Scheffe optimization of the California Bearing Ratio of a kaolin blended lateritic soil for pavement construction

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Abstract

Improvement of the mechanical behavior of problematic lateritic soil using naturally occurring materials that can be sourced within our immediate environment has been understudied over the years due to the availability and predominance of Portland Limestone Cement (PLC) as a readily available stabilization agent. Therefore, this study presents an approach to the use of Scheffe's optimization method to model the California bearing ratio (CBR) properties of problematic lateritic soil blended with kaolin in its natural state for pavement construction purposes. A Scheffe simplex lattice second-degree polynomial was applied in formulating the model for predicting the CBR behavior of the kaolin treated laterite soil. If the mix ratio is known, the soil's said property can be predicted. A maximum CBR value of 76.6% (Y_2) was recorded for the stabilized soil sample. The Scheffe model that was used in the study of CBR behavior has been found to be adequate at a 95% confidence level. The adequacy of the model was checked using the student T-test and analysis of variance (ANOVA) test, and the model is said to be satisfactory at the same level of adequate. With the optimization model developed, the CBR behavior of soil samples with similar geotechnical properties and stabilization agents can be monitored.

Keywords: lateritic soil, stabilization, CBR, geotechnical, optimization model
Kulcsszavak: lateritikus talaj, stabilizáció, CBR, geotechnikai, optimalizálási modell

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1. Introduction

Over the years, researchers have developed and investigated efficient means of utilizing both agricultural and natural products to combat soil instability problems. One type of natural product that remains untapped with the potential to serve as a stabilization agent due to its binding property is kaolin. Kaolinite is formed by the weathering or hydrothermal alteration of aluminosilicate minerals. Thus, feldspar-rich rocks commonly weather to kaolinite. To form, ions like Na, K, Ca, Mg, and Fe must first be leached away by the weathering or alteration process. Kaolin serves an important function in the cement industry when highly calcinated; pulverized Kaolin adds comprehensive strength, flexural strength, and water permeability to cement [1-2].

It can be considered an interesting area for research to ascertain its optimal applicability in the stabilization of lateritic soil. Its water permeability characteristic is useful in prolonging the durability of concrete and reducing weakening. Kaolin adds flexibility, which is often preferred to the usually brittle finished product. High-performance concrete (cement with Kaolin additives) can be modified to meet a variety of applications. Its shrinkage strength when compressed and water permeability make high-performance concrete useful for pavement construction purposes, among other purposes [3].

Mathematical prediction models can be very useful tools for making informed decisions and predicting future outcomes. However, it's important to use them in conjunction with other sources of information and to be aware of their limitations and potential biases. Mathematical prediction models are very crucial in civil engineering especially in laboratory works because they help in minimize time and cost to find the properties of mixes and determine the optimum amount of additives [4, 5].

According to Usoh *et al.* [6], a mathematical model and numerical simulation of heavy metal transport in a municipal solid waste (MSW) dumpsite in Akwa Ibom State, Nigeria was developed using a two-dimensional finite element model. The results of the study showed that the transport of heavy metals in the dumpsite is influenced by several factors, including the type of heavy metal, the soil properties, and the rainfall. The study also showed that the numerical model was able to accurately simulate the transport of heavy metals in the dumpsite. Several other studies on the development of mathematical prediction models for engineering purposes have over the years also be published in various journals all over the world. These prediction models have farther been developed from just mathematical models to artificial intelligence aided models.

This study aims to find the best mixture design for pavement construction purposes by optimizing the CBR of weak lateritic soil using the Scheffe simplex lattice method by

- First ascertaining the aggregates' physical characteristics.
- Establish the ideal Kaolin content for the mix.
- Create a mathematical model that can accurately predict the California Bearing Ratio (CBR) of the blended soil sample under study.

Scheffe models were specifically developed to handle the natural constraints of mixture designs. Bearing in mind the loopholes in the trial-and-error method of choosing a working mix design, there's always a great need to subject such projects as this, requiring the mixture of three-component samples at varying proportions, to an optimization model to obtain the best mixture formula; hence, the application of the Scheffe optimization model. It was developed in 1963 for the assessment of the response of a particular characteristic of a mixture to variations in the proportions of its component materials [7, 8].

Some of the applications of Scheffe mix design includes.

