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Tesis

Subgrade Improvement With Recycled Polymer (PET) in Clay Soils for Rural Roads

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Subgrade Improvement with Recycled Polymer (PET) in Clay Soils for Rural Roads

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Abstract The project provides information on the physical and mechanical properties of clay soils stabilized with recycled polymers (PET) as subgrade improvement in rural roads in the district of Sicaya, because this area does not have paved roads nearby which cause inaccessibility to the population; also by using PET for soil improvement, an added value was given to this material generating a lower environmental impact. In order to fulfill the objective of the research, the physical properties of two soil specimens from Jr. La Libertad in the district of Sicaya were determined; sieving tests of granulometry, consistency limits, modified proctor and soil classification by SUCS and AASHTO were performed. Once the soil properties were evaluated, the optimum size of the PET particles for its application was determined by CBR tests using 1% of PET as a proof. It was found that the optimum size was from 5 mm to 10 mm, and to find the optimum percentage of polymers to be applied, four percentages of recycled polymers were used: 0.5%, 1.0%, 1.5% and 2.0%; these percentages were proposed for the two specimens analyzed. It was obtained that the percentage of 1.5% was the one that provided the highest CBR index, having 7.15% and 4. 87% of CBR at 95% compaction for the first and second specimen respectively; the latter turned out to be lower than the 6% CBR required as a minimum by the Highway Manual, and this was because the second specimen presented more fine material than the first specimen having a high value of 77.77%, which is not recommended for using recycled polymers according to this research.

Keywords Clay Soils, CBR Index, PET, Dosage, Rural Roads

1. Introduction and Backgrounds

The socioeconomic growth of any population depends on land access roads that are in good condition. Communication infrastructure is important for Economic growth [1], facilitating trade, promoting tourism and other activities. In 2022, the Peruvian Ministry of Transportation and Communications developed rehabilitation and improvement projects for 1,440 kilometers of national roads for population growth [2]. In many cases, foundation soils with low bearing capacity were found, making it necessary to improve or replace them with other materials, generating an increase in budgets to reach the minimum standards established by the Highway Manual [3]. According to [4], it was determined that more than 40% of the soils in the district of Sicaya are clay, and most of the roads surrounding the district are not paved which do not guarantee good stability and durability for the population. According to the technical specifications established by [5], there are several methods for the improvement of subgrade such as the addition of lime, cement, slag and others. This study proposes the use of a new additive to reduce the environmental impact; moreover, chemical additives are costly, that is why it is proposed to replace these additives with recycled materials such as disposable PET bottles, which are a hard material to degrade [6]. Since Peru produces 267 thousand tons of PET containers per year, 72% of which become waste in less than a year [7], by proposing this methodology, an added value will be given to this material. Among the studies carried out on soil stabilization with polymers, one was found in Amazonas by Chávez [8], who proposed stabilizing clay soil at the subgrade level by adding molten polyethylene at 4%, 8% and 12%, concluding that at 12% the CBR achieves up to 10.3%, having a subgrade from regular to good [3].

The project developed in Peru by Nesterenko [9], who proposed the stabilization of soils with polymers according to Peruvian regulations, and then determined the structural parameters using 5 types of specimens from different projects that were carried out in Peru, giving results of CBR higher than 20% with 0.0026% PET in relation to the loose soil weight, classified as very good soil by the Ministry of Transportations and Communications [3].

Unlike the studies, the present investigation will analyze the subgrade of the Sicaya district with recycled polymers (PET) added in dosages of 0.50%, 1.00%, 1.50% and 2.00% with respect to the dry weight of the soil, to achieve the minimum requirement according to MTC [3].

Stabilization with recycled polyethylene terephthalate in clay soils proposes to improve the bearing capacity of access to the roads in rural areas, improving the physical and mechanical characteristics of the clay soil, as well as adding value to the polymers by reducing the pollution they generate. It is desired that stabilization using recycled polymers becomes a good option to be applied in future road projects at a national level or in projects where it is required to improve the bearing capacity of the subgrade, and subsequently this material could be recognized as a soil stabilization method in the Road Manual [5].

