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Evaluation on the Potential of Palm Oil Fuel Ash (POFA) as Partial Cement Replacement in Soil Stabilization in Cabambangan, Bacolor, Pampanga

John Edward M. Cañete[1], Erika B. Carreon[2], Pamela G. Castro[3], Ylaine Krazel M. Castro[4], John Michael Y. Cinco[5], Charls L. Cruz[6], Ma. Angelu S. Castro[7], Carl Jason A. Coronel[8]

[1](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: edwardcanete904@gmail.com)

[2](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: erikacarreon0109@gmail.com)

[3](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: pamelacastro0429@gmail.com)

[4](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: castroylaine@gmail.com)

[5](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: johnmichaelcinco678@gmail.com)

[6](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: charlscruz70@gmail.com)

[7](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: angelucastro.rce@gmail.com)

[8](*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga*
Email: cjacoronel@dhvsu.edu.ph)

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Abstract:

Driven by the need for sustainable construction solutions, this study investigates the potential of Palm Oil Fuel Ash (POFA) and ordinary Portland cement (OPC) as stabilizing agents for silty soil from Cabambangan, Bacolor, Pampanga. The soil, classified by AASHTO as A-4 (0), indicates very low geotechnical quality. To explore stabilization possibilities, various POFA to OPC ratios were tested at 1:13 (10%, 20%, 30%). Sieve analysis confirmed the soil as silty, with poor geotechnical properties. The study revealed significant improvements in geotechnical properties with POFA-OPC mixtures compared to the control. Standard Proctor Test (SPT) results showed an increase in Maximum Dry Density (MDD) from 1384.0 kg/m³ in pure soil to 1404.0 kg/m³ at 10% POFA. The Optimum Moisture Content (OMC) data from SPT was utilized in the California Bearing Ratio (CBR) test, which measured CBR swell and percentage. The findings indicate that adding stabilizers improved CBR values from 14% in pure soil to 67% at 10% POFA, with a swelling potential of 0.02%. However, increasing the stabilizer content to 20% and 30% resulted in reduced CBR values of 57% and 50%, respectively. This study highlights the potential of POFA and OPC in enhancing silty soil's geotechnical properties for construction applications.

Indexed Terms— Palm Oil Fuel Ash, Soil Stabilization.

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I. INTRODUCTION

Bacolor, Pampanga, a municipality in the Philippines, has been no stranger to adversity, particularly when Mount Pinatubo erupted in 1991. This disaster caused permanent changes in the local landscape, which resulted in burying its original natural grade line (NGL) 3 to 6 meters below the current ground surface [1]. Because of the problems with soil instability, the municipality of Bacolor has subsequently faced numerous difficulties with the construction of pavement and the development of infrastructure. It has been found that the Department of Public Works and Highways (DPWH) use soil stabilization techniques within the area to aid from these problems. However, because of these challenges, researchers found an opportunity for innovation and advancement. The primary goal of this study is to conduct a comprehensive experiment on the potential utility of Palm Oil Fuel Ash (POFA) as an environmentally sustainable and effective agent for soil stabilization in Bacolor, Pampanga, using soil samples collected from Barangay Cabambangan.

Palm Oil Fuel Ash (POFA) is a solid waste by-product generated when extracting palm oils in palm mills or power plants [2]. Due to the substantial growth the palm oil industry is experiencing, the accumulation of palm oil waste becomes a concern. Because of excess and inadequate waste handling, it has led to the aggravation of the country's waste issue. In the process of making palm oil, because the entire tree was utilized waste are formed from the mills, therefore seeing it as an abundant waste in the country [3].

Numerous research studies have found the potential of POFA because of its similar strength to cement [4]. By using this waste product as an admixture in concrete formulations, researchers have found that POFA enhances the strength of the resulting concrete, with improvements ranging from 2.5% to 20% [5] [6]. The categorization of lahar soil in Bacolor, Pampanga as silty soil, based from the data from Local Government Unit (LGU), was supported when the sample was analyzed. The American Association of State Highway Transportation Officials (AASHTO) categorization system determined that the sample fits into the A-4 (0) category, which denotes fair to poor quality. Soil that falls under this category is known to have poor geotechnical properties due to its low porosity, weak interparticle cementation, and loose structure [7]. As a result, the purpose of this research is to improve soil quality in Cabambangan, Bacolor, Pampanga by testing a combination of POFA and OPC, in specific percentages, which is to be used as a soil stabilizing element.

