Universidad Continental

FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Civil

Tesis

Stabilization of Clay Soils in the Optimization of Urban Subgrade Using Common Glass, Tarma-Peru

Stefany Milagros Mucha Marticorena
Gaby Noely Ordaya Aliaga
Vidal Victor Calsina Colqui

Para optar el Título Profesional de
Ingeniero Civil

Huancayo, 2025

Repositorio Institucional Continental
Tesis

Esta obra está bajo una Licencia "Creative Commons Atribución 4.0 Internacional" .

INFORME DE CONFORMIDAD DE ORIGINALIDAD DE TRABAJO DE INVESTIGACIÓN

A	:	Decano de la Facultad de Ingeniería
DE	:	Calsina Colqui Vidal Victor Asesor de trabajo de investigación
ASUNTO	:	Remito resultado de evaluación de originalidad de trabajo de investigación
FECHA	:	24 de Marzo de 2025

Con sumo agrado me dirijo a vuestro despacho para informar que, en mi condición de asesor del trabajo de investigación:

Título:
Stabilization of Clay Soils in the Optimization of Urban Subgrade Using Common Glass, Tarma - Peru

URL / DOI:
https://www.hrpub.org/journals/article_info.php?aid=14667 **/** 10.13189/cea.2025.130124

Autores:
1. Mucha Marticorena Stefany Milagros – EAP. Ingeniería Civil
2. Ordaya Aliaga Gaby Noely – EAP. Ingeniería Civil
3. Calsina Colqui Vidal Victor – EAP. Ingeniería Civil

Se procedió con la carga del documento a la plataforma "Turnitin" y se realizó la verificación completa de las coincidencias resaltadas por el software dando por resultado 18 % de similitud sin encontrarse hallazgos relacionados a plagio. Se utilizaron los siguientes filtros:

	SI	NO
• Filtro de exclusión de bibliografía		X
• Filtro de exclusión de grupos de palabras menores N° de palabras excluidas **(en caso de elegir "SI")**:		X
• Exclusión de fuente por trabajo anterior del mismo estudiante		X

En consecuencia, se determina que el trabajo de investigación constituye un documento original al presentar similitud de otros autores (citas) por debajo del porcentaje establecido por la Universidad Continental.

Recae toda responsabilidad del contenido del trabajo de investigación sobre el autor y asesor, en concordancia a los principios expresados en el Reglamento del Registro Nacional de Trabajos conducentes a Grados y Títulos – RENATI y en la normativa de la Universidad Continental.

Atentamente,

La firma del asesor obra en el archivo original
(No se muestra en este documento por estar expuesto a publicación)

Civil Engineering and Architecture 13(1): 391-400, 2025 http://www.hrpub.org
DOI: 10.13189/cea.2025.130124

Stabilization of Clay Soils in the Optimization of Urban Subgrade Using Common Glass, Tarma - Peru

Stefany M. Mucha Marticorena*, **Gaby N. Ordaya Aliaga**, **Vidal V. Calsina Colqui**

Faculty of Civil Engineering, Universidad Continental, Peru

Received August 22, 2024; Revised November 6, 2024; Accepted November 24, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Stefany M. Mucha Marticorena, Gaby N. Ordaya Aliaga, Vidal V. Calsina Colqui , "Stabilization of Clay Soils in the Optimization of Urban Subgrade Using Common Glass, Tarma - Peru," Civil Engineering and Architecture, Vol. 13, No. 1, pp. 391 - 400, 2025. DOI: 10.13189/cea.2025.130124.*

(b): *Stefany M. Mucha Marticorena, Gaby N. Ordaya Aliaga, Vidal V. Calsina Colqui (2024). Stabilization of Clay Soils in the Optimization of Urban Subgrade Using Common Glass, Tarma - Peru. Civil Engineering and Architecture, 13(1), 391 - 400. DOI: 10.13189/cea.2025.130124.*

Copyright©2025 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract The present study aimed to analyze the stabilization of clay soils for the optimization of urban subgrades through the use of common glass in the province of Tarma, Peru. An experimental design methodology was employed, with 5 test pits excavated for soil extraction. Recycled glass was used, ground, and added in varying percentages of 0%, 10%, 20%, 30%, and 60%. An observation sheet was used to record all relevant data. The results indicated that the SiO_2 content in the glass was 71.166% and the CaO content was 25.683%, with Si (53.355%) and Ca (41.355%) being the predominant elements. Regarding Maximum Dry Density (MDD), the highest value was recorded with the addition of 20% ground glass (1.987 g/cm^3). Additionally, the Optimum Moisture Content (OMC) decreased as the percentage of added glass increased. Concerning the California Bearing Ratio (CBR) at 100% of the MDD, the maximum value was observed with 20% glass addition (17.8%), indicating that the subgrade is of good quality. Finally, the ANOVA analysis showed an F-statistic value of 267.1722 and a p-value of 0.00, suggesting statistically significant differences between the groups with different percentages of glass addition. It was concluded that the addition of ground glass improves the density and moisture providing an effective solution for the stabilization of clay soils in terms of sustainability and performance.

Keywords Maximum Dry Density, Optimum Moisture Content, CBR, Clay Soils, Glass

1. Introduction

Challenging geographical conditions, such as steep slopes and unstable soils, can complicate road construction, necessitating the use of advanced topographical techniques and geological surveys to identify and resolve issues, ensuring safe construction [1]. Soil stabilization generally improves its physical, mechanical, and strength properties, ensuring long-term durability. Designing a stabilization method with additives involves classifying the soil, selecting the type and quantity of stabilizer, and determining the appropriate stabilization process. The design method depends on the intended use of the stabilized soil. It is challenging to establish standard stabilization patterns, particularly with the wide range of pavement design methods available [2].

Clay, upon drying, undergoes shrinkage and cracking, which can lead to uneven settlements in buildings. Therefore, it is crucial to implement effective waterproofing techniques. Despite the challenges posed by clayey soils, with proper knowledge and the application of appropriate mitigation techniques, it is possible to prevent the associated problems [3].

