Behaviour of Undrained Cohesion in Fly Ash Stabilized Lateritic Soil

[1]Awarri, A.W. ; [2]Otto, C. G.
Department of Civil Engineering
Rivers State University, Port Harcourt PMB. 5080.

Abstract:- An investigation of the behaviour of undrained cohesion in fly ash stabilized lateritic soil was carried out with respect to the strength of the lateritic soil. This study looks into the possibility of using fly ash to enhance the strength of lateritic soils for construction purposes. The soil samples were obtained from three (3) boreholes (BH1-BH3) at different locations at a depth of 1.0, 1.5 and 2.0 meters each. Several preliminary laboratory tests, including specific gravity, moisture content, bulk density, Atterberg limit, particle size analysis and triaxial tests were carried out first to characterize the lateritic soil. The stabilization process was carried out with varying percentages of 5%, 10%, 15%, 20% and 25% fly ash by weight of the lateritic soil to determine the undrained cohesion and shear strength of the modified lateritic soil through triaxial test. The result showed an increase in the undrained cohesion and shear strength for the three (3) boreholes at the various depths respectively upon adding fly ash up until 15%, after which further increase in fly ash caused a decrease in the undrained cohesion and strength. However, it was discovered that 15% fly ash gave the optimum undrained cohesion and shear strength of the modified soil. This study will help the construction sector utilize fly ash more effectively for stability, economic and environmental benefits.

Keywords:- *Undrained Cohesion, Fly Ash, Soil Stabilization, Lateritic Soil, Shear Strength.*

I. INTRODUCTION

According to Soil Survey staff (2014), lateritic soils are developed in tropical and subtropical regions under intense heat and rainfall. These soils have unique profiles and characteristics due to their weathering processes, and they are usually rich in iron and aluminium oxides. Because laterites have a high concentration of iron oxide, they have a rusty red or yellow colour. The underlying parent rock is subjected to an intense and protracted chemical weathering process, resulting in variations in the resultant soils' thickness, grade, chemistry, and ore mineralogy (Schwarz, 1996).

According to Oyelami and Van Rooy (2016), lateritic soils are highly weathered tropical residual soils that contain varied proportions of clay-to-gravel-sized particles and are typically covered in concretions rich in sesquioxide. They are often unsuited for construction due to their high compressibility and poor shear strength. Additionally, fluctuations in moisture can cause volumetric changes in the soil, leading to swelling and shrinking (Koshy et al., 2021).

By minimizing these undesirable soil movements, stabilization reduces the possibility of infrastructure and structural damage and also construction constraints (Awarri & Otto, 2022). Lateritic soil that has yet to be stabilized is prone to erosion, particularly after prolonged rainfall. Slopes and embankments can be protected by stabilization, such as introducing binders or additives, which improve the cohesion and soil's resistance to erosion (Renolith, 2023).

Fly ash is a glass-like powder obtained from the gases released when coal is burned to produce energy. It is the mineral residue that is obtained for use from the power plant's exhaust pipes after burning coal. Fly ash and other chemicals combine to form a cementing material used to increase soil's bearing capacity (Li & Zhang, 2020). Fly ash is a valuable material for many different purposes, such as producing cement, bricks, tiles, etc (ASTM C618, 2008). When used to stabilize soil, fly ash's primary advantage is its capacity to reduce specific gravity and increase shear strength. However, when fly ash is produced in large quantities, it poses a threat to the environment. Fly ash can be used for engineering purposes in order to reduce the potential hazards and pollution it causes to the environment (Hossain et al., 2018).

Undrained cohesion (c_u) is the cohesion or measure of the shear strength of a soil when it is loaded and sheared under undrained conditions. Undrained conditions suggest that there is not enough time for the excess pore water pressure to dissipate throughout the shearing process. This usually occurs in cohesive soils that are saturated during rapid loading or when drainage is restricted, as in the case of quick loading events or under certain construction conditions (Kong et al., 2022). It is one of the critical parameters in geotechnical engineering used to analyze the stability and behaviour of soils; it represents the soil's resistance to deformation.

This study is based on ascertaining the behaviour of the fly ash stabilized lateritic soil with regard to undrained cohesion and the optimal fly ash content required to stabilize the soil.

II. MATERIALS AND METHODS

- *Materials*

The soil samples were obtained from three different boreholes within Port Harcourt. Fly ash was purchased from charcoal vendors at the Mile 3 market in Diobu, Port Harcourt.