II. REVIEW OF RELATED LITERATURE

A. *Palm Oil Fuel Ash*

Palm Oil Fuel Ash (POFA) is a waste by product produced upon the extraction of palm oils in palm plantation mills. In the Philippines, the South Cotabato region homes the largest and main producer of palm oil with an estimated area of 58,769 hectares of Oil Palm Plantation. The amount of POFA produced may vary depending on different factors such as the scale of palm oil production, processing method, and industry practices [10]. Different researchers explore the different potential uses of POFA to minimize the solid waste generated by the different palm oil mills. Currently, POFA is used as a construction material in producing concrete. However, excessed or unused POFA from palm mills is being disposed at the dumpster.

POFA is one of the solid wastes produced when extracting palm oils in power plants. Due to abundance and lack of proper waste management, it contributed to the growing waste problem of the country, for every 100 tons of palm materials, around 52 tons of solid waste is produced. POFA is a pozzolanic material that can be used as a replacement for cement in producing stronger yet cheaper concrete [12].

Soil stabilization is very expensive. Therefore, the researchers need to utilize the available resources that are cost-effective to develop a material that will aid the problem regarding soil stabilization. With that, the researchers decided to incorporate POFA as a stabilizing agent. It is a residual or engineering by-product generated after oil removal in palm oil mills that possesses a high amount of silica oxide and has a pozzolanic property that can be potentially used as a replacement for cement which is commonly used as a stabilizing agent. Additionally, incorporating POFA decreases the cement needed in soil stabilization which results in less greenhouse gas emissions, reduces energy consumption, and lessens the production cost.

B. *Palm Oil Fuel Ash (POFA) as Cement Replacement*

POFA is a waste by-product that is abundant in Southeast Asian countries. This material is found to have a large amount of silica oxide and is considered to have a pozzolanic property that can be potentially used as a replacement for cement. In the year 1990, it was first used in Malaysia as a partial replacement for cement in producing concrete. They replaced 10%-60% of the total weight of the cement by POFA and concluded that replacing 20% of the cement weight produced more durable concrete as compared with a pure cement (OPC). Despite the amazing properties of POFA, palm oil mills dispose of it in an open space besides palm oil mills without any control [13].

A certain study was conducted to investigate the effectiveness of POFA, a solid waste by-product as a substitute for cement in producing a concrete. The study was conducted by replacing a fractional amount of cement with POFA by 2.5%, 5%, 10%, 15%, and 20%. The results are then compared with control group that is entirely made from OPC. The result shows a significant result by replacing 2.5% and 5% of the cement weight as compared with the 100% OPC [14].

Cement is one of the most common materials used to stabilize the soil due to its advanced composition. On the second column of this table shows the components of cement. And, Calcium oxide is the major component of cement and it is of 60–65% of cement composition. On the other hand, the components of POFA make it suitable for soil stabilization. Although, this material has a low percentage of calcium oxide, silica and alumina had the major role in this pozzolanic reactivity which helps to increase the engineering properties of the soil.

C. *Soil*

Soil is an essential component of the natural environment that offers an important medium for the growth of plants, water supply regulators, and the natural environment of numerous species [15]. Volcanic mudflows or debris flows, are commonly referred to as lahar soil. It has exceptional movement, crossing valleys and steep volcanic terrain over long distances. Lahars present problems in areas where volcanic activity is common, like Bacolor, Pampanga, where primary and secondary lahars are brought by volcanic eruptions and pyroclastic deposits triggered during heavy rainfall. These lahars' observable properties such as flow speed, temperature, and triggering events like rainfall, are critical for understanding and controlling the associated risks. Lahars come in a different viscosity from thick, viscous slurries look similar wet concrete (known as debris flows) or more fluid, mostly mud and sand with the consistency of motor oil (known as highly concentrated flows.) Those two types of flows regularly take place in all types of mountain terrain across the world. They originate in volcanoes, the most extensive, where both unstable rock debris and exceptionally large volumes of water can be mobilized.