1. Concrete Mix Design: Scheffe's mixture design method can be used to optimize the composition of concrete mixes, including the selection, and proportioning of different cementitious materials, aggregates, and other additives, to achieve the desired properties and performance [9].
2. Asphalt Mix Design: Scheffe's mixture design method can also be applied to optimize the composition of asphalt mixes, including the selection, and proportioning of different aggregates, asphalt binders, and additives, to achieve the desired performance characteristics such as stability, durability, and resistance to deformation [10].
3. Soil Stabilization: Scheffe's mixture design method can be used to optimize the composition of soil stabilization mixtures, including the selection, and proportioning of different soil types, binders, and other additives, to improve the strength and stability of the soil for various geotechnical engineering applications [11].
4. Composite Materials: Scheffe's mixture design method can also be applied to optimize the composition of composite materials used in civil engineering applications, including fiber-reinforced composites, polymer composites, and other types of advanced materials, to achieve the desired properties and performance [12].

Ambrose *et al* [13] investigated the effect of crushed recycled-ceramic tiles (CRT) fine aggregate content on the compressive strength of concrete. The authors found that the incorporation of CRT as fine aggregate improves the compressive strength of concrete, and this increase is directly proportional to its content. The authors also developed Scheffe's second-degree polynomial models to predict the compressive strength, slump height, and cost of CRT concrete. The models were found to be adequate at 95% confidence level. A. O. Ogunsanwo *et al* [14] in the Application of Scheffe Optimization Models on Soil Stabilization used Scheffe models to optimize the mix proportions of cement and lime for stabilizing a tropical clayey soil found that the Scheffe models were able to predict the strength and durability of the stabilized soil with a high degree of accuracy. Furthermore, Ogunsanwo *et al* [15] reviewed the application of Scheffe models on soil stabilization and concluded that Scheffe models are effective tools for optimizing the mix proportions of stabilization materials. They also recommended that more research be done on the application of Scheffe models on soil stabilization. Scheffe model was also applied in the stabilization of Amuro-okigwe subgrade using male inflorescence of oil palm ash (MIPA) [16]. They used Scheffe's model to optimize the mix proportions of MIPA and soil. They found that the optimum mix proportion of MIPA was 10.5%, which resulted in a significant improvement in the strength and durability of the soil.

2. Materials and method

2.1 Mathematical modelling and formulation of mix proportions

2.1.1 The Scheffe Model

Scheffe is an advanced system of regression analysis derived from Response Surface Methodology (RSM) through hard computing algorithms. In Scheffe's mixture optimization model, the goal is to find the optimal combination of ingredients in a mixture that will result in the desired response or outcome. This can be applied in various fields such as engineering, pharmaceuticals, food science and industrial manufacturing [17]. The model involves creating a design matrix that represents different combination of mixture components and conducting experiments to measure the response variable for each combination [18]. These measurements are then used to estimate the parameters of RSM which describes the relationship between the mixture components and the response variable. Using the estimated RSM, Scheffe's method allows for the determination for the optimal combination of mixture components that maximizes the response variable, while taking into account any constraints or limitations. The technique typically involves the use of mathematical optimization algorithms to search for the optimal solution within the defined parameter space [19]. RSM involves three major steps, which are:

i. The design of the experiment,

ii. formulation of model equations, and

iii. optimization of the equations under certain given constraints.

2.1.2 Scheffe's simplex Lattice method:

A simplex is defined as a convex polyhedron with $(k + 1)$ vertices produced by k intersecting hyperplanes in k-dimensional space. While an ordered arrangement consisting of a uniformly spaced distribution of points on a simplex is known as a lattice. Studying a mixture of n-components mixture which are dependent on the component ratio only, the factor space is a regular $(q\text{-}1)$ simplex and for the mixture the following relationship holds [20].

$$\sum_{i=1}^{q} X_i = 1 \qquad (1)$$

Where: q= No of components and $X_i \geq 0$ = concentration of component.

If q = 2, we have the lattice simplex as a straight line, for q = 3, it is an equilateral triangle while for q= 4, the simplex will be a regular tetrahedron with each vertex representing each of the components. Scheffe considered experiments with mixtures, in which the property studied depends on the proportions of the components but not their quantities in the mixture. He introduced polynomial regression to model the response, called "*q, n*-polynomial." Note that these polynomials must be of lower degree, otherwise they will be complex to interpret [21].