- *Methods*

Soil samples were collected from each borehole (BH1-BH3) at 1.0m, 1.5m, and 2.0m depths using the Hand Auger method. Afterwards, the obtained materials were brought to Rivers State University's Civil Engineering Laboratory for laboratory testing. All laboratory procedures and data analysis followed the British Standard (BS 1377:1975, 1990) for soil testing. Initially, various tests such as triaxial, Atterberg limit, specific gravity, moisture content, and particle size distribution were conducted on the lateritic soil. Further, the specific gravity, physical and chemical characteristics of fly ash were tested. At varying depths, triaxial tests were conducted on fly ash-modified soil for every borehole. The fly ash was mixed with the lateritic soil in varying proportions of 5%, 10%, 15%, 20%, and 25% by weight of the lateritic soil. Table 1 shows the number of trials conducted for the fly ash-stabilized soil samples.

Table 1 Number of trials for the Fly Ash Stabilized Soil Samples per Borehole

Fly Ash Content (%)	**No. of Samples**	**No. of trials**	**Total No. of Samples**
5	3	3	9
10	3	3	9
15	3	3	9
20	3	3	9
25	3	3	9
Total Samples			**45**

- *Triaxial Test of Fly Ash Modified Lateritic Soil*

As previously mentioned, the lateritic soil was blended with fly ash at 5%, 10%, 15%, 20%, and 25% by weight of the lateritic soil. The lateritic soil was then subjected to a triaxial test in compliance with BS 1377:1990 standard procedures. Plates 1a and 1b show the modified soil sample during and after the triaxial test.

Plate 1: Fly Ash Modified Lateritic Soil During and after Triaxial Test

After the triaxial test, the stress and strain values were obtained and the stress-strain curves were drawn. The maximum stress at failure was obtained from the curves from which the major principal stresses were determined. Subsequently, Mohr circle diagram was drawn with σ_1 and σ_3 as the major and minor principal stresses to obtain the undrained cohesion, c_u.

III. RESULTS AND DISCUSSION

➢ *Index Properties of the Soil*

Table 2 summarizes the lateritic soil's index properties, and Table 3 presents the fly ash's chemical and physical properties. Lateritic soil was found to have a natural moisture content of 21.58%, indicating a strong water-holding capacity. The Unified Soil Classification System classifies it as CL (inorganic clay of low or medium plasticity) based on the liquid limit of 47.0% and the plasticity index of 24.7%. The soil had a specific gravity of 2.6. The soil's unit weight and bulk density were 10.44 kN/m^3 and 16.53 kg/m^3, respectively. The soil is well-graded, according to the results of the sieve analysis test.

Table 2 Index Properties of the Lateritic Soil

Parameters	**Value**
Specific gravity	2.60
Liquid limit (%)	47.0
Plastic limit (%)	40.7
Plasticity index (%)	24.7
USCS	CL
Moisture Content (%)	21.58
Percentage Passing Sieve No. 200	30.4

Table 3 Physical and Chemical Properties of Fly Ash

Description	**Value**	**Requirement as per IS: 3812: 2003**
Specific Gravity	2.10	-
fineness	335	320 (min)
Silica (SiO_2)	61.45	35 (min)
Alumina (Al_2O_3)	30.85	-
Iron oxide (Fe_2O_3)	5.10	-
Magnesia (MgO)	0.74	5 (max)
Sodium oxide (Na_2O)	0.22	-
Calcium oxide (CaO)	1.46	-
Potassium oxide (K_2O)	1.58	5 (max)
Colour	Grey to black	-
Loss in Ignition	0.62	5(max)

➢ *Undrained Cohesion of Unstabilized and Stabilized Lateritic Soil*

Figures 1, 2, and 3 depict the behaviour of the lateritic soil for each percentage increase of fly ash content at depths of 1.0, 1.5, and 2.0 meters, at BH1-BH3 respectively. Fly ash addition increased the lateritic soil's undrained cohesion by up to 15% fly ash content. This is primarily because of the lateritic soil's pozzolanic reaction to fly ash, which formed cementitious compounds and increased the soil's overall strength. Nevertheless, the undrained cohesion decreased after 15% fly ash addition. This was because it became more difficult to thoroughly mix the sample at this point, which resulted in a decrease in undrained cohesion.