In particular, the lahars that resulted from the 1991 eruption of Mount Pinatubo in the Philippines are the subject of this study because of their distinctive characteristics and extensive effects. Understanding volcanic soils - including their implications - is important, as demonstrated by the hundreds of lives and enormous economic loss caused by lahars. It is evident from studies on the particle size distribution of new lahar materials including their impact on the natural environment that lahars, which are created by volcanic eruptions, significantly change soil properties and landscape [19].

The study provides knowledge and information regarding soil dynamics and the long-term effects of volcanic risks on the ecosystem. It serves as sufficient context for a centered study on lahars. Depending on the amount of sediment present, Mount Pinatubo lahars had varying traits that affected their behavior and effects [20].

D. *Soil Stabilization*

Clay-rich soils, when dry, are stiff but lose this stiffness when saturated. Soft clay has low compressive strength and settles significantly. Moisture reduces soil strength, risking damage to buildings and foundations. These soils have inadequate load-bearing capabilities, requiring enhancement through stabilization methods. Worldwide, damages from expansive soils are estimated at about $1 billion in the USA, 150 million euros in the UK, and significant amounts in other countries annually [21]. Soil stabilization enhances soil properties by integrating cementing agents or other materials with natural soil. This method aims to improve various characteristics by increasing soil shear strength, thereby enhancing its bearing capacity. It modifies soil to enhance physical attributes, engineering qualities, and overall performance while reducing soil permeability and compressibility within Earth structures [22].

Different soil stabilization techniques like the grouting and injection method and deep mixing method (DMM) consist of additives or chemical processes. DMM is best used for soft soil and employs a mechanized process using a rotating mixing tool to blend a dry binder thoroughly, triggering an immediate reaction [27]. Injecting specialized fluid materials into the ground in suspension or solution is also a process of stabilizing the soil namely stabilization through grouting. This method is best used for soils that is highly permeable uses stabilizers with high viscosity to decrease void spaces and improve the soil's load-bearing capacity [28]. The grouting and injection method which is particularly applicable to lahar soils in Bacolor, wherein it serves to decrease voids and increase the soil's load-bearing capacity, highlighting the specific needs of this type of soil.

To reinforce road pavement sections with weak soil subgrade, the cement stabilization technique can be applied. This involves initially loosening the topsoil by scarifying the top 6–8 inches using a tiller. In a study conducted in Ground Improvement Case Histories, pavement stabilization is achieved by mixing the cement stabilizer with the topsoil using a tiller. The initial soil mixing should involve no fewer than six passes. Subsequently, uniformly spraying water over the entire mixed soil is necessary [30].

III. METHODOLOGY

A. *Research Design*

The researchers aim to incorporate POFA as a partial cement replacement to stabilize and improve the SBC of Cabambangan, Bacolor, Pampanga. This study will be an experimental research design, a method of conducting experiments based on scientific evidence involving two variables [31]. The researchers will replace a portion of cement with a certain percentage of POFA with cement (10%, 20%, and 30%) to determine its effect on soil. Thus, a series of laboratory tests will be performed which are the Atterberg Limit Test, Standard Proctor Test (SPT), and California Bearing Ratio (CBR) Test.

B. *Materials*

The materials required for the experiment includes Palm Oil Fuel Ash (POFA), lahar soil, and Ordinary Portland Cement (OPC). The soil samples were retrieved from Cabambangan, Bacolor, Pampanga, while palm trees that were used in making POFA was gathered from various palm tree plantations in Bacolor, Pampanga.

C. *Tools and Equipment*

The following tools and equipment were used by the researchers to perform the experiment; Digital Weighing Scale; Oven; Proctor

Compaction Test Equipment; Sieve Analysis Set Equipment; California Bearing Ratio (CBR) Mold Set; and California Bearing Ratio (CBR) Test Machine.

D. *Preparation of Materials*

Palm trees was obtained from different areas around the municipality and the province of Pampanga. The researchers adapted the procedure based from an article of Zafar. The palm oil fuel ash underwent various processes to be finely powdered. After gathering a sufficient amount of dry palm tree, the researchers burned these to create a fine powder. After cooling down the palm tree ash, the final step involved removing impurities and excess dirt using a strainer [33].