Note that this polynomial must be of lower degree, otherwise it will be complex to interpret. Scheffe used a regular (q-1) simplex to represent a factor space to describe a response surface for mixtures consisting of several components. If the number of components is denoted by q, then for binary system ($q = 2$) the required simplex is a straight line; for $q = 3$, the required simplex is an equilateral triangle; and for $q = 4$, the simplex is a regular tetrahedron [22]. The proportions used for each factor have $m + 1$ equally spaced levels from 0 to 1 ($x_1 = 0$ 1/m, 2/m………1), and all possible combinations are derived from such values of the component concentrations. This implies that all possible mixtures with these proportions are utilized. Hence, for the quadratic lattice (q, 2), approximating the response surface with the second-degree polynomials ($m = 2$), the following levels of every factor must be used 0, ½ and 1 [23, 24]. The number of runs N in a mix design can be calculated thus

$$\mathrm{N} = \frac{(q+m-1)!}{m!(q-1)!} \tag{2}$$

Where: q = No of components present in the mix = 3

M = Desired degree of polynomial = 2

Therefore, $\mathrm{N}=\frac{(3+2-1)!}{2!(3-1)!} = \frac{4!}{2!2!} = 6$

Mix components are assumed to interact within a factor space. The research is comprised of a 3-component mixture (soil, Kaolin, and water), which was analyzed using a triangle simplex lattice having a 2-dimensional factor space. The triangular simplex components are illustrated in *Fig. 1*.

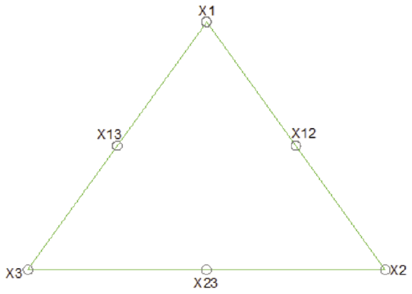

Fig. 1 Three component mixture in a three-dimensional factor space showing six points of observation
1. ábra Három komponensű keverék egy háromdimenziós tényezőtérben, amely hat megfigyelési pontot mutat

2.1.3 Pseudo and actual components

Pseudo-components are imaginary or coded variables used to simplify design construction and model fitting, thereby reducing the correlation between component bounds in constrained designs. Scheffe provided an equation for elucidating the relationship between the pseudo component(x) and the actual component (z) in their mixture designs [25]. The summation of the pseudo components must be equal to unity as written in *Eq.4*

$$\mathrm{Z = AX} \tag{3}$$

$$0 \le x_1 \le 1 \tag{4}$$

According to (9) Z represents the actual components while X represent the pseudo components, where A is the constant; a three-by-three matrix for the present work under study. The value of matrix A will be obtained from the three mix ratios. The mix ratios which are the actual components at the vertices are chosen at random with the key component being optimized kept at a constant value not more than unity [26].

A being a matrix of coefficient.

Therefore $X = ZA^{-1}$ (5)

From the actual components Z, a three-by-three matrix is formed which when transposed becomes a conversion factor from the pseudo to real components. Assuming we select the first three mix rations as; thus, $Z_1(A_{11}, A_{21}, A_{31},)$, $Z_2(A_{12}, A_{22}, A_{32},)$, $Z_3(A_{13}, A_{23}, A_{33},)$ then the actual component simplex is shown below.

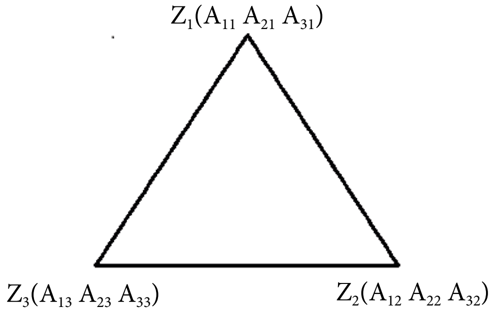

Fig. 2 Simplex components at vertices only
2. ábra Szimplex komponensek csak csúcsokban

With a 3 by 3 matric of

$$\begin{vmatrix} A_{11} & A_{21} & A_{31} \\ A_{12} & A_{22} & A_{32} \\ A_{13} & A_{23} & A_{33} \end{vmatrix} \tag{6}$$

When transposed becomes

$$\mathrm{Z^T} = \begin{vmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{vmatrix} \tag{7}$$

Furthermore, the actual components along the vertices can be gotten by substituting the required data into *Eq. 8*

$$\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} = \begin{vmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{vmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} \tag{8}$$

The value of A derived from the first three mix ratios. The mix ratios are.

$Z_1(1.00,\ 0.25,\ 0.15)$, $Z_2(1.00,0.55,0.16)$, $Z_3(1.00,0.75,0.17)$, with corresponding pseudo mix ratios in the form of an identity matrix which signifies that these points lie on the vertices of the simplex; thus, $X_1(1, 0, 0)$, $X_2(0,1,0)$, $X_3(0,0,1)$.

Substitution of X_i^{th} and Z^{ith} into *Eq. 8*, then the corresponding pseudo components are used to determine the corresponding actual mixture components. However, X_1 equals proportion of sample soil, X_2 equals proportion of kaolin, and X_3 equals proportion of water [27, 28].