2. Materials and Methods

For the study of subgrade improvement with recycled polymers, the study area was first defined considering places where the most significant amount of clay soils was present, whose particles are less than 0.002mm [10], and whose location is a rural area where dirt roads are evident. Therefore, an area adjacent to the district of Sicaya was chosen, exactly in Jr. La Libertad, which has a road length of approximately 1.23km as shown in Figure 1. Here at least 2 pits were made to obtain 2 soil samples for the study [3]. The samples obtained were from the second layer, the first layer is organic which varies from 20 to 35 centimeters as indicated in [11].

Figure 1. Study section Jr. La Libertad

2.1. Materials

2.1.1. Clay Soils

Clay soils can be defined as those whose granulometric composition has a special weight of small particles, smaller than two microns (0.002 mm) or five microns according to the MTC [11]. These particles are mostly composed of clay minerals, iron silicates, aluminum and magnesium; they are originated by the chemical alteration of other original minerals [12]. They have the characteristic of being of low bearing capacity which produces problems such as expansion. At the same time, these are divided into high plasticity and low plasticity by their liquid limit (LL) [13]. The extraction of the 2 soil samples for this study was done manually using picks, lamps and airtight bags for their preservation and transport to the laboratory.

2.1.2. Polymer

It is a non-renewable material, coming from petroleum and processed with antimony to obtain PET (Polyethylene Terephthalate), belonging to the group of synthetic materials, being a material with a very slow degradation process [6], since microorganisms do not have mechanisms to attack them. Currently, polymer production is classified into 7 groups: PET, HDPE, PVC, LDPE, PP, among others [15]. The acquisition of this material was through the city collectors. They were then washed and dried removing all impregnated dirt and were cut into rectangular shapes of different dimensions. For our case study, we worked with four PET dosages of 0.5%, 1%, 1.5% and 2% for the stabilization of the subgrade.

2.1.3. Wgater

The main function of water is to wet the soil mixture added with the polymer to achieve maximum compaction of the material. Sulfates, chloride or organic matter should not be in the water. The water used should be clean and should not contain solid residues [16]. The workability of the material will be reflected by the amount of moisture, whether it is excessive or dry, which is evidenced by the surface finish, the strength of the subgrade and its durability.

2.2. Methodological Procedure

To carry out the present investigation, the following sequence was followed: the first part was to locate and situate the samples, then the 2 samples were selected and obtained to carry out the preliminary tests such as the physical properties of the soil: Granulometry, Consistency Limits and Soil Classification; then to continue with the specific tests such as the Proctor and CBR. Figure 2 shows a schematic summary of the methodology to be applied.

