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Stabilization of local roads in the southeast of Guayas province

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ABSTRACT: The soils of rural roads in Guayas province are characterized by being clayey and expansive, causing problems for vehicular and pedestrian traffic. This research analyzes the use of gravel as granular material in its natural state and then combined with another aggregate of the same category for soil stabilization. A qualitative experimental procedure was conducted to obtain laboratory results from natural and combined samples.
After testing, soil properties were compared in both states, determining that a 50% dosage of each material improved the soil's physical-mechanical characteristics: reduced plasticity index, increased maximum dry density, and significantly improved bearing capacity, meeting MTOP guidelines for subgrade improvement with selected material.

KEYWORDS: soils, combination, stabilization, gravel, testing.

1 INTRODUCTION

Local and rural roads from ancient times, even today, continue to play a fundamental role in the development of a community, city, or country in all parts of the world, as this means is used for the transportation of their inhabitants as well as for merchandise from agricultural, livestock, and aquaculture activities. Therefore, it is vitally important that these unpaved roads have adequate mechanical and physical properties for their respective use.

The growing demand for road infrastructure requires high-quality materials, which are regularly difficult to obtain. In this scenario, there is a wide variety of construction options that include soil stabilization through the use of stabilizing agents that improve their engineering characteristics and make it a suitable medium for traffic. Alarcon et al (2020).

When plastic soils exist, an effective way to solve this problem is to subject natural soils to a process of manipulation or treatment to take advantage of their best qualities, obtaining a firm and stable soil that can resist traffic and the most extreme weather conditions, widely improving swelling, bearing capacity, and permeability. Hernandez et al (2016).

This research work is focused on the study of granular material, specifically gravel for the stabilization and improvement of local roads in the southeast of Guayas province, as it has been shown that these soils are of poor quality, which refers to their tendency to be expansive and have low bearing capacity.

Furthermore, these characteristics cause them to not meet the necessary requirements to be considered in paving projects as this would represent a high investment cost for the competent governmental entity without obtaining the expected benefits since the demand for the use of these roads is not sufficient.

The granular material to be used will be taken from a quarry near the study site to avoid increasing transportation costs that would entail extracting it from an external region. After knowing the properties of this soil, its improvement will be carried out through physical stabilization, so quarry ballast will be used to combine it. All of this will be carried out with the development of laboratory tests and methods such as: particle size, Atterberg limits, and soil classification by the SUCS and AASHTO system, modified Proctor, and finally CBR test.

The study material was obtained from the Chanchan River quarry in the Coronel Marcelino Maridueña city.

Fig. 1. Location of Chanchan River

2 HISTORICAL BACKGROUND

A study in Colombia addresses soil stabilization through the use of oily sludge. For this, two types of soils from the Tunja area were used; a granular material and a clayey subgrade soil. Both materials were characterized and then mixed with different amounts of oily sludge. Each mixture was subjected to various tests, including CBR tests and resilient modulus. The results showed that for the granular material, the optimal mixture was achieved with 6% sludge while for the subgrade using 4% of this substance. The necessary curing time was 26 days. These proportions optimized the strength and plasticity characteristics of both materials [1].

A research in Ecuador aims to stabilize different types of soils with different properties by adding steel slag extracted from the Ambato canton. The characterization included particle size, analysis and the determination of consistency limits, thus allowing soil classification according to the criteria established by SUCS. The results showed that the soil sample taken from the Pilisurco canton in Tungurahua is a sandy silt of low plasticity according to the classification established by the mentioned method, while the sample taken from Murialdo in Pastaza was a high plasticity clay according to the same classification method. It was concluded through CBR testing that there is a positive correlation between the increase in steel slag content and soil bearing capacity. This effect was significant in the sandy silt sample compared to the clay sample [3].

The research work carried out in Peru aims to evaluate the influence of a byproduct obtained from the burning of mineral coal and charcoal from a brick industry in the city of Chachapoyas in improving the mechanical properties of soil samples. The research showed that the addition of coal ash improved the mechanical properties of CH and OH type soils, although the CBR values achieved did not reach the minimum required 6% established by the road manual to be considered as suitable material for subgrade. The results showed that the increase in bearing capacity was directly proportional to the percentage of ash added, with the 25% dosage providing the best behavior for both types of soils [4].

An Ecuadorian investigation in the province of Manabí aims to determine the optimal percentage of lime and cement for subgrade stabilization. The work showed that the appropriate combination for soil stabilization was achieved with the addition of 2% lime and 4% cement, which reduced the plasticity index from 22.21% to 8.16% and increased CBR resistance up to 8.80%. Lime mainly contributed to the reduction of plasticity, while the subsequent addition of cement significantly improved the soil's bearing capacity compared to its natural state, which had a CBR of only 1% [5].