Across the globe, there are millions of kilometers of paved roads that deteriorate over time. In response to this challenge, researchers are investigating the use of recycled materials as a sustainable option to enhance road systems. In the United States, researchers at the Mizzou Asphalt Pavement and Innovation Laboratory are utilizing recycled materials for road repairs. This approach not only promotes the sustainability of asphalt mixtures but also contributes to environmental preservation by preventing the leaching of waste into the surroundings [4].

In Latin America and the Caribbean (LAC), public mass transit enhances access to employment and education, leading to increased income for the population and contributing to poverty reduction. Despite these benefits, LAC faces significant challenges compared to leading countries in transport infrastructure. In OECD nations, the average road length per square kilometer of land area is 1.3 kilometers, whereas in LAC, it barely reaches 0.5 kilometers. Moreover, the quality of road infrastructure in the region is significantly below the standards of leading countries. For instance, in Brazil, most roads are unpaved, resulting in considerable maintenance costs, which are often inefficient due to a lack of technical skills and appropriate technology [5]. Consequently, there is an increasing need to implement improvements in paving materials.

In the Peruvian context, the diverse geomorphology, varying climates, and heavy traffic contribute to a more rapid deterioration of roads, as pavements must withstand extreme conditions [6]. Therefore, it is crucial to utilize soils that can be maximized and possess characteristics that ensure safe paving. However, the presence of deficient subgrades in various areas can lead to ruts, fatigue, and cracks on the surface [5].

Tarma, located in a region characterized by conglomerate lithology with the presence of silt-clay lenses [7], faces specific challenges regarding soil stabilization for urban infrastructure. Therefore, optimizing subgrades through the use of common glass as a stabilizing material presents an opportunity to enhance the strength and durability of local roads, as well as to address the issues of subsidence and deformation associated with the clayey soils in the area.

As a result, studies such as the one by Ouslimane et al. [8] demonstrated that the addition of glass to clay reduces swelling and compaction indices. Similarly, in the study by Ogundairo et al. [9], where glass was used as a soil stabilizer to assess the mechanical strength of clayey subgrade soils, an improvement in durability was observed, along with a 125% increase in the California Bearing Ratio (CBR). Furthermore, the study by Behboudi et al. [10] showed that the addition of recycled glass powder for soil stabilization led to a reduction in soil dispersion, an increase in plasticity index, and an increase in the maximum dry density of the soil. In line with this, the study by Nategh et al. [11] employed recycled glass from photovoltaic panels to enhance the properties of clayey soils, demonstrating improved strength and stiffness when 12% glass powder was used. Additionally, Attom et al. [12] in their research utilized crushed glass for the stabilization of clayey soils, showing that treatments with 5% and 8% glass reduced internal erosion and increased critical shear stress.

The research aims to address the challenges posed by clayey soils in the Tarma region, an area characterized by its complex geography and extreme climatic conditions. Under these conditions, clayey soils tend to experience shrinkage and cracking, which can lead to issues in infrastructure construction, such as uneven settlements and accelerated deterioration of roadways. The study explores the use of recycled glass as a stabilizing material to enhance the strength and durability of urban subgrades. The addition of glass not only has the potential to improve the mechanical properties of the soil, such as moisture stability but also offers a sustainable solution by utilizing recycled materials, thereby contributing to environmental preservation. Previous studies have demonstrated that recycled glass can reduce swelling, increase the California Bearing Ratio (CBR), and improve the maximum dry density of the soil. These studies include Ouslimane et al., who evidenced a reduction in swelling indices and improved soil compaction; Ogundairo et al., who reported a 125% increase in CBR when using glass as a stabilizer; Behboudi et al., who showed an enhancement in maximum dry density and a reduction in soil dispersion with the use of recycled glass powder; Nategh et al., who found improvements in soil strength and stiffness with a 12% addition of recycled glass powder; and Attom et al., who documented a reduction in internal erosion and an increase in critical shear stress with the addition of crushed glass. This research seeks to apply these findings to the specific context of Tarma, offering an effective and eco-friendly solution for the region's pavement challenges.

2. Materials and Methods

The scientific method was employed in this study, following a series of systematized procedures [13], in order to generate new knowledge through the use of common glass to stabilize clayey soils, thus optimizing urban subgrade.

2.1. Research Scope

This study adopted an explanatory scope, as its purpose extended beyond the mere description of details or concepts; it aimed to elucidate the causes underlying events and phenomena in social and physical environments [14]. Consequently, specific data on the chemical, physical, and mechanical properties of clayey soils treated with common glass were employed to determine their effectiveness in improving urban subgrade.

2.2. Type of Research

The applied research type involved the application of theoretical knowledge to benefit the groups involved in the processes and society at large, as well as to contribute to the advancement of the field [15]. Therefore, this study was categorized under this modality, as it used practical principles to stabilize clayey soils through the application of common glass, generating results that effectively supported the achievement of the study's objectives and provided a solution for enhancing urban subgrade.

2.3. Research Design

The factorial experimental design is a type of design in which the effects of two or more factors, as well as their interactions, on one or more variables of interest are studied simultaneously. In this type of design, each level of one factor is combined with each level of the other factors, allowing for the analysis of both the individual effect of each factor and their interactions [16]. Thus, the factorial design was employed in this study, as illustrated in Table 1, to investigate the effects of various glass dosages on different samples of clayey soils.

Table 1. Experimental Design

Clay soil	Glass dosage	Treatment	Repetitions				
			I	II	III	IV	V
Test pit 1	0%	Control (t)	t I	t II	t III	t IV	t V
Test pit 2	10%	a	a I	a II	a III	a IV	a V
Test pit 3	20%	b	b I	b II	b III	b IV	b V
Test pit 4	30%	c	c I	c II	c III	c IV	c V
Test pit 5	60%	d	d I	d II	d III	d IV	d V

2.4. Procedures

2.4.1. Material Acquisition

The study area was surveyed to define the research points, and subsequently, 5 test pits were excavated to a depth of 1.50 meters. Soil samples were collected from each test pit and sent to a laboratory for separate characterization to enhance the reliability of the experiment. Laboratory tests included granulometry, plastic and liquid limits, moisture content, classification according to AASTHO and SUCS, stratigraphic profiles, modified Proctor tests, CBR tests, and chemical analyses of salts, chlorides, and sulfates.