E. *Design Mixture of Specimen*

Soil samples were collected from our chosen locale, Cabambangan in Bacolor, Pampanga, specifically around the DHVSU jeepney terminal area. Researchers gathered the lahar soil from the ground surface or the top layer of soil in the DHVSU jeepney terminal, ensuring a sufficient amount was collected and utilized throughout the testing process. The concept of incorporating POFA in soil stabilization was adopted on several studies where it emphasizes its pozzolanic property in concrete. A study was conducted to identify the capacity (SBC) of the soil which was accumulated in Pandeglang District Banten using CBR as a parameter. The non-organic clay soil has a CBR value of 3.524%. Through the incorporation of 20% fly ash and 20% steel slag, the CBR value has increased 26.14% based on laboratory test [37]. Based on that, the researchers designed the samples to have 10%, 20%, and 30% of POFA-infused cement by the soil weight.

Table 1. Proposed Stabilizing Design Mixture

Materials	Percentages of Materials Per Specimen (%) (1:13 cement to soil ratio)			
	1	2	3	4
Soil	100%	100%	100%	100%
OPC	0%	6. 93%	6.16%	5. 39%
POFA	0%	0.77%	1.54%	2.34%

Table 2. Design Mixture for Atterberg Limit Test

Materials	Percentages of Materials Per Specimen (%) (1:13 cement to soil ratio)			
	1	2	3	4
Soil	100g	100g	100g	100g
OPC	0g	6. 93g	6.16g	5. 39g
POFA	0g	0.77g	1.54g	2.34g

Table 3. Design Mixture for Standard Proctor Test

Materials	Percentages of Materials Per Specimen (%) (1:13 cement to soil ratio)			
	1	2	3	4
Soil	6000g	6000g	6000g	6000g
OPC	0g	415.8g	369.6g	323.4g
POFA	0g	46.2g	92.4g	138.6g

Table 4. Design Mixture for California Bearing Ratio (CBR) Test (Soaked)

Materials	Percentages of Materials Per Specimen (%) (1:13 cement to soil ratio)			
	1	2	3	4
Soil	8000g	8000g	8000g	8000g
OPC	0g	554.4g	492.8g	431.2g
POFA	0g	61.6g	123.2g	184.8g

F. *Test procedures*

This study introduces POFA as an alternative soil stabilizer to increase the bearing capacity of lahar soil. The main objective is to substitute the traditional cement to POFA with soil stabilization in Cabambangan, Bacolor, Pampanga. The study employs testing align by the American Society for Testing and Materials (ASTM) International, the ASTM D698, ASTM D1883, and ASTM D4318-00, guaranteed the accuracy in methods and complying with standards. With these tests, it will provide data regarding soil's mechanical, plastic and shear properties [16].

The California Bearing Ratio (CBR) Test, Atterberg Limit Test and the Standard Proctor Test

(SPT) are three laboratory procedures which offers data about the mechanical and physical characteristics of soils. The SPT defines the maximum unit weight of a specific type of soil through applying the controlled compaction force and determining its optimal water content. Atterberg Limit test indicate its moisture content at which soil reaches its plastic and liquid limit. The CBR Test examine the soil's capacity to withstand loads. Those tests contribute in providing data in assessing soil's compatibility with different engineering uses like understanding the capacity of the soil for carrying loads.

IV. RESULTS AND DISCUSSION

In this study, the results from the Sieve Analysis, Standard Proctor test, and California Bearing Tests are summarized and established the following findings:

Table 5. Atterberg Limit, Compaction, CBR Swell and CBR Test Results

Sample	AASHTO Soil Clas.	Soil Type	MDD Kg/m³	OMC %	CBR Swell %	CBR %
Specimen 1	A-4(0)	Silty Soil	1384.0	17.5	0.02	14
Specimen 2			1404.0	17.75	0.02	67
Specimen 3			1395.0	21	0	57
Specimen 4			1377.0	20.30	0	50

Based on sieve analysis, the result shows that the soil specimen (pure soil) was categorized as A-4 (0) and classified as Silty Soil under the AASHTO soil classification. Silty soils are fine-grained soils where the particle size falls between sand and clay. It is best suited for gardening due to its water retention properties [39]. However, due to its poor engineering properties such as low strength, low stiffness, and compaction problems, it is not suitable for building foundations. Silty soils have poor draining ability making the soil shift and expand, which may result in structural failure. Therefore, chemical stabilization takes place to enhance the engineering characteristics of silty soils [40]. Prior to this study, the researchers used OPC and POFA to improve the lahar soil (Silty Soil).