An article prepared in Peru aims to determine the influence of sodium chloride addition in subgrade stabilization in the road section between the town center of Primorpampa and the District of Cascapara. The results showed that the soil has an initial CBR value of 5.80%, while chemical stabilization through the addition of sodium chloride in proportions 1.50% - 3.00% and 4.50% generated CBR values of 6.30%, 6.50%, and 6.00% respectively. The optimal stabilizing percentage (3.00%) increased the CBR up to 6.50% at maximum dry density, improving the soil's bearing capacity and recategorizing it from insufficient subgrade to regular subgrade [6].

DEFINITION OF SOILS

It is defined as a three-phase system consisting of a matrix of non-cohesive mineral particles and decomposing organic material (solid phase), in conjunction with fluids and gases that occupy the void spaces between solid particles [2].

PROBLEMATIC SOILS

There is a great diversity of soils with very different physical and mechanical properties, among which some materials have been identified as difficult to handle due to their characteristics of deformability, low resistance, expansibility, and sensitivity, features that generate serious problems in the construction process and subsequent behavior of a pavement structure [7].

CLAY SOILS AND ORGANIC SOILS

The climatic conditions of the tropical zone with high humidity, high saturation percentages, and groundwater levels close to the surface often cause deposits of highly compressible soft clays to appear, as well as organic soils with poor characteristics [7].

VOLCANIC SOILS

There are soils that show problems in the grading and compaction procedure due to their moisture characteristics, susceptibility to remolding, and property changes in the drying process. These materials are formed by weathering in place of Quaternary volcanic ejecta, having particular properties such as high natural moisture contents and difficult-to-explain variations between sampling and testing. In addition to this, they have low unit weights, high void ratios, and moisture contents above the liquid limit, which are preserved during summer season, particularly in places above the water table [7].

EXPANSIVE SOILS

Expansive clay soils are characterized by their volumetric instability when faced with fluctuations in their moisture content. Their laminar structure experiences expansion during hydration and contraction during dehydration of the material. Additionally, these soils present low permeability due to their mineralogical composition [8].

SOIL BEARING CAPACITY

Bearing capacity is the parameter that quantifies soil resistance to deformations produced by vehicular loads. This property is mainly conditioned by shear strength, which is a function of the material's density and moisture content. There is an inverse correlation between the degree of saturation and bearing capacity, being lower in saturated soils because the increase in moisture content significantly reduces their mechanical resistance [9].

SOIL STABILIZATION

Soil stabilization is defined as the process of modifying the physical-mechanical properties of a material to increase its bearing capacity and resistance to design loads [10].

MECHANICAL STABILIZATION

Mechanical stabilization seeks to optimize in-situ soil properties through compaction processes, without altering its original mineralogical composition. This method increases material density through void ratio reduction, resulting in a significant improvement of its geotechnical parameters: greater shear strength, optimization in load distribution, reduction of susceptibility to volumetric changes, and minimization of differential settlements [11].

PHYSICAL STABILIZATION

Physical soil improvement can be achieved through three main methodologies: particle size stabilization (combination of different soil types), replacement of inadequate material with select material, and implementation of geo synthetics as structural reinforcement elements [11].

CHEMICAL STABILIZATION

Chemical stabilization consists of incorporating specific stabilizing agents, both in solid state (Portland cement, lime, fly ash, slag) and liquid, which when interacting with the soil generate chemical reactions that modify its physical-mechanical properties. This process seeks to optimize the material's response to cyclic loads, improving its structural behavior during the design period [7].

SUBGRADE IMPROVEMENT

Improvement can be done with selected soil that should be obtained from the excavation for the road platform. It has to be granular soil, rocky or combinations of both, and will have a particle size so that no more than 20% will pass through the No. 200 sieve, its plasticity index not greater than 9, liquid limit up to 35%, and CBR value greater than 10% [12].

WEARING COURSE

The upper layer of the pavement is called the wearing surface, which can be constructed with bituminous materials (considered flexible pavement), Portland cement concrete (called rigid pavement), or can be formed by pavers. Its main function lies in directly supporting loads from vehicular traffic [13].

3 METHODOLOGY

METHODS

The method to be applied in this research is of a quantitative experimental nature because laboratory tests will be carried out to obtain the values corresponding to various physical-mechanical properties of the soils that allow analyzing their suitability for use as material for subgrade improvement in soils located in the southeast of Guayas.

TECHNIQUES

The research will apply direct observation techniques and the use of standards for the execution of the corresponding soil tests, which are:

- Moisture Content, considering ASTM D 2216 - 19 standard.
- Particle size, using NTE INEN 154 and ASTM D 6913 - D 6913 M - 17 standards.
- Atterberg Limits, through ASTM D 4318 - 05 standard.
- Soil classification by USCS and AASHTO.
- Modified Proctor Test to obtain Maximum Dry Density along with Optimum Moisture, using ASTM D 1557 - 12 standard.
- California Bearing Ratio (CBR) considering ASTM D 1883 - 07 standard.