The glass was obtained from waste generated by a glass factory, including materials from the production of trophies, windows, and bottles of various shapes (such as beer, soda, and wine bottles). Approximately 140 kg of waste was collected, washed with high-pressure water to remove impurities, and then dried for 24 hours. Initial crushing was done manually using a mallet, followed by further crushing to obtain finer particles. The crushed material was sieved through No. 50, No. 100, and No. 200 meshes. Finally, the material retained in the No. 200 mesh was subjected to chemical analysis using X-ray fluorescence (XRF), as illustrated in Figure 1.

2.4.2. Material Mixing

For the mixing of clay soils with ground glass, proportions of 0%, 10%, 20%, 30%, and 60% by dry weight of the clay soil were used, resulting in five different combinations. The clay soil samples were dried in an oven until a constant mass was achieved, and each sample was mixed with a specific amount of ground glass until a homogeneous mixture was obtained. Subsequently, each sample was stored in transparent bags. Finally, the various mixtures were sent to the laboratory for analysis, which included granulometric testing, plastic and liquid limits, moisture content, and classification according to the Peruvian Guide Indecopi: Gp:004: 1993 [17], ASTM D1883 [18] and NTP 339.175 [19] and NTP 339.141 [20], stratigraphic profiles, CBR and modified Proctor tests, as well as chemical analysis of salts, chlorides, and sulfates, with five repetitions for each sample.

Figure 1. Laboratory Testing

2.5. Techniques and Instruments for Data Collection and Analysis

The observation technique refers to the reliable, systematic, and valid recording of situations and behaviors that occur [21]. Therefore, this technique was employed in the research to collect data on the mechanical and physical characteristics resulting from the combination of glass powder with clay soil, as well as data obtained from the corresponding laboratory analyses. The observation sheet, as an essential instrument, allowed the researcher to systematically focus on the true subject of study and served as a foundation for guiding the collection of information about the observed phenomena. Consequently, in the research, this instrument was used to gather data on various variables such as granulometry, liquid and plastic limits, moisture content, concentration of salts, chlorides, and sulfates, as well as the California Bearing Ratio (CBR) for clayey soils and the modified Proctor test, all based on the specifications outlined in the MTC Materials Testing Manual.

To analyze the information collected through experimentation and laboratory analysis, the primary tools employed were Excel and R Studio spreadsheet programs. These programs featured specific formats that were tailored to each of the processes conducted in the study.

3. Results

3.1. Chemical Characteristics of Glass

The identified particle size was 75 µm; furthermore, the chemical components are described below.

Figure 2 illustrates the chemical composition of glass in terms of oxides. Silicon dioxide (SiO_2) constitutes 71.166% of the composition, indicating that silica is the primary component, contributing to both transparency and strength. Calcium oxide (CaO) comprises 25.683%, enhancing the glass's durability and chemical stability. Iron oxide (Fe_2O_3) at 1.291% may affect the color of the glass, imparting a greenish or yellowish hue. Potassium oxide (K_2O) at 0.827% aids in durability and lowers the melting point, while sulfur trioxide (SO_3) at 0.566% functions as a clarifying agent. Barium oxide (BaO) at 0.183% and strontium oxide (SrO) at 0.06% increase density and improve optical properties. Titanium dioxide (TiO_2) at 0.128% enhances UV radiation resistance, and manganese oxide (MnO) at 0.031% serves as a decolorizing agent. Zinc oxide (ZnO) at 0.024% contributes to corrosion resistance, whereas chromium oxide (Cr_2O_3) at 0.022% affects the green color and chemical resistance. Copper oxide (CuO) at 0.011% imparts blue or green hues, and rubidium oxide (Rb_2O) at 0.008% can slightly influence thermal and electrical properties. Collectively, these components provide the glass with durability, chemical resistance, and specific optical properties. These findings are consistent with the study conducted by Hordieiev and Amelina [22], which identified SiO_2 as constituting 60%.

Figure 3 displays the chemical composition of glass expressed in terms of elements. Silicon (Si) accounts for 53.355%, indicating a high amount of silica responsible for the rigidity and transparency of the glass. Calcium (Ca) represents 41.355%, improving chemical resistance and durability. Iron (Fe) at 2.446% may affect glass coloration and UV radiation resistance. Potassium (K) at 1.442% contributes to durability and lowers the melting point. Sulfur (S) at 0.458% is associated with the use of clarifying agents, while barium (Ba) at 0.305% and strontium (Sr) at 0.145% increase density and enhance optical properties. Titanium (Ti) at 0.291% improves UV resistance, manganese (Mn) at 0.064% acts as a decolorizing agent, and zinc (Zn) at 0.049% adds corrosion resistance. Chromium (Cr) at 0.044% affects green coloration and chemical resistance, while copper (Cu) at 0.025% provides green or blue hues. Finally, rubidium (Rb) at 0.02% can slightly influence the thermal and electrical properties of the glass.