For the first run:

$$\begin{bmatrix}1\\0.25\\0.15\end{bmatrix}=\begin{vmatrix}A_{11}&A_{12}&A_{13}\\A_{21}&A_{22}&A_{23}\\A_{31}&A_{32}&A_{33}\end{vmatrix}\begin{bmatrix}1\\0\\0\end{bmatrix} \tag{9}$$

a_{11}= 1.0, a_{21}= 0.25, a_{31}= 0.15

For the second run

$$\begin{bmatrix}1\\0.55\\0.16\end{bmatrix}=\begin{vmatrix}A_{11}&A_{12}&A_{13}\\A_{21}&A_{22}&A_{23}\\A_{31}&A_{32}&A_{33}\end{vmatrix}\begin{bmatrix}0\\1\\0\end{bmatrix} \tag{10}$$

a_{12}=1.0, a_{22}= 0.55, a_{32}= 0.16

For the third run

$$\begin{bmatrix}1\\0.75\\0.17\end{bmatrix}=\begin{vmatrix}A_{11}&A_{12}&A_{13}\\A_{21}&A_{22}&A_{23}\\A_{31}&A_{32}&A_{33}\end{vmatrix}\begin{bmatrix}0\\0\\1\end{bmatrix} \tag{11}$$

a_{13}= 1.0, a_{23} = 0.75, a_{33} = 0.17

Substituting the values of the constants, we have $[A]$ matrix.

$$[A]=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix} \tag{12}$$

This derived first three points are located on the vertices of the simplex factor space, however, the remaining three experimental points which are the interraction points are calculated by substituting in *Eq. 8* as follows;

For A_{12}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{vmatrix}0.5\\0.5\\0\end{vmatrix}=\begin{bmatrix}1\\0.4\\0.155\end{bmatrix} \tag{13}$$

For A_{13}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{vmatrix}0.5\\0\\0.5\end{vmatrix}=\begin{bmatrix}1\\0.5\\0.16\end{bmatrix} \tag{14}$$

For A_{23}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{vmatrix}0\\0.5\\0.5\end{vmatrix}=\begin{bmatrix}1\\0.65\\0.165\end{bmatrix} \tag{15}$$

The computation matrix table for the mixture proportion formulation is presented in *Table 1*.

Actual				Pseudo		
Z_1	Z_2	Z_3	Response	X_1	X_2	X_3
1	0.25	0.15	Y_1	1	0	0
1	0.55	0.16	Y_2	0	1	0
1	0.75	0.17	Y_3	0	0	1
1	0.4	0.155	Y_{12}	0.5	0.5	0
1	0.5	0.16	Y_{13}	0.5	0	0.5
1	0.65	0.165	Y_{23}	0	0.5	0.5

Table 1 Second order mixture formulation matrix table
1. táblázat Másodrendű keverék-összetétel mátrix táblázat

The experimental control points' mixture formulations are also calculated which were designed for the validation of the generated Scheffe's regression model.

For C_1

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0\\0.3333\\0.6667\end{bmatrix}=\begin{bmatrix}1\\0.683\\0.1667\end{bmatrix} \tag{16}$$

For C_2

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0.25\\0.65\\0.1\end{bmatrix}=\begin{bmatrix}1\\0.495\\0.1585\end{bmatrix} \tag{17}$$

For C_3

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0.1\\0.3\\0.6\end{bmatrix}=\begin{bmatrix}1\\0.64\\0.165\end{bmatrix} \tag{18}$$

For C_{12}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0.6\\0.1\\0.3\end{bmatrix}=\begin{bmatrix}1\\0.43\\0.157\end{bmatrix} \tag{19}$$

For C_{13}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0.1\\0.6\\0.3\end{bmatrix}=\begin{bmatrix}1\\0.58\\0.162\end{bmatrix} \tag{20}$$

For C_{23}

$$\begin{bmatrix}Z_1\\Z_2\\Z_3\end{bmatrix}=\begin{vmatrix}1&1&1\\0.25&0.55&0.75\\0.15&0.16&0.17\end{vmatrix}*\begin{bmatrix}0.65\\0.25\\0.1\end{bmatrix}=\begin{bmatrix}1\\0.375\\0.1545\end{bmatrix} \tag{21}$$

The computation matrix table for the mixture proportion formulation is presented in *Table 2*.