SOIL CHARACTERIZATION TESTS

The gravel samples to be used were extracted from the Guayas province, belonging to the Ecuadorian coast, specifically from the Chanchan River that crosses the Coronel Marcelino Maridueña canton. Once the material arrived at the soil laboratory, it was spread on the floor and mixed for proper homogenization. Since it is a granular soil, it was sieved and separated through the ¾" mesh into two groups, the passing and retained, in order to extract the larger-sized stones and proceed with the development of laboratory tests. The material samples were also homogenized and exposed to the environment for drying.

Fig. 2. ***Mixing of gravel samples***

Moisture content

The procedure consisted of selecting an empty metal container to which a sample of gravel and ballast was added, then weighed on the laboratory scale and recording this value corresponding to the mass of the container along with the wet soil. Afterward, this sample was taken to dry in the oven at a temperature of 110 ± 5 °C, for approximately 16 hours. Once this time had elapsed, the samples were removed from the oven and exposed to the environment for cooling. Finally, the sample was weighed again to determine the dry soil mass.

Particle Size

The particle size analysis was performed for two samples of each granular material. The test was carried out via wet method, for which the soil samples were washed with tap water and then left to dry in the oven.

Consistency Limits

Liquid limit

A liquid limit test was performed using the Casagrande cup. The material (gravel) was previously sieved through No.40 mesh according to the standard. Water was added until forming a homogeneous paste and placed in the cup with 1 cm thickness in the center. A groove was made with the grooving tool and blows were applied (2 per second) until the channel closed 13 mm. This process was repeated with 4 different samples, determining the moisture content of each one by weighing before and after oven drying.

Plastic limit

For the execution of this test, water was added to a sample of the soils in their natural state and then combined, which passed through No.40 mesh until it had a dense paste consistency with which long rolls of around 3 mm in diameter were molded. Then, these samples were weighed as in the liquid limit test, before and after being dried in the oven. However, molding the gravel sample that is composed of sand proved quite difficult as the small rolls broke in half, so several attempts were made to give them the desired shape.

Soil classification

Considering the data obtained through particle size analysis and Atterberg limits, soil samples will be classified using the USCS (Unified Soil Classification System) and AASHTO (American Association of State Highway and Transportation Officials) classification system.

Modified Proctor

Tests were performed with 6 kg gravel samples sieved through ¾" mesh, increasing water content in 2% increments. The material was compacted in a 6" cylindrical mold in 5 layers, applying 56 blows per layer with a 10 pound hammer. After leveling and weighing each compacted sample, the process was repeated until a decrease in weight was observed. Moisture content was determined by taking samples of the collar material before and after drying. The same procedure was applied to the ballast and subsequently to the combination of both materials.

California Bearing Ratio Test

Three samples of 6 kg each (gravel, ballast, and their combination) were prepared using the optimal moisture content determined in the modified Proctor test. Each sample was compacted in 5 layers in a 6" mold with different numbers of blows (12, 25, and 56) using a 10 pound hammer. The molds were submerged in water for 96 hours, monitoring swelling daily.

After this period, they were dried in ambient conditions for one hour and subjected to penetration tests with a piston. Loads were recorded for 1" and 2" penetrations (with standard loads of 1000 and 1500 pounds/in^2 respectively) to calculate CBR values. Finally, these values were plotted against dry densities to determine CBR at 95% and 100% compaction.

4 Interpretation Of Results

Particle size of soils in natural state

Gravel material.- The percentage of fines was less than 5%, therefore the sample requires a single classification symbol.

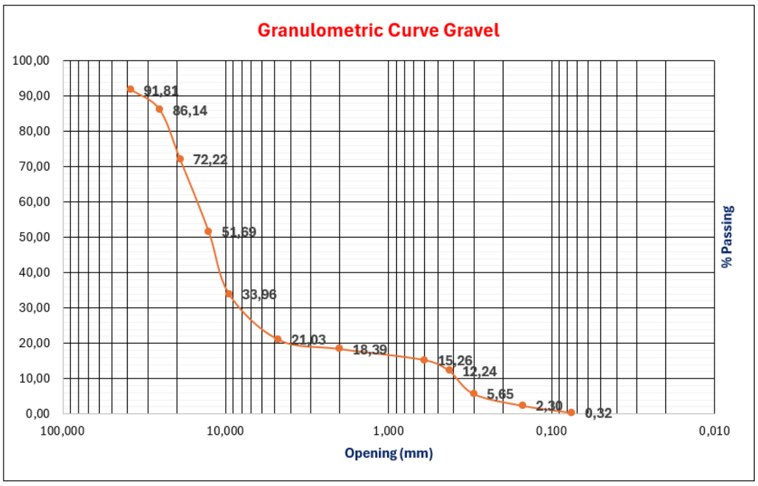

Fig. 3. Particle size - Distribution curve of Gravel

Lastre – Ballast.- Since this material contains a percentage of fines between 5% - 12%, then its classification will contain double symbols.