The Atterberg Limit Tests didn't push through because during the soil grading process, the soil sample is discovered to be non-plastic having a Liquid Limit (LL) and Plastic Index (PI) of 0% and it was classified as Silty Soil A-4 (0) according to the AASHTO Classification System. This classification has a fair to poor quality that is not ideal for building foundation construction.

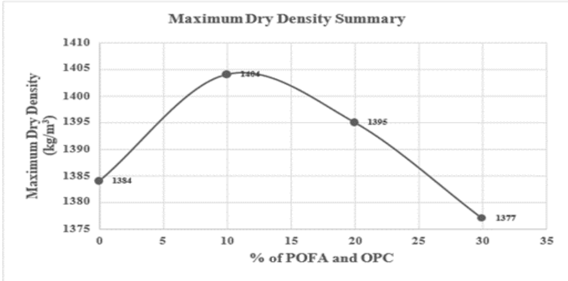

Fig. 1. Maximum Dry Density Summary

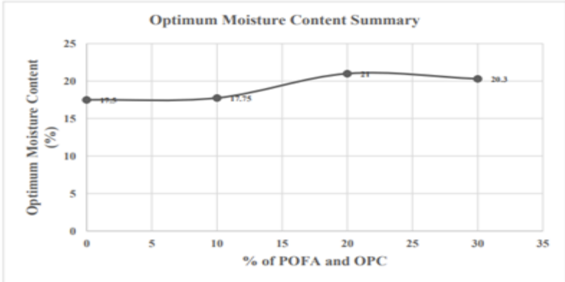

Fig. 2. Optimum Moisture Content Summary

In the Standard Proctor Test (SPT), the researchers identified the MDD and OMC of the specimens. The highest MDD occurs in the second specimen, which contains 10% POFA and OPC. However, it declines on the third and fourth specimens having 20% and 30% of POFA and OPC. On the other hand, the OMC from the first to the third specimen increases continually but declines in the fourth specimen.

The first specimen has less weight compared to the other soil sample because it has 0% POFA and OPC. Regardless, comparing it with the other three specimen shows an improvement, specifically in the second specimen which consists of 10% POFA and OPC. However, the percentage of OPC is greater than that of POFA since based on the 1:13 ratio, the amount of POFA added was 10% while 90% consisted of OPC. Therefore, the inclination of the MDD and OMC on the second specimen was mainly because of OPC since it is commonly used in chemical stabilization.

The value of MDD in the third and fourth specimens declines because of the amount of POFA added. In the third specimen, the researchers added 20% POFA and 80% OPC based on the ratio 1:13. However, the difference between the value of the MDD and OMC in the four specimens is minimal.

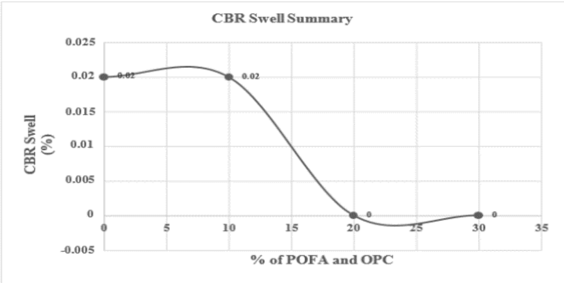

Fig. 3. California Bearing Ratio Swell Summary

The figure above shows the CBR swelling of the four specimens, showing that the accumulated number only ranges from 0% to 0.2%. On the first specimen with 0% POFA and OPC, the CBR swell percentage is 0.02. The second specimen with 10% POFA and OPC has the same swell as the first sample, which is 0.02%. However, on the third and fourth specimens, the swell percentage declines to 0%, respectively.

In building a pavement, various parameters must be considered to ensure its safety and stability. The CBR value is essential that must be assessed before building a pavement or any structure. It is a crucial engineering property of soil for designing the subgrade of rural roads. Factors such as MDD and OMC are necessary for determining the CBR value of the soil. According to a study conducted in Baghdad, Iraq, the estimated CBR values is directly proportional to the ultimate bearing capacity of a soil. This means that higher CBR values correspond to higher soil bearing capacity [18].