	Actual				Pseudo		
Runs	Z_1	Z_2	Z_3	Response	X_1	X_2	X_3
1	1	0.683	0.166	C_1	0	0.333	0.667
2	1	0.495	0.158	C_2	0.25	0.65	0.10
3	1	0.640	0.165	C_3	0.1	0.30	0.60
4	1	0.430	0.157	C_{12}	0.6	0.10	0.30
5	1	0.580	0.162	C_{13}	0.1	0.60	0.30
6	1	0.375	0.154	C_{23}	0.65	0.25	0.10

Table 2 Design matrix table for control points based on Scheffe's (3, 2) - lattice polynomial
2. táblázat Tervezési mátrix táblázat a vezérlőpontokhoz Scheffe (3, 2) - rácspolinom alapján

2.2 Responses

A simplex design expression will enable us to predict responses for different mixtures. Responses can be defined as a blend of selected properties of the additives or treatment matrix. For the soil-additive blend mixture, the constituent elements are water, kaolin, and soil. This approach is based on response surface methodology (RSM).

Hence, a simplex design expression will have the form [7, 29].

$$Y=b_0+b_1x_1+b_2x_2+b_3x_3+b_{11}x_1^2+b_{12}x_1x_2+b_{13}x_1x_3+b_{22}x_2^2+b_{23}x_2x_3+b_{33}x_3^2 \tag{22}$$

Since the sum of the respective component for a ternary mixture as considered in this work

$$x_1+x_2+x_3=1\ \ ie.\sum x_i-1\ =0 \tag{23}$$

Where b is the constant coefficients, x_i the component proportions and Y is the response.

The reduced second-degree polynomial can be obtained as follows.

$$b_0x_1 + b_0x_2 + b_0x_3 = b_0 \tag{24}$$

$$b_0 = b_0(x_1 + x_2 + x_3) \tag{25}$$

Multiplying *Eq. 23* by x_1, x_2, x_3 in successions

$$x_1^2 = x_1 - x_1x_2 - x_1x_3 \tag{26}$$

$$x_2^2 = x_2 - x_1x_2 - x_2x_3 \tag{27}$$

$$x_3^2 = x_3 - x_1x_2 - x_2x_3 \tag{28}$$

Substituting *Eq. 24* into *Eq. 26, 27, 28*, we obtain after necessary transformation that.

$$\hat{Y} = (b_0 + b_1 + b_{11})x_1 + (b_0 + b_2 + b_{22})x_2 + (b_0 + b_3 + b_{33})x_3 + (b_{12} + b_{11} + b_{22})x_1x_2 + (b_{13} + b_{11} + b_{33})x_1x_3 + (b_{23} + b_{22} + b_{33})x_2x_3 \tag{29}$$

Simplifying as follows:

$$b_{ii} + b_i + b_0 = \beta \tag{30}$$

$$b_{ij} + b_{ii} + b_{jj} = \beta_{ij} \tag{31}$$

Eq. 29 becomes:

$$\hat{Y} = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 \tag{32}$$

Eq. 32 becomes the reduced second-degree polynomial.

Where:

$$Y_1 = \beta_1 \tag{33}$$

$$Y_2 = \beta_2 \tag{34}$$

$$Y_3 = \beta_3 \tag{35}$$

$$\beta_{12} = 4Y_{12} - 2Y_1 - 2Y_2 \tag{36}$$

$$\beta_{13} = 4Y_{13} - 2Y_1 - 2Y_3 \tag{37}$$

$$\beta_{23} = 4Y_{23} - 2Y_2 - 2Y_3 \tag{38}$$

3. Test materials

A kaolin sample was obtained from Agbaghara-Nsu in the Ehime Mbano Local Government Area of Imo State, Nigeria, using geological bedrock maps provided by the Geological Survey Agency of Nigeria for locating mineral deposits throughout the federation. The sample was crushed to a fine powder with an electric grinder (Model: 4E Grinding Mill, made in Germany) set to a gap width of 0.2 mm at 89 rpm. The crushed sample was sieved using a BS sieve set to obtain the desired powder form for easy mixing with the other mix constituents.

The soil sample was collected from a construction site at Alex Ekwueme Federal University Ndufu-Alike, Ikwo, Ebonyi State, Nigeria at a depth of 1.5 m using the disturbed sample technique. About 500 g of the sample was collected and the moisture content of the soil was determined before it was air dried for 7 days.

3.1 Methods

The experimental programs for the investigational study were carried out in accordance with the British Standard BS 1377-2 [30] for soil testing in civil engineering which is a widely recognized and accepted guideline. Following these guidelines ensures that the experimental programs are carried out with precision and accuracy, resulting in reliable results for Specific gravity testing, Atterberg limits, sieve analysis, and the California Bearing Ratio (CBR) test. The Kaolin, sample soil, and water sourced from a borehole within the laboratory are the three component materials in this mixture experiment problem [28].