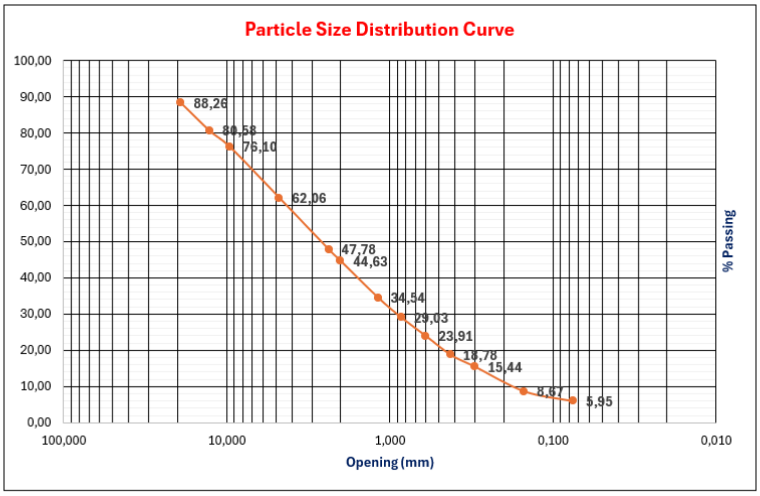

Fig. 4. Particle Size - Distribution curve of the Base Material

SOIL CLASSIFICATION

The gravel classification was carried out considering the particle size analysis and Atterberg limits. By the AASHTO method, the soil sample belongs to a granular material containing rock fragments, gravel, and sand, falling into group A-1-a (0), having a general subgrade classification of excellent to good material. On the other hand, the USCS method revealed that it is a coarse-grained soil, consisting of clean and poorly graded gravel with symbol GP.

Meanwhile, according to the AASHTO method, the ballast belongs to a granular soil with silt or clayey gravel and sand from group A-2-7 (0), with its general subgrade classification being excellent to good. By the USCS method, the material is a coarse soil of well-graded sands with low plasticity silts (SW-SM).

CBR OF GRAVEL AND LASTRE BALLAST IN NATURAL STATE

Once the values of maximum dry density and optimal moisture were known, the CBR test was carried out. In this section, 6 kg of sample was used for both gravel and ballast, with an optimal water amount of 240 ml and 360 ml respectively. After carrying out the process, the data with which the bearing capacity of the soils was calculated was recorded, which are presented as follows:

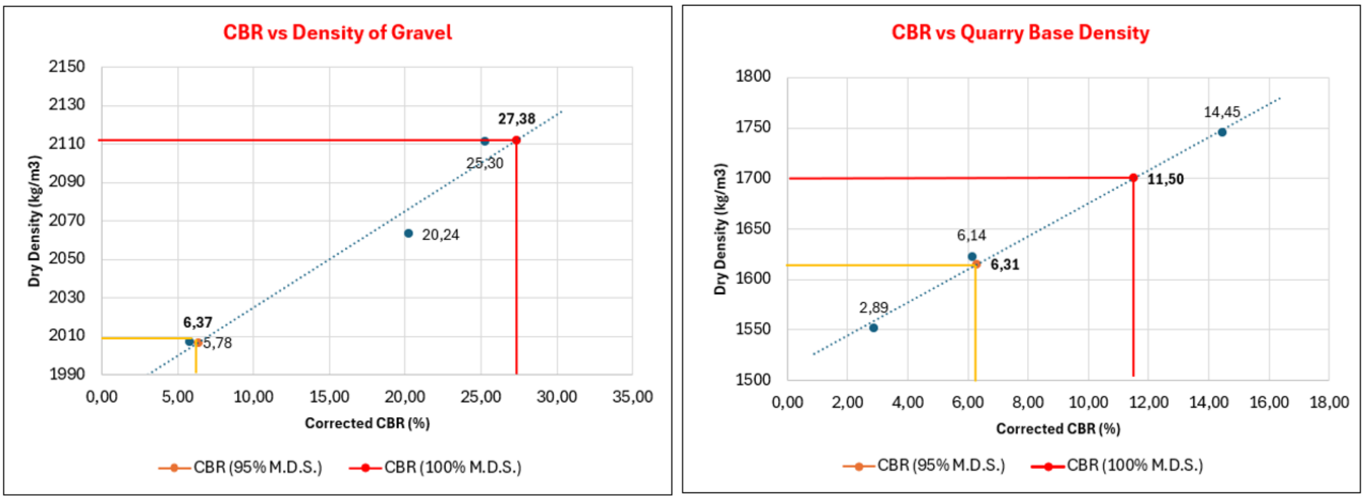

Fig. 5. Distribution Curve CBR Graph of Gravel and of lastre (ballast)

