture content also increased from 0.90 to 5.60%.
- The specific gravity of the AD soil samples was found to be larger than that of the OD soil samples, indicating that specific gravity varies with both soil texture and drying conditions.
- The soils in the study area are generally well-graded reddish-brown sandy silt with medium plasticity and compressibility. They are suitable for road subgrade materials and range from excellent to good.
- Fresh samples were used for each moisture content point in the Atterberg limit test.
- It is recommended that AD soil samples be used for plasticity index tests with mixing times not exceeding 5 min.
- The Pre-test treatment should reflect the field conditions at the time of construction. Soil samples should not be over-dried before testing, because the soils might not have experienced such high temperatures in the field.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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