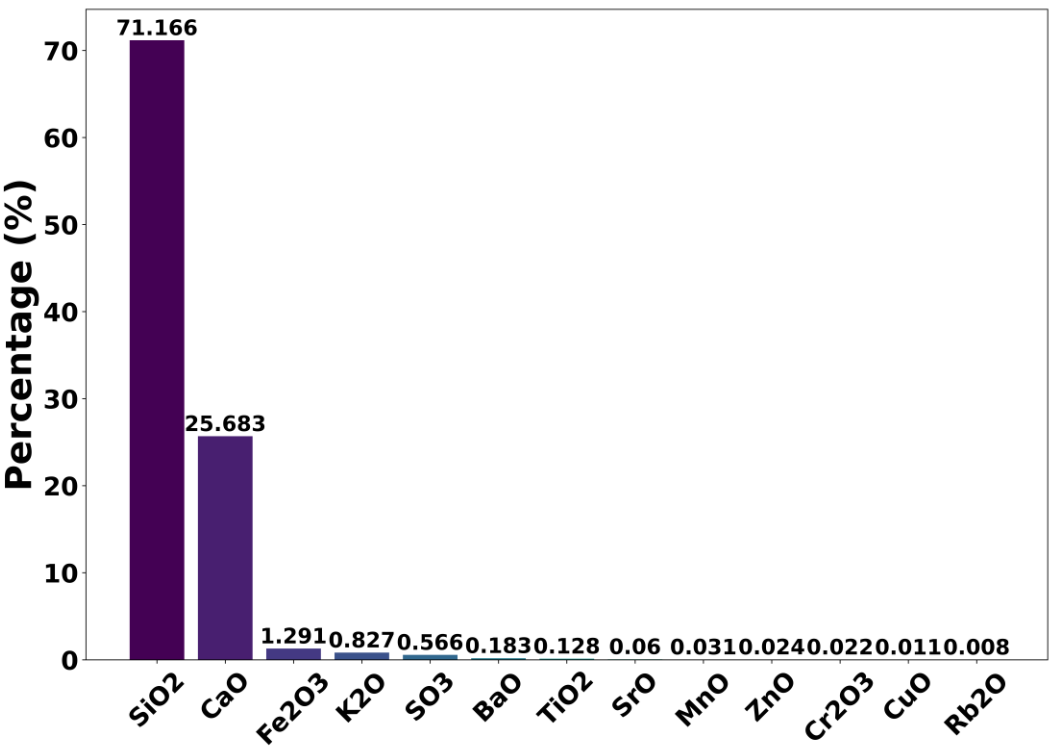

Figure 2. Chemical components expressed as oxides

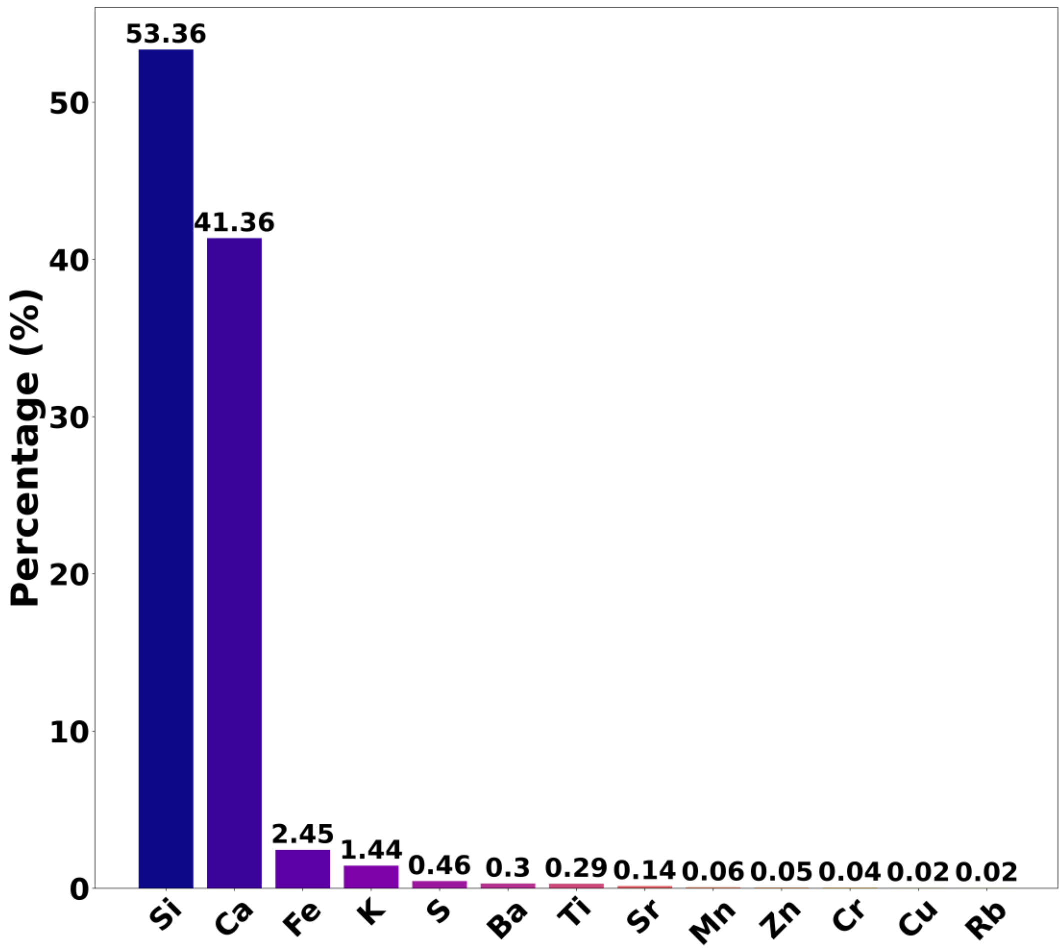

Figure 3. Chemical components expressed as elements

3.2. Physical and Chemical Characteristics of the Soil

Figure 4 illustrates the results of an analysis of soluble salts, soluble chlorides, and soluble sulfates in five test pits (C1 to C5), measured in parts per million (ppm). The concentrations of soluble salts range from 12,034 ppm in C1 to 13,208 ppm in C4, with C2 and C4 exhibiting the highest levels. Soluble chlorides vary from 4,202 ppm in C1 to 4,647 ppm in C2, with C2 having the highest concentration. For soluble sulfates, the values range from 6,324 ppm in C5 to 7,106 ppm in C2, with C2 showing the highest concentration. Overall, C2 exhibits the highest concentrations of salts, chlorides, and sulfates, suggesting a higher salinity in this test pit compared to the others.

3.3. Results of Maximum Dry Density (Proctor Test)

In Figure 5, the box-and-whisker plot demonstrates the impact of glass addition on the Maximum Dry Density (MDD). At 0% glass, the median MDD values are low, indicating a relatively low material density. As the glass content increases to 10% and 20%, there is a noticeable rise in the median MDD values, suggesting that the incorporation of glass enhances the maximum dry density of the material. However, at 30% glass content, the median values stabilize, indicating that the improvement in maximum dry density plateaus does not significantly increase with higher glass proportions. At a 60% glass content, the median MDD values show a slight decrease, which may suggest that excessive glass content could negatively impact the maximum dry density. In summary, the addition of glass increases the MDD up to a certain level, after which the maximum density stabilizes and may even decrease with higher additions. These findings align with Perera et al. [23], who demonstrated that the addition of crushed glass to clay soil resulted in an increase in MDD compared to the clay sample without additives. However, interestingly, increasing the glass content from 5% to 15% led to a decrease in MDD from 1.50 to 1.47 t/m^3. This is also consistent with Haro [24], who reported that at 8% experimental glass content, MDD values ranged from 1.890 to 1.990 g/cm^3. These results indicate that the maximum dry density of the material remains relatively constant across samples, with minor variations. This range should be considered to ensure adequate compaction and stability of the material in practical applications.