3.1.1 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) is a standardized British test used to evaluate the strength and bearing capacity of subgrade and base course materials for roads, pavements, and other infrastructure projects. The test measures the ratio of the bearing capacity of a soil sample (in this case, a series of different variations of constituent components alongside sample soil mixes developed by the Scheffe mix design) to that of a standard crushed rock material. The test involves compacting the sample in a 2360 cm^3 mold using a 2.5 kg rammer in three layers. The first layer is compacted by dropping the rammer 25 times from a height of 30 cm. The second and third layers are compacted by dropping the rammer 50 times from a height of 15 cm. After compaction, the soil sample is allowed to be cured for 24 hours before the CBR test is conducted [31].

3.1.2 Specific gravity test

Based on the outline as described in BS 1377 [30] Part 4, the relative density of soil particles is gauged by the specific gravity of the soil. It is described as the proportion between the weight of an equal volume of soil particles and water. It can be used to determine the density, void ratio, and water content of soil. The specific gravity of soil is a crucial property for engineers and geotechnical experts. There are several ways to calculate soil's specific gravity, but the pycnometer method was used in this research study.

3.1.3 Compaction Test

The typical Proctor Test, also known as the compaction test, entails a lab procedure used to identify the ideal water for a specific compaction energy for a specific soil compaction energy. The purpose of this test is to determine whether soil has been compacted to the required density for use as a foundation for buildings, roads, and other structures. Although the Proctor Test is frequently used, there are other ways to assess the compaction properties of soil that might be more suitable for definite applications. For instance, the Scheffe mix design method entails developing unique soil mixtures using various constituent components and analyzing their laboratory compaction characteristics. This strategy can lead to more effective engineering by allowing them to adjust soil properties to specific project requirements [32].

4. Result and discussion

4.1 Characterization of test materials

The grain size distribution of the test soil from the laboratory experiments is represented as plotted in *Fig. 3*. From the obtained sieve analysis results, 80.5–6.15% are passing through sieve sizes of 2 mm–75 m, respectively. Tracing through the semi-log plot, the coefficients of gradation are derived as shown in *Eq. 39–41*. The obtained results indicate poorly graded silty clayey soil particles [33].

4.1.1 Test soil

$$C_u = \frac{D_{60}}{D_{10}} \quad (39)$$

$$C_c = \frac{{D_{30}}^2}{D_{60} \times D_{10}} \quad (40)$$

Coefficient of curvature $C_c = \frac{0.35^2}{0.75 \times 0.2} = 0.82$; Coefficient of Uniformity $C_u = \frac{0.75}{0.2} = 3.75$ (41)

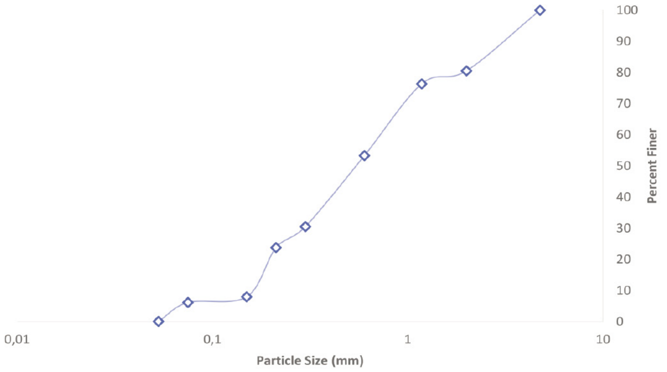

Fig. 3 Sieve analysis graph of the test soil
3. ábra A vizsgált talaj szitaelemzési grafikonja

The obtained laboratory results further showed that the soil has a specific gravity of 2.21 and a plasticity index of 17.67, which explains the plastic behavior of the sample soil. The AASHTO/USCS [34, 35] classification is A-7-6/CL, which indicates poorly graded silty clay soil with loose sedimentary materials and tiny rock particles. Applying the Atterberg limits in Casagrande's plasticity chart, the clay mineral identified is an inorganic clay of low plasticity. This soil type is rated poor for foundation and pavement construction purposes; hence, the need for stabilization. Also, the California bearing ratio test carried out on the soil sample showed a bearing capacity of 5.5%. These soil properties indicate inadequate conformance to the specifications of the Federal Ministry of Works for construction foundation materials [36, 37].

S/N	Properties	Standards	Result
1	Soil color	-	Reddish brown
2	Natural moisture content	BS 1377-2	23.4%
3	Specific gravity	BS 1377-2	2.21
4	% Passing sieve 0.075mm	BS 1377-2	6.15
5	Liquid limit	BS 1377-2	45.66
6	Plastic limit	BS 1377-2	27.99
7	Plasticity index	BS 1377-2	17.67
8	AASHTO /USCS classification	AASHTO 1986/ ASTM D 2487–11	A-7-6/CL
9	C.B. R	BS 1377-2	5.5%

Table 3 Properties of Sample soil
3. táblázat A talajminta tulajdonságai

The test for compaction showed the relationship between dry density and moisture content for different responses as shown in *Fig. 4* and *5* below.