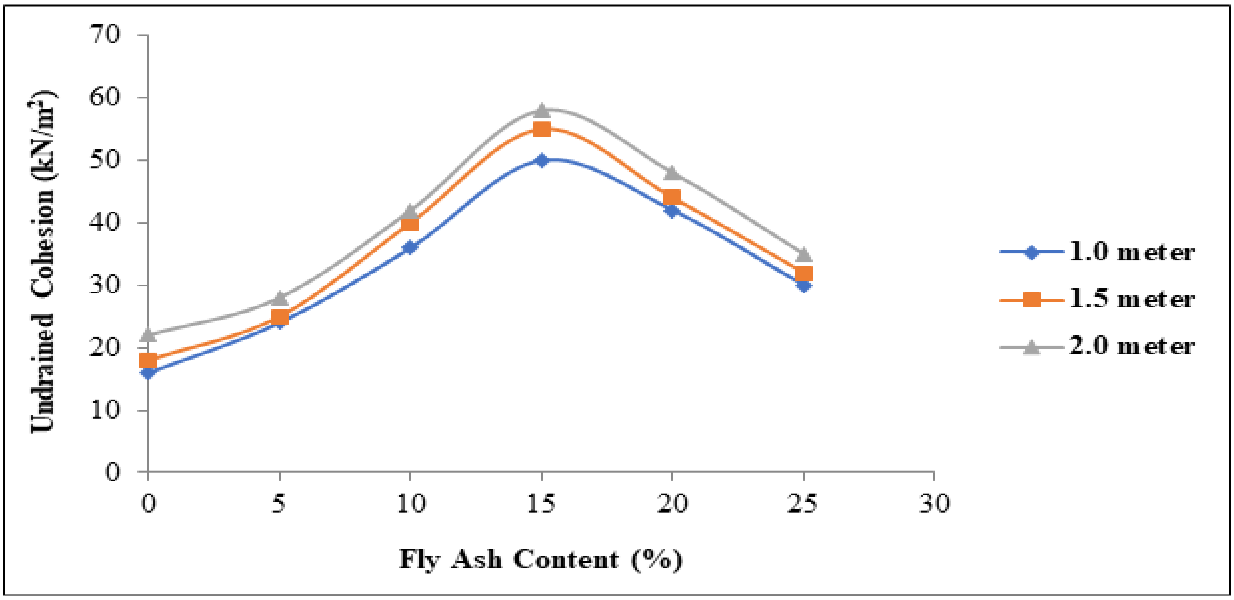

Fig 1 Undrained Cohesion of Unstabilized and Stabilized Lateritic Soil for Borehole 1