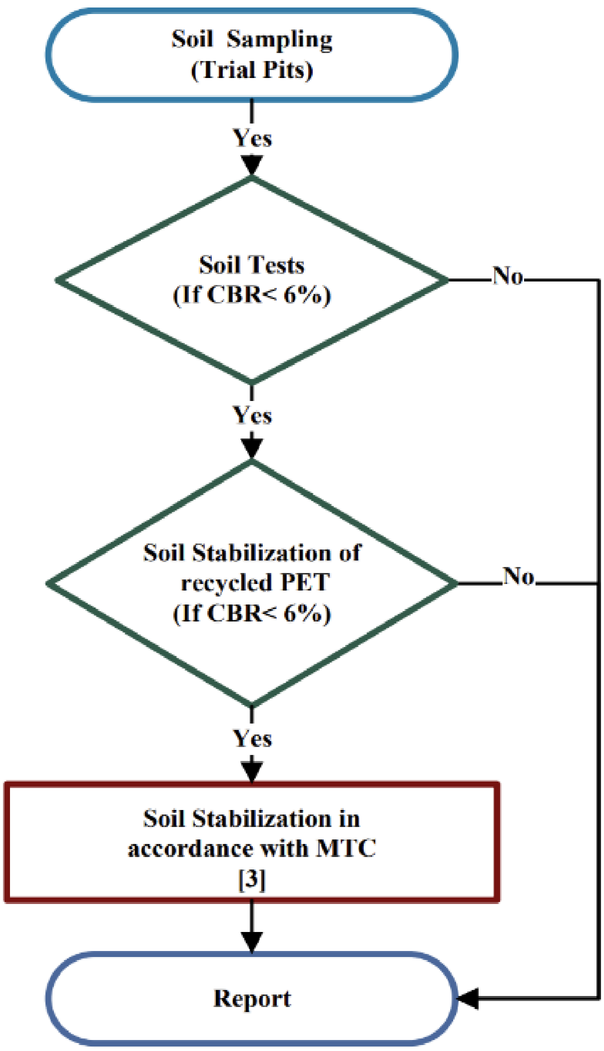

Figure 2. Study Methodology

2.2.1. Particle-Size Analysis of Soils

The objective of this test was to determine the soil percentages of the 2 study samples passing through the different sieves of the series, from 3" to 0.075 mm (N °200). The test was performed according to ASTM-D 422 [17], the equipment and accessories used were: square mesh sieves, balance with 0.1-gram sensitivity, drying oven, trays, brushes and brushes. The soil sample had to be dried in the open air, then quartered until a representative specimen was obtained. The procedure carried out was first to weigh the representative soil sample obtained from the quartering and take it to the oven for 24 hours, then the sample was washed through the N °200 mesh and the sample was thrown in portions so as not to lose particles larger than 0.074mm. Once the sample was washed through the N °200 mesh, the retained material was dried in the oven for 24 hours and finally the specimen was cooled and weighed. The washed and oven-dried weight was obtained.

The soil sample was poured through the upper part of the series of sieves and then shaken for ten to fifteen minutes; after sieving, the material retained on each sieve was weighed. To determine the percentage retained in each sieve, the following formula was applied (1).

$$\%\ \text{Retained} = \frac{\text{Weight retained on the sieve (kg)}}{\text{Total weight of soil sample (kg)}} x100 \quad (1)$$

Once the percentage retained on each sieve was obtained, the accumulated % retained could be calculated, and then the passing % could be calculated, which is the difference between the value of 100 and the accumulated retained %.

2.2.2. Consistency Limits

According to ASTM-D4318 [18], the consistency limits were found in the 2 soil samples for the classification of the soil and to know if it turns out to be very clay. The liquid limit is the moisture content, below which the soil behaves as a plastic material. For the liquid limit, a dry sample of 150 to 200 gr. was obtained through the No 40 and 25 gr. sieve. The plastic limit is the percentage of moisture, when the soil is between the plastic state and the semisolid state, this worked with the material prepared for the liquid limit with a sample of approximately 20 gr. The plastic index was obtained from the difference between the liquid and plastic limits as shown in formula (2), indicating the variation of soil plasticity. The Atterberg limits allowed classifying and identifying the soils. The equipment and accessories used were containers for storage and mixing, sieve No. 40, flexible blade spatula, liquid limit apparatus (Casagrande cup), capsules to obtain the moisture content, a balance with a sensitivity of 0.1 gr. and a ground glass plate of at least 30 cm. on each side, square in shape and 1 cm. thick.