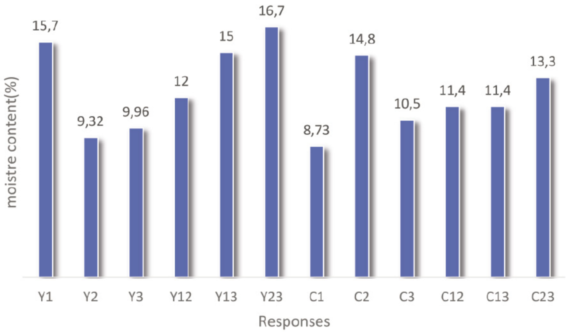

Fig. 4 Variations of Average Moisture Content
4. ábra Az átlagos nedvességtartalom változása

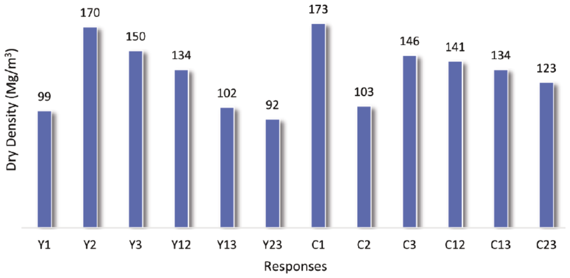

Fig. 5 Variations of Dry Density
5. ábra A száraz sűrűség változása

The derived laboratory results in comparison with the control experiment indicate a maximum average moisture content of 16.7% at experimental run Y_{23} and a minimum average moisture content of 9.32% at experimental point Y_2. Also, the dry density results obtained showed a maximum value of 170 mg/m³ at experimental point Y_2, and 92 mg/m³ at experimental run Y_{23} was recorded as the minimum value. Compaction property behavior can be said to show significant improvement at mix design experiment Y_{23}, which contains 35.81% kaolin, 9.09% water, and 55.10% test soil [38].

3.2 California Bearing Ratio (CBR)

The responses of the experimental, modelling and coefficients on the CBR exercise of the kaolin treated lateritic soil is represented in *Table 4* below.

Code	Z_1	Z_2	Z_3	Experimental response	X_1	X_2	X_3
Y_1	1	0.25	0.15	38.9	1	0	0
Y_2	1	0.55	0.16	76.6	0	1	0
Y_3	1	0.75	0.17	26.8	0	0	1
Y_{12}	1	0.4	0.155	59.1	0.5	0.5	0
Y_{13}	1	0.5	0.16	71.3	0.5	0	0.5
Y_{23}	1	0.65	0.165	68.1	0	0.5	0.5
C_1	1	0.68	0.166	58.7	0	0.333	0.667
C_2	1	0.50	0.159	70.0	0.25	0.65	0.1
C_3	1	0.64	0.165	68.4	0.1	0.3	0.6
C_{12}	1	0.43	0.157	71.3	0.6	0.1	0.3
C_{13}	1	0.58	0.162	75.5	0.1	0.6	0.3
C_{23}	1	0.38	0.154	60.6	0.65	0.25	0.1

Table 4 California bearing ratio responses from the experimental exercise and the model
4. táblázat Kaliforniai teherbírási arány a kísérletek és a modell alapján

The minimum condition for the use of a material as a Sub-base for pavement construction purposes in terms of CBR as stipulated by the Nigerian general specification for roads and bridges works volume III [39] to be 30% for sub-base. Based on the standard as stated, the peak value at 76.6% at mix design Y_2 for the unsoaked sample was recorded at a mix ratio of (1.00:0.55:0.16) for the sample soil, kaolin, and water respectively and thereafter there was a decrease in strength. Considering regression equation for the California bearing ratio from equ.33, 34, 35, 36, 37 and 38, and the experimental responses of the actual components, where.

$Y_1 = \beta_1 = 38.9$
$Y_2 = \beta_2 = 76.6$
$Y_3 = \beta_3 = 26.8$

And further substituting into *Eq. 36*, *37* and *38* for the values of β_1, β_2, β_3 respectively, the coefficients of the Scheffe's second-degree polynomials were as shown in *Table 5*.