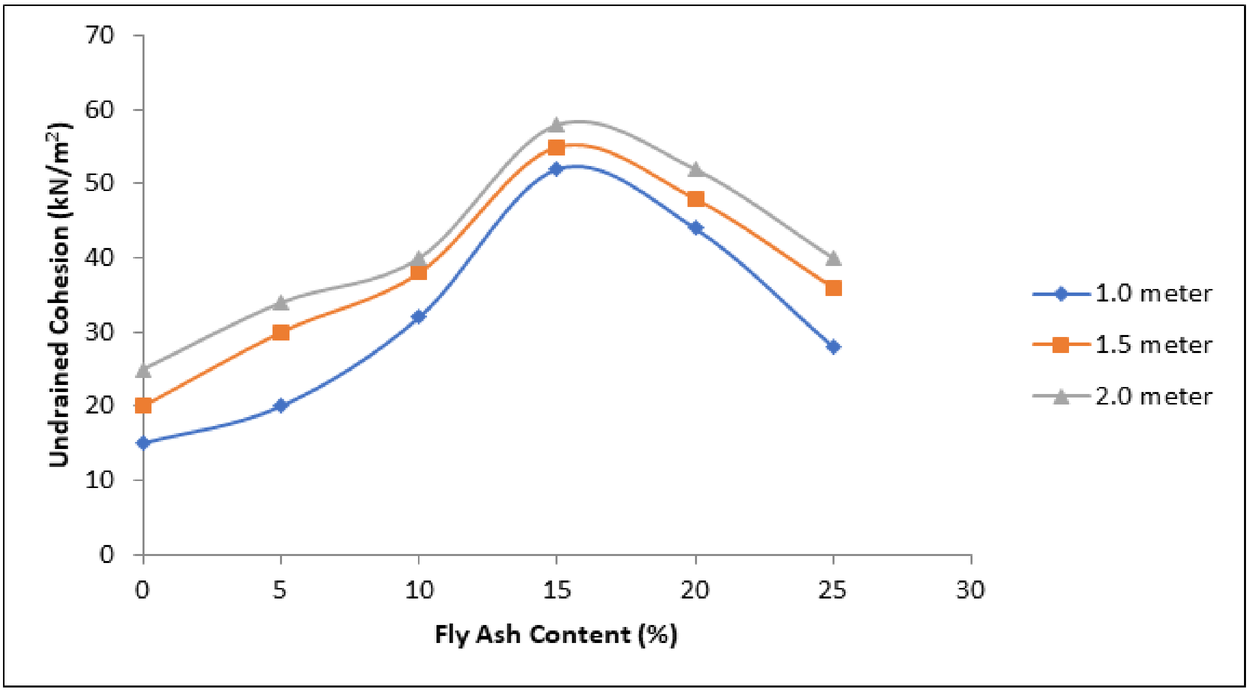

Fig 2 Undrained Cohesion of Unstabilized and Stabilized Lateritic Soil for Borehole 2

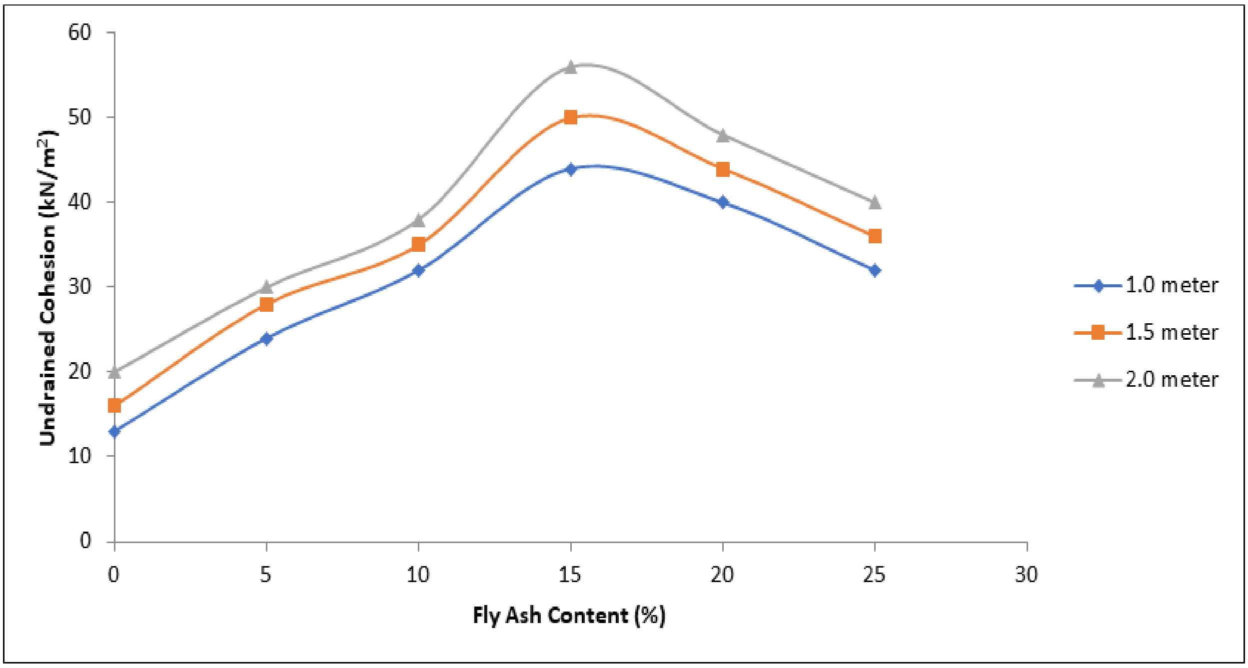

Fig 3 Undrained Cohesion of Unstabilized and Stabilized Lateritic soil for Borehole 3

IV. CONCLUSIONS

➢ *The Following Findings may be Drawn from this Investigation.*

- Fly ash increased the lateritic soil's undrained cohesion, which in turn increased the soil's strength from a soft to a stiff lateritic condition.
- 15% fly ash is the optimum fly ash percentage by weight of lateritic soil in terms of undrained cohesion.

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