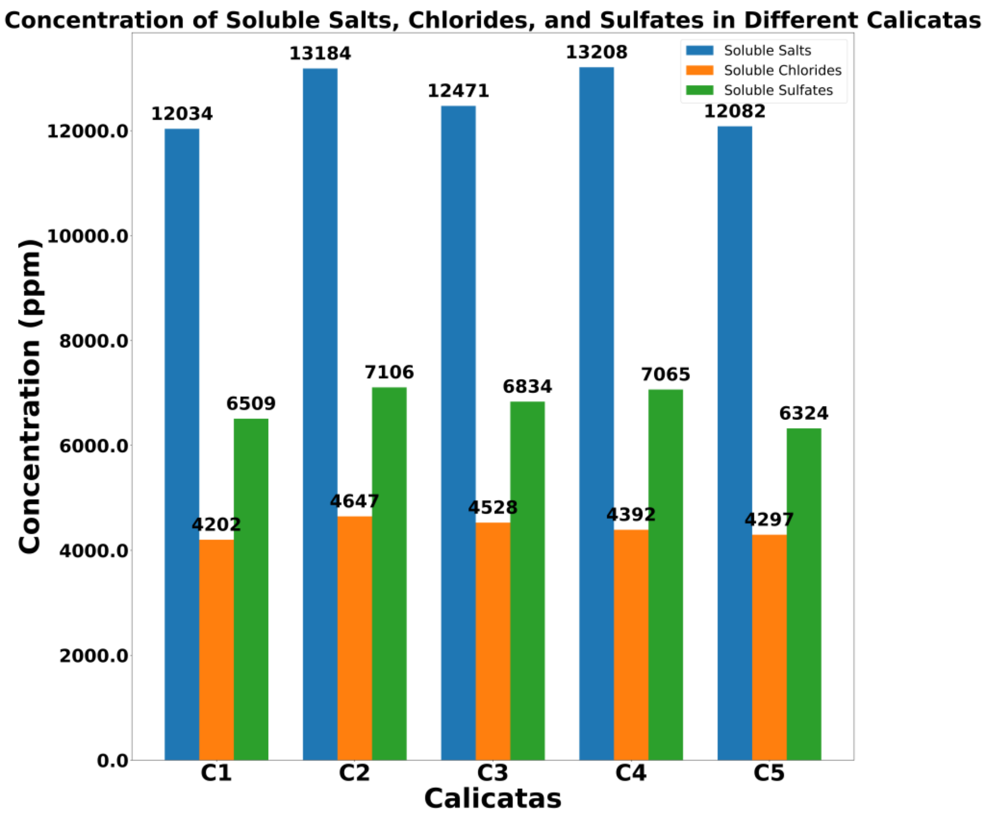

Figure 4. Chemical Components of the Soil

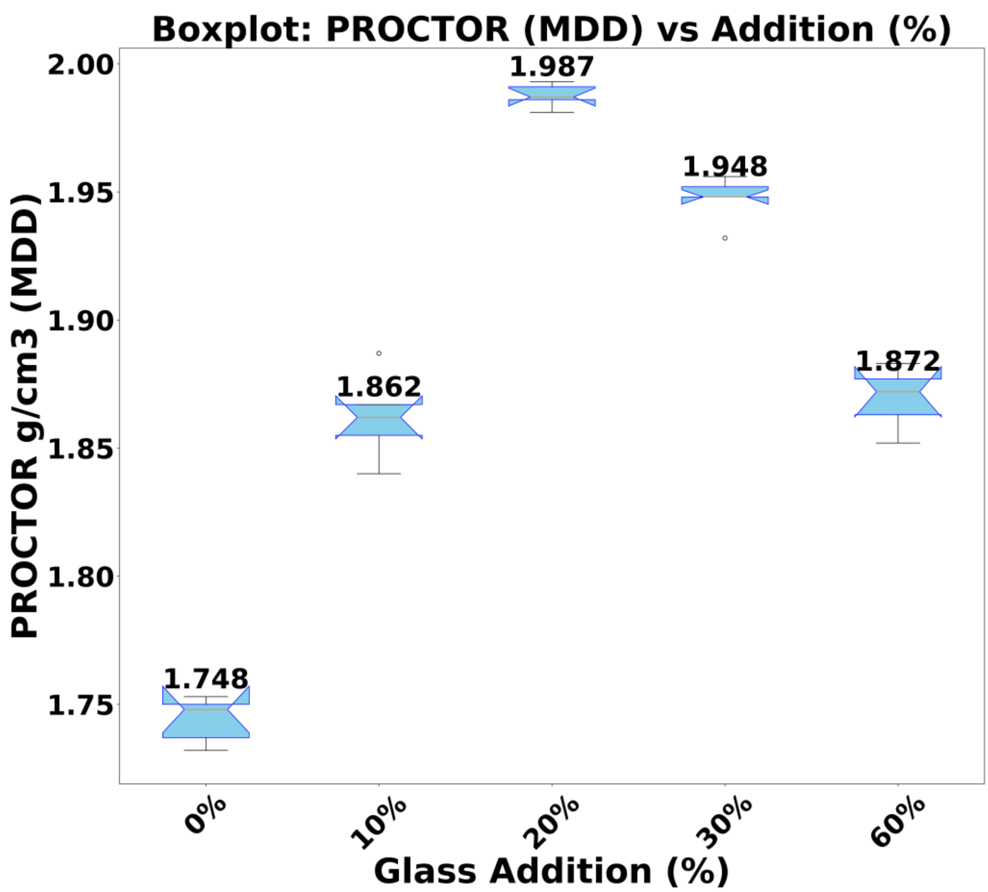

Figure 5. Proctor (MDD)