Model coefficients					
β_1	β_2	β_3	β_{12}	β_{13}	β_{23}
38.9	76.6	26.8	5.4	153.8	65.6

Table 5 Coefficients of the Scheffe's second-degree polynomials
5. táblázat A Scheffe-féle másodfokú polinomok együtthatói

Further substitution of the values as shown in *Table 6* into *Eq. 32*, the values for the model responses were derived thus,

$$Y_{CBR} = 38.9x_1 + 76.6x_2 + 26.8x_3 + 5.4x_1x_2 + 153.8x_1x_3 + 65.6x_2x_3 \quad (42)$$

3.3 Test of adequacy of Scheffe's model developed

Eq. 42 is the modelled mathematical relationship to aid in optimization of California Bearing Ratio of kaolin stabilized Ikwo lateritic soil. Using the developed regression model in *Eq. 42*, the predicted results were determined and compared with the experimental test results to evaluate the prediction performance using the statistical methods ANOVA and the student's t-test [40, 41]. The compared and computed results are presented in *Fig. 6* and *Table 6*.

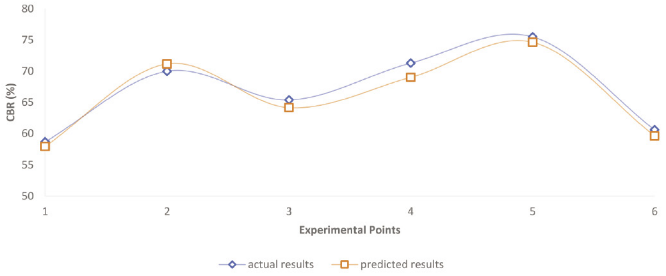

Fig. 6 Experimental and model predicted results
6. ábra A kísérleti és a modellel előre jelzett eredmények

s/n	Actual results	Predicted results
C_1	58.7	57.977
C_2	70.0	71.181
C_3	65.4	64.148
C_{12}	71.3	69.016
C_{13}	75.5	74.636
C_{23}	60.6	59.629

Table 6 Experimental and Scheffe's model predicted results
6. táblázat A kísérleti és a Scheffe-modell alkalmazásával előrejelzett eredmények

	Actual results	Predicted results
Mean	66.916	66.098
Variance	42.421	43.767
Observations	6	6
Pearson Correlation	0.985	
Df	5	
t Stat	1.776	
P(T<=t) one-tail	0.067	
t Critical one-tail	2.015	
P(T<=t) two-tail	0.135	
t Critical two-tail	2.570	

Table 7 Table t-Test statistical result
7. táblázat A t-teszt statisztikai eredménye

Scheffe's model is adequate for use in predicting the probable California bearing ratio strength properties of lateritic clayey soil-kaolin blend. The statistical model validation tests were carried out at 95% confidence interval using Microsoft Excel software. *P(T<=t)* two-tail of 0.1358 was obtained from the t-test and ANOVA respectively which indicates that the null hypothesis that there is no significant difference between the actual and Scheffe's models predicted values is accepted [42].

		SUMMARY				
Groups	**Count**	**Sum**	**Average**	**Variance**		
Actual results	6	401.5	66.916	42.421		
Predicted results	6	396.6	66.098	43.767		
Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	2.010	1	2.010	0.046	0.833	4.964
Within Groups	430.944	10	43.094			
Total	432.954	11				

Table 8 Table ANOVA results
8. táblázat ANOVA eredmények

4. Conclusions

Based on the results, the reddish shelly Ikwo lateritic soil was classified as A-7-6 according to AASHTO and CL (inorganic clay) in the unified classification system of soil, respectively. The following conclusions were drawn:

1. The lateritic soil sample is a problematic soil with a low plasticity index.
2. The kaolin sourced from Agbaghara Nsu in its natural state can be a good pozzolana.
3. The kaolin sourced from Agbaghara Nsu can serve as a good binder for the stabilization of Ikwo lateritic soil.
4. A Scheffe second degree polynomial was successfully used in formulating a model for the prediction of the CBR behavior of the stabilized Ikwo lateritic soil.
5. The optimum mixture design was achieved.
6. The models developed from this thesis work provided a very good prediction of the responses used, and as such, this model

can be used in making critical decisions concerning the CBR of soil samples having similar geotechnical properties.

7. The student T-test and analysis of variance (ANOVA) test were used to check the validity of the models, and the model was found to be adequate at a 95% confidence level.
8. It was also concluded from the T-test and ANOVA statistical results that the P-value of 0.83 further explains that there is no significant difference between the actual CBR value, and the Scheffe model predicted value.

4.1 Recommendations

The requirement for a sub-base material can be said to be adequately satisfied by Ikwo lateritic soil when it's treated with Kaolin sourced from Agbaghara Nsu in Imo State. However, the behavior of this same sample soil will likely differ with the application of kaolin gotten from other sources.

However, the recommendation of its adequacy as a sub-base material is based on the prediction of the Scheffe mix design of **1:0.55:0.16** for the soil, kaolin, and water, respectively.

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