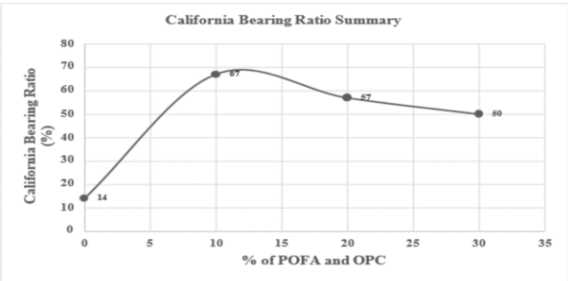

Fig. 4. California Bearing Ratio Summary

The California Bearing Ratio (CBR) test based from the experiment has CBR value ranges from 14% to 67% for the four specimens. On the first specimen (pure soil), the CBR is 14%. It increased on the second specimen (10% POFA and OPC) as it became 67%. It declines on the third specimen (20% POFA and OPC) and fourth specimen (30% POFA and OPC) which are 57% and 50%.

In terms of CBR, there is a huge difference between the controlled specimen and the specimens with additives. Based on the personnel of the Department of Public Works and Highways (DPWH) Region III - Quality Assurance and Hydrology Division (QAHD), the CBR value for embankment soils is low, therefore the addition of POFA and OPC on the specimens shows a significant improvement. However, the increase in value is possibly from the addition of OPC since it is usually used to enhance the bearing capacity of soil.

A study from Anambra State was performed to determine the effectiveness of cement in stabilizing silty soil (A-2-6). The percentage of cement used were 0%, 5%, 5.5%, 6%, 6.5%, 7%, and 7.5% [19]. The table below shows the result of the CBR values for different percentages of cement stabilization.

% of Cement Added	0	5	5.5	6	6.5	7	7.5
Quantity of Soil, g	6000	6000	6000	6000	6000	6000	6000
Quantity of Cement, g	0	300	330	360	390	420	450
CBR Values, %	15	27	33	50	86	111	122

Table 6. CBR Values for Different Percentages of Cement Stabilization

The researchers utilized a 1:13 ratio for the quantity of soil and stabilizing agent. The said ratio is equivalent to 7.7% of additives concerning soil. Based on the table above, the stabilization of soil with 7% and 7.5% cement accumulated CBR values of 111% and 122% [19]. Therefore, the use of pure cement to stabilize silty soil has a higher percentage of CBR values in comparison to POFA-infused specimens.

The addition of POFA in soil-cement stabilization, based on the result, decreases the CBR value of the specimens as the amount of POFA increases. Aside from that, the inclusion of POFA and OPC in lahar soil did not reach the minimum CBR value required for base stabilization which is 80%. Therefore, the inclusion of POFA on the specimens does not improve the bearing capacity of lahar soil (Silty Soil) in Cabambangan, Bacolor, Pampanga.

V. CONCLUSIONS

Bacolor, Pampanga was among the most highly affected during the Mount Pinatubo eruption. The natural grade line of the soil was buried meters deep from its original grade line. With that, the construction industry within the municipality encountered a series of problems due to soil issues. The researchers searched for a series of possible greener alternatives that can be used to aid this problem and they found the potential of using POFA. It is waste generated during the process of extraction of palm oil in power plants and factories. The researchers saw that POFA has similar properties to cement, adapting it as a chemical stabilization and incorporating it into OPC. The researchers utilized a combination POFA and OPC at various percentages to assess its effectiveness as soil stabilizers. A ratio of 1:13 was employed, with 1 part representing the stabilizing materials - consisting of 10%, 20%, or 30% POFA, and the remainder being OPC - to 13 parts soil. The soil stabilization experiment undergone testing procedures, specifically the Standard Proctor Test (SPT) and California Bearing Ratio (CBR) Test. Sieve Analysis was also conducted in order to determine the soil type of the targeted locale**.**

Through sieve analysis, it has been found that the soil sample collected from Cabambangan, Bacolor, Pampanga falls under the silty soil A-4 category of the AASHTO classification system. This classification indicates that the soil has fair to poor quality and it is ideal for utilizing different geotechnical techniques and approaches.

The results of the SPT and CBR test showed significant improvement with the use of OPC, indicating its effectiveness as chemical stabilizing element. While the addition of POFA did not significantly impact the quality of silty soil in Cabambangan, Bacolor, Pampanga, this research provides valuable and additional insights into the use of OPC for soil stabilization. This research also opens opportunities for additional research exploration of POFA's potential applications in other studies.

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