3.4. Results of Optimum Moisture Content (Proctor)

In Figure 6, the box-and-whisker plot of the optimum moisture content (OMC) is shown as a function of glass addition percentages. The data show that at 0% glass addition, the OMC is relatively high, with median values around 18.4%. As the glass addition is increased to 10%, the OMC significantly decreases to approximately 15.2%, indicating that the incorporation of glass reduces the amount of moisture required to achieve maximum compaction. This decrease continues with 20% and 30% additions, where the OMC further reduces to median values of 14.0% and 13.5%, respectively. At 60% addition, the OMC reaches its lowest value of 12.8%, suggesting that higher quantities of glass significantly lower the optimal moisture required. These findings align with Perera et al. [23], who identified that the incorporation of crushed glass into clay resulted in a decrease in the optimum moisture content (OMC); specifically, increasing the glass content from 0% to 20% reduced the OMC from 24.90% to 21.92%. This can be attributed to the lower water absorption capacity of glass compared to clay soil. The results are also consistent with Haro [24], who found that the analysis of the optimum moisture content at 8% revealed values ranging from 9.60% to 12.80%. Sample 2 exhibited the highest optimum moisture content, suggesting that this sample might require specific adjustments in the compaction process. These data are crucial for adjusting moisture conditions during material preparation to optimize its performance properties.

3.5. CBR Results (100% of MDS)

In Figure 7, the box-and-whisker plot shows how glass addition affects the California Bearing Ratio (CBR) at 100% Maximum Dry Density (MDD). With 0% glass addition, the median CBR values are relatively low, ranging from approximately 4.2% to 5.6%, indicating a subgrade with low capacity. As the glass addition increases to 10%, the median CBR values improve significantly, reaching around 8.6% to 9.6%, although they still do not fall within the range considered good (10% ≤ CBR < 20%). At 20% glass addition, the median CBR values rise to approximately 17.6% to 18.4%, entering the optimal range for a good subgrade. However, at 30% addition, the CBR decreases slightly, with median values ranging from 13.7% to 14.7%.

With 60% glass addition, the CBR further decreases, with median values ranging from 10.9% to 13.8%, suggesting that higher amounts of glass can reduce the subgrade’s capacity, though it remains within an acceptable range. Overall, the addition of glass improves CBR up to a certain point, with 20% addition being optimal, but higher amounts may lead to decreased effectiveness. These findings are consistent with Ikara et al. [25], who determined that the addition of ground glass resulted in an approximately 407.5% increase in CBR value. This is also related to the findings of Karami et al. [26], where the addition of an optimal soil stabilization mix consisting of 25% glass powder, 7.5% fly ash, and 3% lime, compared to raw soil, helped control moisture fluctuation and optimize. Similarly, Perera et al. [23] observed that these values stayed within the range of good subgrade quality, while noting an improvement in CBR with the incorporation of glass into expansive clay. As the glass content increased from 5% to 15%, the CBR value rose from 13.6% to 18.1%. However, further glass addition (20%) resulted in a decrease in CBR, reducing it to 15.8%. The increase in CBR with glass addition is attributed to greater friction between glass and clay particles, as well as the compact packing of glass with clay particles. These findings also align with Haro et al. [24], who determined that the CBR at 100% MDD for samples 1, 2, 3, and 4 was 30.20%, 29.20%, 29.10%, and 29.80%, respectively, suggesting that these CBR values are classified in the very good subgrade category.

3.6. Hypothesis Testing

Table 2 shows that the ANOVA test revealed an F-statistic of 267.1722 and a p-value of 0.0000, indicating statistically significant differences among the groups with varying percentages of glass addition. This result suggests that different levels of glass addition significantly impact the CBR, with at least one group showing a notable difference compared to the others. Given the extremely low p-value, the null hypothesis of equal means is rejected, underscoring that the addition of glass has a significant influence on the CBR.

The results indicate that all compared group pairs exhibit significant differences in their CBR means, with a p-value less than 0.05 for each comparison. Overall, CBR decreases with an increase in the percentage of glass addition, with the highest additions (20%, 30%, and 60%) showing significantly lower values than the lower percentages (0% and 10%). This suggests that an increase in the glass percentage tends to reduce the subgrade's CBR.