SUMMARY OF SOIL PROPERTIES IN NATURAL STATE

The results from each test carried out in the soil laboratory for the quarry gravel and lastre samples are compiled and detailed in the table presented below:

Tabla 1. Summary of soil properties in natural state

Sample	Gravel	Ballast
Moisture content (%)	1,16	5,45
Liquid limit (%)	12	42,45
Plastic limit (%)	16,07	29,54
Plasticity index (%)	NP	13
AASHTO Classification	A-1-a (0)	A-2-7 (0)
SUCS Classification	Coarse-grained soil, consisting of clean and poorly graded gravel (GP)	Coarse soil of well-graded sand with low plasticity silts (SW-SM)
Maximum dry density (kg/m^3)	2112	1921
Optimum moinsture content (%)	2,2	9,6
Bearning capacity CBR (%)	Al 100% MDS: 27,38 (1") y 35,76 (2") Al 95% MDS: 6,37 (1") y 9,91 (2")	Al 100% MDS: 11,50 (1") y 18,03 (2") Al 95% MDS: 6,31 (1") y 10,03 (2")

MIXTURE DOSING FOR GRAVEL AND LASTRE SAMPLES

After the characterization of the two selected soils, the combination of gravel and ballast was carried out through physical stabilization, where the particle size of both materials must be plotted along with their resultant, which must be within the particle size limits established by the NEVI 2013 standard and described in the figure 6. In this case as subbase material in local roads since this is the layer that is located immediately above the natural soil. Regarding the improvement of the subgrade with selected material, no limits are stipulated regarding the particle size of the aggregates.

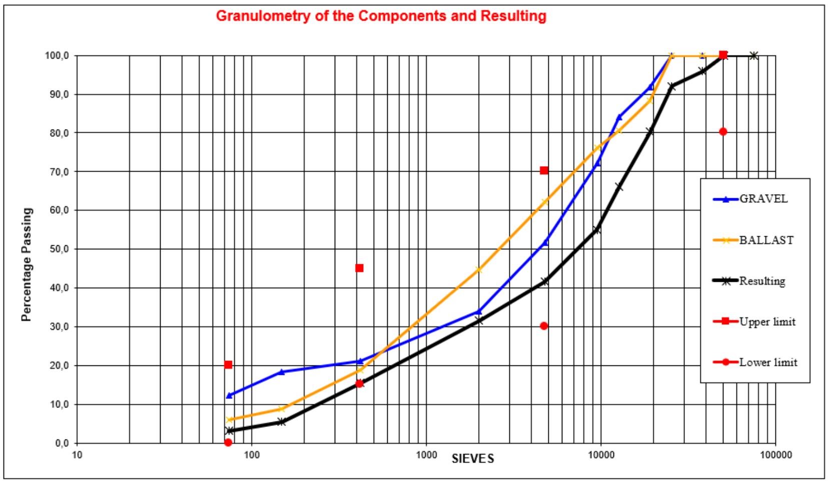

Fig. 6. Particle size curves of Gravel and Ballast along with resultant

According to the attached graph, the dosage corresponding to 50% of each soil generates a resultant that falls within the limits defined by MTOP, the same occurs for mixtures that have a proportion of gravel lower than the mentioned one, therefore the respective tests will be carried out considering the 50/50 and 40/60 combination.

COMPARISON OF PROPERTIES IN NATURAL STATE VS COMBINED STATE

After obtaining the results from the soil samples of Gravel and Ballast in natural state, as well as from the combination of both for two proportions, the first of 50% gravel with 50% ballast and the second for 40% gravel with 60% ballast, we proceed to compare the values to observe the behavior that the materials had after being mixed as a physical stabilization method and analyze if their physical-mechanical properties had any improvement.

ATTERBERG LIMITS

Analyzing the presented graphs, it can be seen that the liquid limit of the soil combination is higher than that of the gravel, however, it turns out to be lower than that of the ballast, which causes the plastic index to increase with respect to the 40-60 mixture with the first aggregate by 6% and decrease by 7% in reference to the second aggregate.