$$PI = \text{LL-PL} \quad (2)$$

PI=Plasticity Index
LL=Liquid Limit

PL=Plastic Limit

2.2.3. Modified Proctor

The objective of the test was to determine the optimum moisture content for which the soil reaches its maximum dry density. This test was done for the 2 samples from the pits according to ASTM-D1557 [19]. The equipment and accessories used were a 6" mold, a tamper, a 1 g scale, a metal ruler and 3/4", 3/8" and n°4 sieves. For the process, the sample was first dried in the environment, then it was sieved to start with the compaction, applying 25 blows for each layer; in total 5 layers were made until it was at the same level of the mold. Then the mass of the specimen was determined and recorded and then the material was removed from the mold and a portion of soil was extracted to determine the moisture content. The samples were also taken to the oven to determine the moisture content. This process was repeated for a minimum of 5 points compacted at different moisture contents, two of which are on the dry side of the curve and the other two on the wet side. Once the moisture content of each sample was determined, the dry density of each point was found with the following expression (4), but previously the wet density was determined with the following formula (3).

$$\rho m = \frac{1000(Mt - Mmd)}{V} \quad (3)$$

ρm = Specimen wet density (mg/m^3)
Mt = Wet specimen and mold mass (kg)
Mmd = Compacted mold mass (kg)
V= Compaction mold volume (m^3)

Having the wet density, the dry density is calculated with the formula (4).

$$\rho d = \rho m\left(1 + \frac{w}{100}\right) \quad (4)$$

ρd=Dry density of the compacted specimen (mg/m^3)
ρm = Specimen wet density (mg/m^3)
w= Water content %

2.2.4. California Bearing Ratio Test

The purpose of this test was to find the bearing capacity (CBR) of the 2 study samples to determine the optimum PET size and dosage to be used as subgrade improvement according to ASTM-D1883 [20]. The 2 samples were compacted in the laboratory at optimum moisture and varying compaction levels. The equipment and accessories used for this test were the CBR press, a cylindrical metal mold of 152.4mm diameter, metal spacer disc, compaction tamper, expansion measuring device, metal penetration piston, immersion tank and drying oven. For the procedure, a 5 kg sample was taken for each CBR mold and the specimen was compacted in three standardized CBR molds of 15.24 cm in diameter and 17.78 cm in height. The specimen was compacted in 5 layers per mold with the compaction energy of each mold being 12, 26 and 55 blows per layer by means of a 2.5 kg hammer dropped freely from a height of 305 mm. The molds were then clamped, disassembled and reassembled inverted, then the molds were immersed in water, the perforated plate and the stem were placed, as well as the weights necessary to calculate the calculated overload, then the measuring tripod was placed on the edge of the mold, coinciding the stem of the microcomparator; daily measurements were taken from the microcomparator for 7 days. Finally, the specimen was taken out of the water for drying and the load was applied on the penetration piston by means of the CBR press and the readings of the penetration pressure curve were taken. For the calculation of the CBR Index, the value of the bearing ratio (CBR index), is the percentage of the pressure exerted by the piston on the soil, for a given penetration, in relation to the pressure corresponding to the same penetration in a standard specimen. The characteristics of the standard specimen are shown in Table 1.

Table 1. Pressure corresponding to the same penetration in a standard specimen

Penetration		Pressure	
Millimeters	Inches	kgf/cm^2	lb/plg^2
2.54	0.1	70.31	1
5.08	0.2	105.46	1.5

The bearing ratio for the soil is normally 2.54 mm (0.1") penetration. When the ratio at 5.08 mm (0.2") penetration is found to be greater, repeat the test. If the check test gives a similar result, use the support ratio for 5.08 mm (0.2") penetration.

3. Results and Discussion

3.1. Granulometric Analysis

Table 2 and Table 4 represent the results of the Granulometric Analysis of the first and second soil samples respectively according to ASTM D-422 [17], these results will be used to determine the physical properties of the soil and their respective classification.

Table 3 shows the granulometric classification of the first soil sample, it is observed that fine material predominates in greater quantity, representing 44.29% of silt and clay.