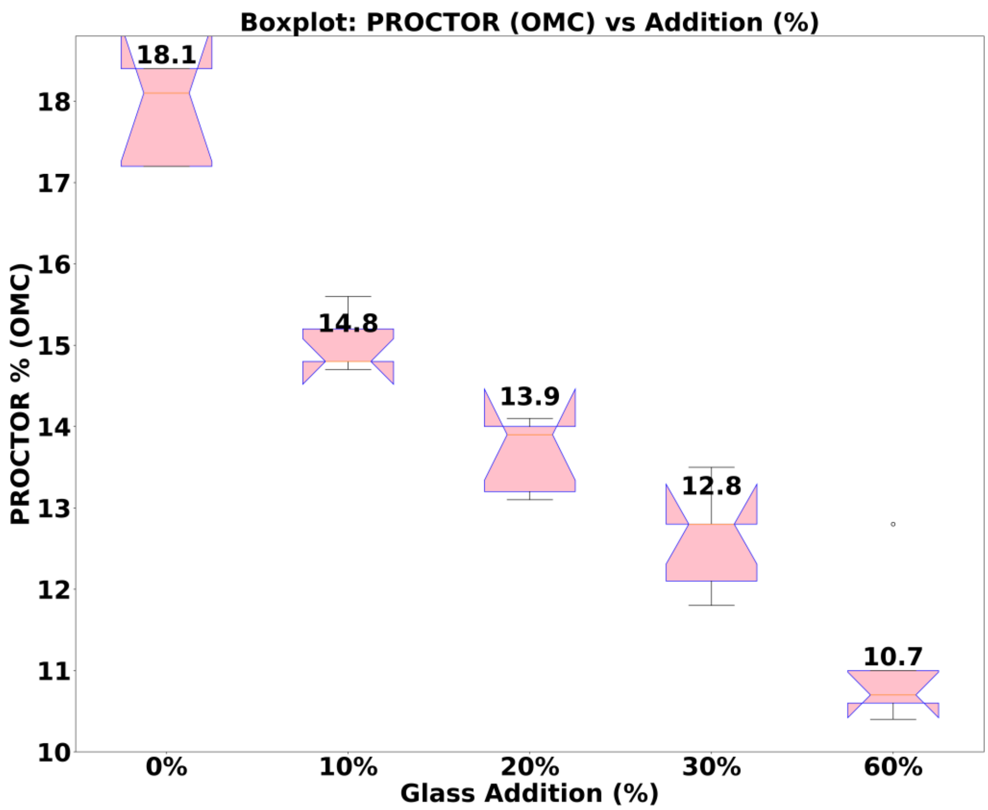

Figure 6. Optimum Moisture Content

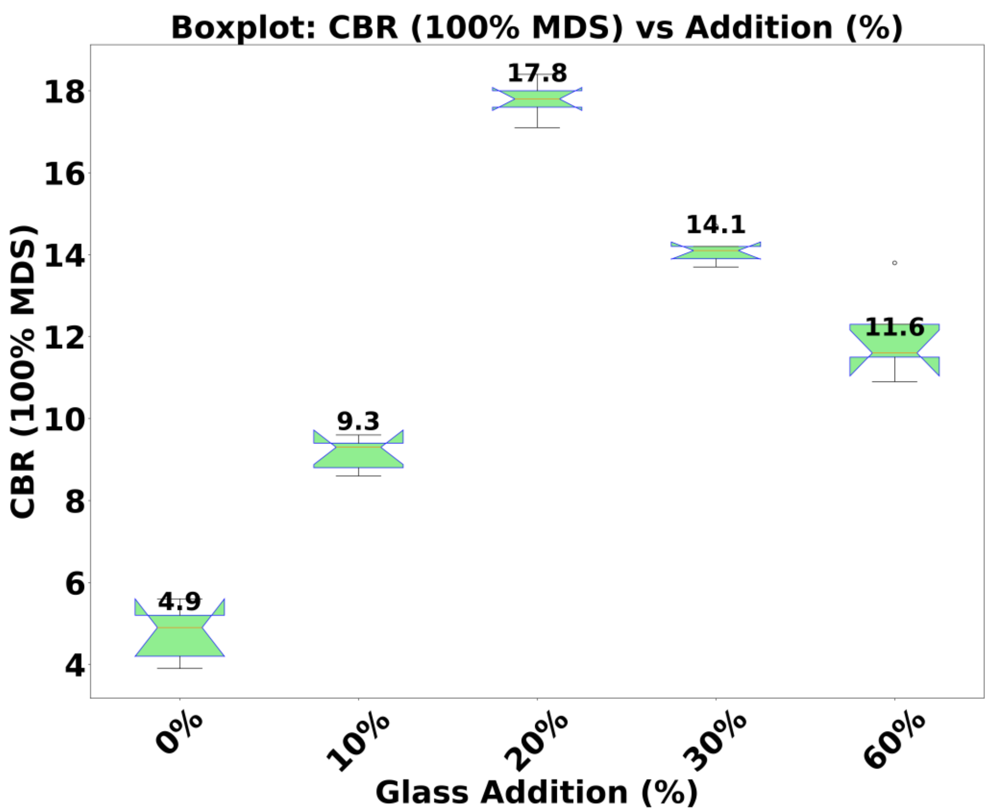

Figure 7. CBR (100% of MDS)

Table 2. Tukey Test

Multiple Comparison of Means - Tukey HSD, FWER=0.05						
Group1	**Group2**	**mean diff**	**p-adj**	**lower**	**upper**	**reject**
0%	10%	4.38	0.0	3.1014	5.6586	True
0%	20%	13.02	0.0	11.7414	14.2986	True
0%	30%	9.36	0.0	8.0814	10.6386	True
0%	60%	7.26	0.0	5.9814	8.5386	True
10%	20%	8.64	0.0	7.3614	9.9186	True
10%	30%	4.98	0.0	3.7014	6.2586	True
10%	60%	2.88	0.0	1.6014	4.1586	True
20%	30%	-3.66	0.0	-4.9386	-2.3814	True
20%	60%	-5.76	0.0	-7.0386	-4.4814	True
30%	60%	-2.1	0.0	-3.3786	-0.8214	True

4. Conclusions

The integrated analysis of Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR) reveals that the percentages of glass addition have a significant impact on soil properties. In terms of MDD, the 20% addition demonstrated an optimal balance, enhancing soil density without excessively compromising the CBR. Regarding OMC, the glass addition percentages reduced the optimum moisture content, with 0% showing the highest values and 60% the lowest, suggesting that higher glass additions decrease the soil's moisture retention capacity. Finally, the CBR analysis indicated that while the 10% glass addition exhibited a significantly higher load- capacity compared to the higher percentages, the 20% provided the best balance between strength and durability, resulting in the most favorable CBR value among the analyzed percentages. Collectively, these results suggest that a 20% glass addition is the most balanced percentage for optimizing soil density, moisture content, and load-bearing capacity, offering an effective solution for stabilizing clayey soils in terms of sustainability and structural performance.

Therefore, future research should explore the use of glass in other clay soils, considering different compositions and environmental conditions to further evaluate its impact on soil stabilization, aiming for sustainable and structural improvements.

Acknowledgements

We would like to express our sincere gratitude to all those who contributed to this study and the completion of this analysis. We deeply appreciate the support and collaboration of our colleagues, as well as the valuable guidance of our advisors.

REFERENCES

[1] I. S. L. E. Constructora, "The Main Problems in Building a Road," Involucra SL, https://involucrasl.es/los-principales-problemas-al-construir-una-carretera/ (accessed Aug. 18, 2024).

[2] J. Alarcón, M. Jiménez, and R. Benítez, "Stabilization of soils through the use of oily sludge Estabilización de suelos mediante el uso de lodos aceitoso," Scielo, vol. 35, no. 1, pp. 5–20, 2020, Accessed: Oct. 06, 2024. [Online]. Available: www.ricuc.cl

[3] Gallaecia, "Expansive Clay: Problem and Solution," Obras Gallaecia, https://www.obrasgallaecia.com/arcilla-expansiva-problema-y-solucion/#:~:text=La (accessed Aug. 18, 2024).