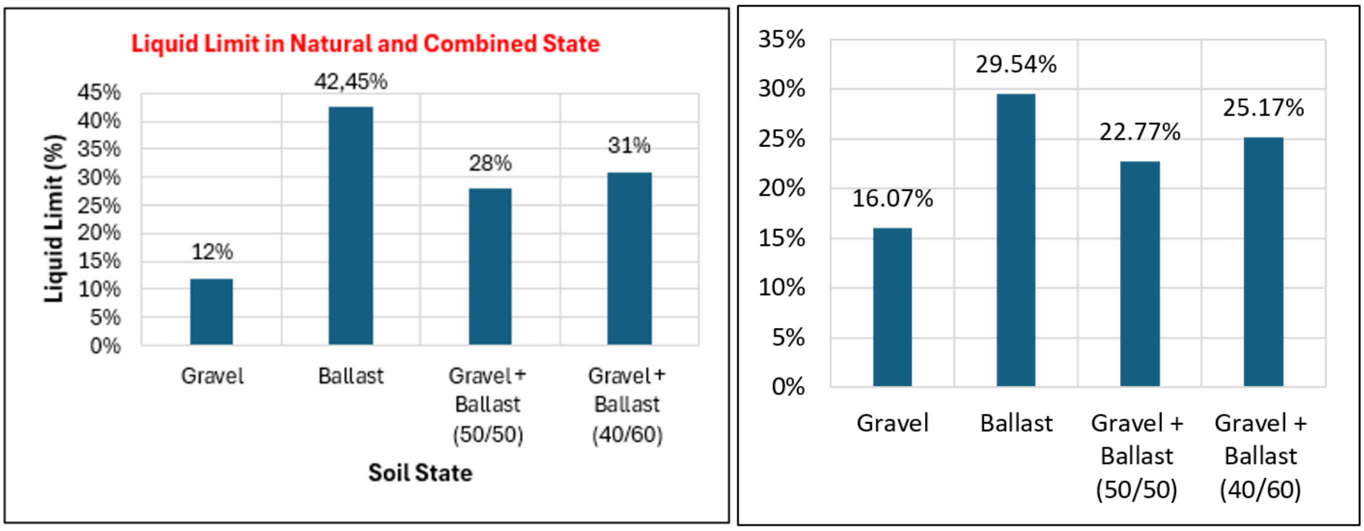

Fig. 7. Liquid limit and plastic limit of natural and Combined State of soils

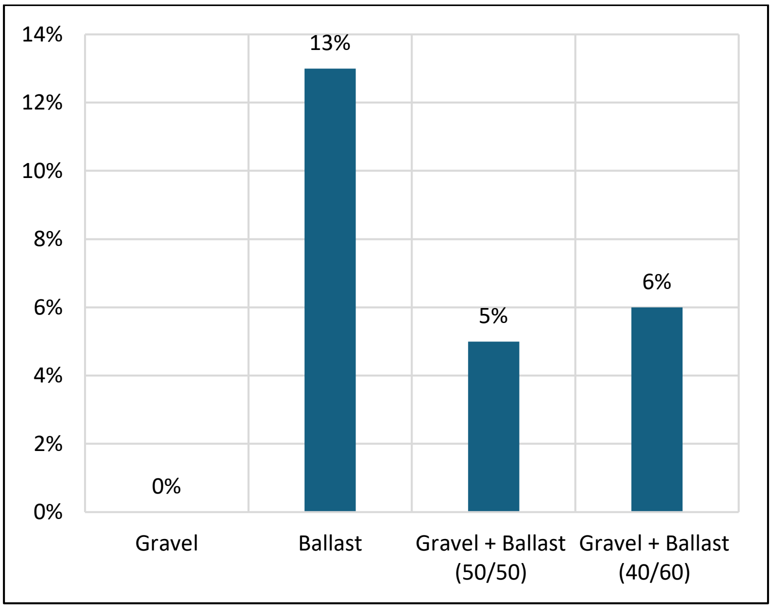

Fig. 8. Plasticity index vs Natural and Combined State of soils

OPTIMUM MOISTURE AND MAXIMUM DRY DENSITY

The optimum moisture contents and maximum dry densities that were calculated by the modified Proctor test for the aggregates in natural and combined states are collected in the following illustrations for their subsequent analysis:

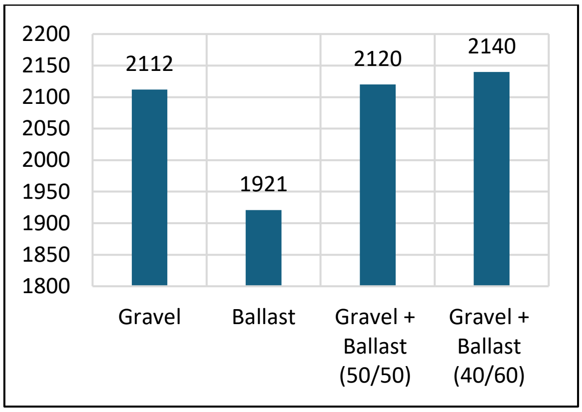

Fig. 9. Maximum dry density vs Natural and Combined State of soils

Analyzing the illustrations, it can be seen that the moisture content for the mixed aggregates was higher than of the gravel, but lower than that of the lastre, and the maximum dry density of the combination of materials increased compared to the two samples in natural state. The optimum moisture of the gravel was 2.2%, of the ballast 9.6%, and of the stabilized soil at 40-60 of 4.5%, with an increase of 2.3% for the first material and a decrease of 5.1% for the second. While the maximum dry density grew in both cases, with an improvement of 1.33% and 11.40% respectively.