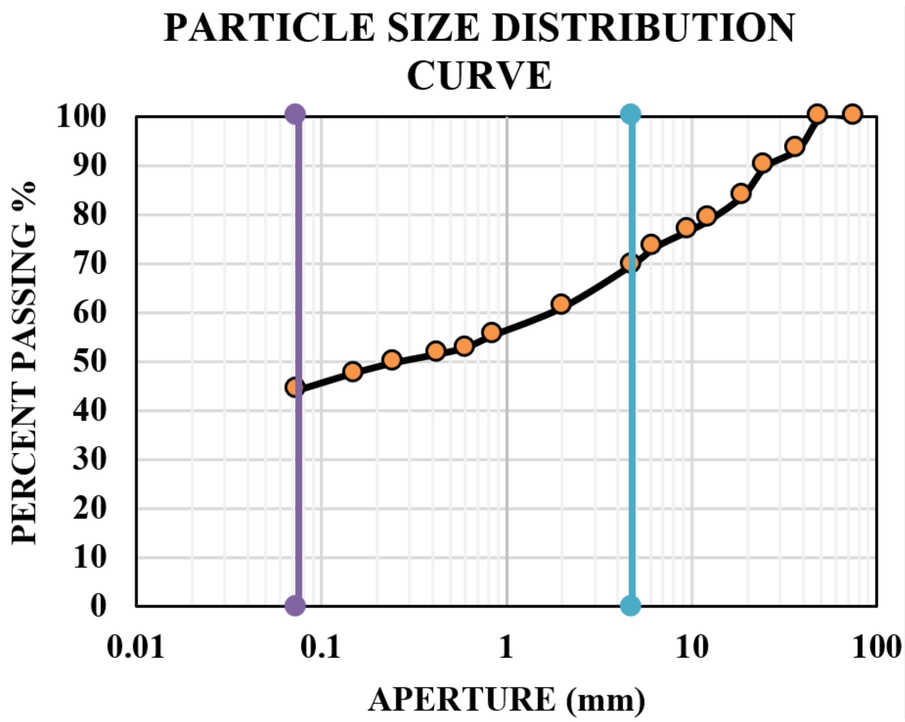

Figure 3. Particle Size Distribution Curve – M1

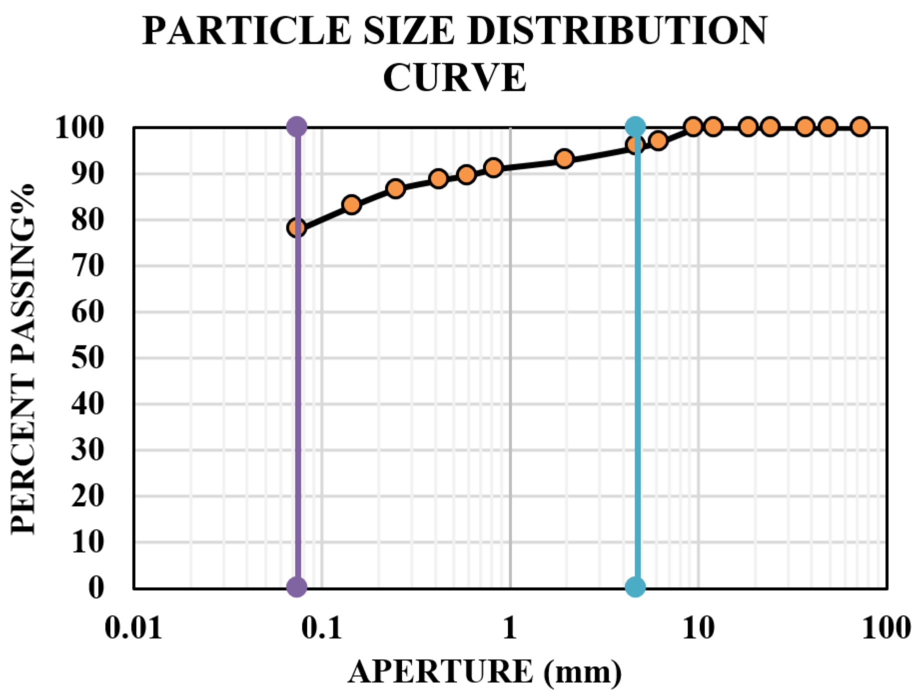

Figure 4. Particle Size Distribution Curve – M2

Table 2. Sieve Analysis for Particle Size Distribution - M1

SIEVE ANALYSIS FOR PARTICLE SIZE DISTRIBUTION		
SIEVE SIZE	APERTURE (mm)	PERCENT PASSING %
3"	75	100.00%
2"	50	100.00%
1 1/2"	37.5	93.46%
1"	25	89.87%
3/4"	19	84.05%
1/2"	12.5	79.04%
3/8"	9.5	76.66%
1/4"	6.3	73.37%
N °4	4.75	69.82%
N °10	2	61.15%
N °20	0.85	55.48%
N °30	0.6	52.96%
N °40	0.425	51.60%
N °60	0.25	49.89%
N °100	0.15	47.74%
N °200	0.075	44.29%

Table 3. Sieve Analysis for Particle Size Distribution – M1

PARTICLE SIZE CLASSIFICATION		
SILT AND CLAY	SAND	GRAVEL
44.29%	25.53%	30.18%
100%		

Figure 3 shows the particle size distribution curve of the first soil sample analyzed by sieving grain size presented in Table 2, according to [13], it has a continuous granulometry, not very uniform, so it can be said that it is a partially well graded soil.

Table 5 shows the granulometry classification of the second sample, it is observed that fine material predominates in greater quantity representing 77.29% of silt and clay, this second sample has 75.6% more fines than the first soil sample, in addition to passing 50% of fines, which indicates that the soil has a high concentration of clay and that it does not have a good bearing capacity.

Figure 4 shows the particle size distribution curve of the second soil sample analyzed by sieving grain size presented in Table 4, according to [13], it has a discontinuous granulometry, it is not uniform so it can be said that it is a poorly graded soil.