[4] Ecoticias.com, "Roads Paved with Plastics and Tire Waste," Ecoticias, https://www.ecoticias.com/residuos-reciclaje/carreteras-pavimentadas-con-plasticos-y-desechos-de-neumaticos (accessed Aug. 18, 2024).

[5] K. Fonseca, Y. Becerra, and S. Muñoz, "Use of Stabilizers for Clayey Soils: A Literature Review," Journal of Engineering Research, vol. 50, no. 50, pp. 54–69, 2020. DOI: 10.47864/SE(50)2020p54-69.

[6] U. de Lima, "Pavements in Peru: New Challenges and Technologies," University of Lima, https://www.ulima.edu.pe/pregrado/ingenieria-civil/noticias/pavimentos-en-el-peru-nuevos-retos-y-tecnologias (accessed Aug. 18, 2024).

[7] M. P. de Tarma, "Urban Development Plan 2014-2024," Municipal Government of Tarma, https://eudora.vivienda.gob.pe/observatorio/PDU_MUNICIPALIDADES/TARMA/PDU (accessed Aug. 18, 2024).

[8] N. Ouslimane et al., "Optimization of Glass Scrap Recovery and Reuse in Road Construction for Promising Physicochemical Stabilization," Scientific Reports, vol. 14, no. 1, p. 12925, Dec. 2024. DOI: 10.1038/s41598-024-62862-x.

[9] T. Ogundairo, D. Olukanni, and I. Akinwumi, "Geopolymer Production from Waste Polyethylene Terephthalate and Glass for Clay Subgrade Stabilization," Journal of Solid Waste Technology and Management, vol. 50, no. 1, pp. 441–457, Dec. 2024. DOI: 10.5276/JSWTM/ISWMAW/501/2024.441.

[10] M. Behboudi, A. A. Zad, M. Yazdi, and A. Tohidi, "Effect of Cellulose Nanofibers and Recycled Glass Powder on the Geotechnical and Microstructural Parameters of Dispersive Soil," Bulletin of Engineering Geology and the Environment, vol. 83, no. 7, p. 290, Jul. 2024. DOI: 10.1007/s10064-024-03785-9.

[11] M. Nategh, A. Ekinci, A. Iravanian, and M. Fahrioğlu, "Enhancing Clay Soil's Geotechnical Properties Utilizing Sintered Gypsum and Glass Powder," Applied Sciences, vol. 14, no. 12, Jun. 2024. DOI: 10.3390/app14124961.

[12] M. F. Attom, M. M. Yamin, Z. Khan, and A. Eltayeb, "Stabilization of Clayey Soils Against Internal Erosion Using Cement-Crushed Glass Mixture," Lecture Notes in Civil Engineering, vol. 530, pp. 250–259, 2023. DOI: 10.1007/978-981-97-5311-6_25.

[13] M. Paragua, N. Bustamante, L. Norberto, M. Paragua, and C. Paragua, "Scientific Research: Formulation of Research Projects and Theses," 1st ed., National University of Hermilio Valdizan, 2022.

[14] R. Hernández, C. Fernández, and M. Baptista, "Research Methodology," 6th ed., McGraw-Hill Education/Interamericana Editores, 2014.

[15] Z. Vargas, "Applied Research: A Way to Understand Realities with Scientific Evidence," *Revista Educación*, vol. 33, no. 1, pp. 155–165, 2009.

[16] H. Gutiérrez and R. De la Vara, "Analysis and Design of Experiments", 2nd ed. Mexico: McGraw-Hill Education/Interamericana Editors, 2008.

[17] National Institute for the Defense of Competition and the Protection of Intellectual Property, "INDECOPI Peruvian Guide," Ministry of Construction and Sanitation, https://www.ingprecon.com/pdf/MC.pdf (accessed Aug. 18, 2024).

[18] ASTM International, "D1883 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils," ASTM International, https://www.astm.org/d1883-21.html (accessed Aug. 18, 2024).

[19] Peruvian Technical Standard 339.175, "Floors. Standardized in situ test methods for CBR (California Bearing Ratio - Bearing Value Relationship) of soils," Lima, 2002.

[20] Peruvian Technical Standard 339.141, "Floors. Test method for laboratory compaction using a modified energy (2700kN-m/m3 (56000 ft-lbf/ft3)," Lima, 2019.

[21] Hernández R., Mendoza C., "Methodology of Research," McGraw-Hill, 2018.

[22] Y. S. Hordieiev and A. Amelina, "Glass formation and properties of glasses in the system SrO–B2O3–SiO2–xAl2O3 (x=0; 10 MOL.%)", Voprosy khimii i khimicheskoi tekhnologii, vol. 2021, no. 5, pp. 43–49, 2021. DOI: 10.32434/0321-4095-2021-138-5-43-49.

[23] S. Perera, M. Saberian, J. Zhu, R. Roychand, and J. Li, "Effect of Crushed Glass on the Mechanical and Microstructural Behavior of Highly Expansive Clay Subgrades," Case Studies in Construction Materials, vol. 17, no. e01244, 2022. DOI: 10.1016/j.cscm.2022.e01244.

[24] L. Haro, M. Cerna, and A. Valdivieso, "Addition of Recycled Glass Powder in the Stabilization of Soils in AA.HH. Villa Hermosa, Nuevo Chimbote (Peru)," Revista Agunkuyâa, vol. 11, no. 2, pp. 22–28, 2021. DOI: 10.33132/27114260.1992.

[25] I. A. Ikara, A. M. Kundiri, and A. Mohammed, "Effects of Waste Glass (WG) on the Strength Characteristics of Cement Stabilized Expansive Soil," American Journal of Engineering Research (AJER), vol. 4, no. 11, pp. 33–41, 2015, Accessed: Aug. 18, 2024. [Online]. Available: www.ajer.org

[26] H. Karami, D. Robert, S. Costa, J. Li, S. Setunge, and S. Venkatesan, "Capa de cobertura a base de vidrio reciclado para cimientos en suelos expansivos," Lecture Notes in Civil Engineering, vol. 356, pp. 431–444, 2023. DOI: 10.1007/978-981-99-3330-3_44.