CALIFORNIA BEARING RATIO (C.B.R.)

The calculated CBR data for 95% and 100% of the maximum dry density at 1" for each soil considered are presented in the following illustration:

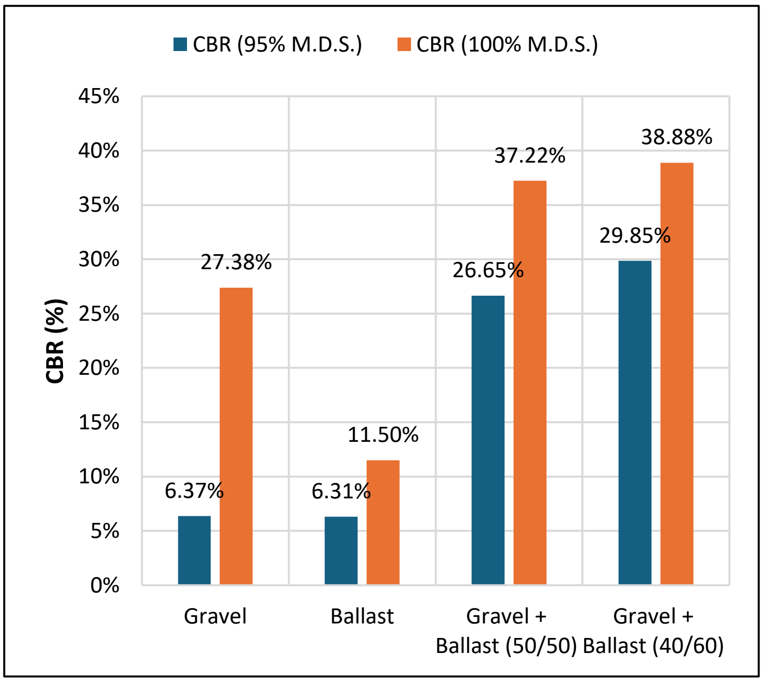

Fig. 10. CBR Index at 95% and 100% M.D.D (1") vs Natural and Combined State of soils

Performing the analysis of the shown graphs, the CBR value for 95% and 100% MDD (1") increases in the 50/50 combination aggregate, reflecting the magnitude of 26.65% and 37.22% compared to soils in natural state, where gravel had the amount of 6.37% and 27.38% resulting in an increase of 20.28% and 9.84% and an improvement of 318% and 36% respectively. Meanwhile, the ballast had indices of 6.31% and 11.50% noting a growth of 20.34% and 25.72%, so the improvement was 322% and 223% compared to the stabilized material.

SWELLING OR VOLUMETRIC EXPANSION

During the CBR test, deformation readings were taken over a 96-hour period with a dial for samples submerged in water, here is presented the expansion that the 56-blow mold had for the natural and combined state of the material.

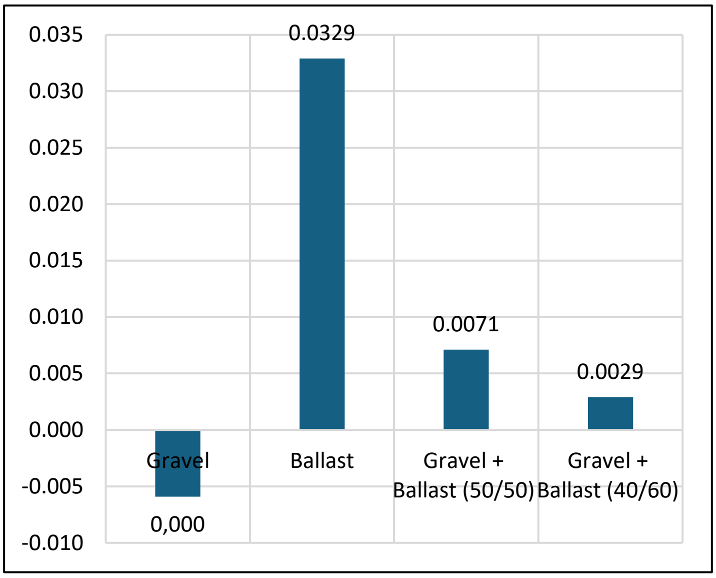

Fig. 11. Swelling vs Natural and Combined State of soils

Examining the illustration, it can be seen that the gravel had an opposite behavior, as it contracted instead of swelling. The recorded volumetric expansion of the aggregate combination was 0,0071%, showing an increase of 0,0012% compared to the gravel, while in relation to the ballast there was a decrease of 0,0258%.

5 DISCUSSION OF RESULTS

The results from laboratory tests revealed that the sample extracted from the Chanchan river quarry belongs to a coarse soil composed of clean and poorly graded gravel with GP symbol by the USCS method, while by the AASHTO method it falls in group A-1-a (0), furthermore, according to Atterberg limits, this material shows no plasticity. On the other hand, the quarry ballast sample according to USCS, is a coarse material of well-graded sands with low plasticity silts with symbol SW-SM, and through the AASHTO method is part of group A-2-7 (0), which has a plasticity index of 13%.

The gravel in natural state obtained a maximum dry density of 2112 kg/m3 with an optimum moisture of 2,2% and a CBR index at 95% of M.D.D. of 6,37% and at 100% of M.D.D. of 27,38% (1"), observing that this material did not experience swelling. In contrast, the quarry ballast presented a maximum dry density of 1921 kg/m3 with an optimum moisture of 9,6% and a CBR index at 95% of M.D.D. of 6,31% and at 100% of M.D.D. of 11,50% (1"), having a minimum swelling of 0,0329%.

The calculation regarding soil dosage met MTOP requirements for a proportion of 50% for each material. The mixed aggregates showed that the plasticity index had an increase of 5% in relation to the gravel, likewise the optimum moisture had a similar behavior because it had a growth of 3,30% and the maximum dry density had an improvement of 0,38% because it went from having a value of 2112 kg/m3 to 2120 kg/m3. The CBR bearing capacity at 95% M.D.D. increased by 20,28% and at 100% M.D.D. by 9,84%, and the volumetric expansion increased slightly by 0,0012%.

The lastre ballast sample compared to the aggregate combination revealed that it had a decrease in plasticity index of up to 8%, moisture reduced by 4,1%, and maximum dry density increased by 10.36%. The CBR index at 95% M.D.D. rose by 20,34% and at 100% M.D.D. by 25,72%, swelling had a decrease of 0,0258%.

The following tables show the parameter verification with respect to MTOP regulations of the combination of materials in 50/50 and 40/60 proportions, being able to evidence that both mixtures meet the requirements as improvement material and the values are very close to adjusting to consider the material as subbase.

Tabla 2. Verification of normative parameters of results for different combinations with Ecuadorian standard

Subgrade Improvement			
Propierties	**MTOP**	**50/50 Combination**	**40/60 Combination**
Percentaje passing sieve #200 (%)	Max 20	✔ 3,14	✔ 3,7
Liquid limit (%)	Max 35	✔ 28	✔ 31
Plastic limit (%)	-	22,77	25,17
Plasticity index(%)	Max 9	✔ 5	✔ 6
CBR (%)	Min 10	✔ 26,65	✔ 29,85

Subbase			
Propierties	**MTOP**	**50/50 Combination**	**40/60 Combination**
Percentaje passing sieve #200 (%)	-	3,14	3,7
Liquid limit (%)	Max 25	✘ 28	✘ 31
Plastic limit (%)	-	22,77%	25,17
Plasticity index(%)	Less than 6	✔ 5	✘ 6
CBR (%)	Min 30	✘ 26,65	✔ 29,85

6 CONCLUSIONS

The physical and mechanical properties of gravel extracted from the Chanchan River quarry reveal specific characteristics: it presents a low moisture content of 1,16%, a particle size composition showing only 0,32% fine particles and 99,68% coarse fraction, and absence of plasticity. The material exhibits high density with a relatively low optimal moisture of 2,20%. CBR tests showed a low index of 6,37% without presenting swelling.

The classification analysis of the granular material defines it as a coarse-grained soil. According to the SUCS system, it is identified as GP (poorly graded clean gravel), while by the AASHTO method it is classified as A-1-a (0), composed of rock fragments, gravel, and sand, indicating an excellent to good subgrade quality.

Regarding the bearing capacity of the gravel in its natural state, tests revealed a CBR of 6,37% at 95% of maximum dry density, while at 100% it reached a significantly higher value of 27,38%. It is important to mention that in less demanding constructions, the first CBR value (95%) is used.

The combination of gravel with quarry base material in a 50-50 proportion proved to be beneficial for soil properties. This mixture significantly improved the maximum dry density and support capacity compared to the natural state, achieving an increase of 20,28% for maximum dry density at 95% and 9,84% at 100%.

The analysis of the effectiveness of gravel in its natural state for stabilizing rural roads reveals important limitations due to its particle size distribution. The high percentage of coarse particles and the absence of fine particles results in poor particle contact and low cohesion. Although the CBR is below Ecuadorian standards, physical stabilization through mixing with quarry base material improves both particle distribution and bearing capacity.

The final evaluation of the combined material demonstrates its compliance with MTOP Technical Specifications for selected soil improvement, satisfying all required control parameters: particle size, Atterberg limits, maximum dry density, and bearing capacity.

7 RECOMMENDATIONS

Conduct an investigation by mixing the studied granular soils in different proportions, adapting to the particle size limits established by MTOP-2003, to verify if there are any changes in the properties of the aggregates in a combined state.

Study the behavior of the Chanchan River gravel after experiencing a crushing process.

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