3.2. Consistency Limits

Table 6 and Table 7 summarize the liquid limit, plastic limit and plasticity index tests of the first and second samples respectively in accordance with ASTM-D4318 [18]. According to [3], it is observed that the first sample had a medium plasticity with a value of 8.43%, characterizing it as soil without much clay. The second sample has a higher plasticity with a value of 14.91% and this is characterized as a clay soil.

Table 4. Sieve Analysis for Particle Size Distribution – M2

SIEVE ANALYSIS FOR PARTICLE SIZE DISTRIBUTION		
SIEVE SIZE	APERTURE (mm)	PERCENT PASSING %
3"	75	100.00%
2"	50	100.00%
1 1/2"	37.5	100.00%
1"	25	100.00%
3/4"	19	100.00%
1/2"	12.5	100.00%
3/8"	9.5	99.65%
1/4"	6.3	96.90%
N °4	4.75	95.65%
N °10	2	92.85%
N °20	0.85	91.00%
N °30	0.6	89.60%
N °40	0.425	88.55%
N °60	0.25	86.60%
N °100	0.15	83.15%
N °200	0.075	77.77%

Table 5. Sieve Analysis for Particle Size Distribution – M2

PARTICLE SIZE CLASSIFICATION		
SILT AND CLAY	SAND	GRAVEL
77.77%	17.88%	4.35%
100%		

Table 6. Consistency Limits – M1

CONSISTENCY LIMITS	
LIQUID LIMIT	31.25%
PLASTIC LIMIT	22.82%
PLASTICITY INDEX	8.43%

Table 7. Consistency Limits – M2

CONSISTENCY LIMITS	
LIQUID LIMIT	32.59%
PLASTIC LIMIT	17.68%
PLASTICITY INDEX	14.91%

3.3. Soil Classification

For the SUCS classification [21], the granulometry, the percentages passing the N°4, N°200 mesh and the plastic characteristics were considered. For the AASHTO classification [22], the granulometry, the percentages passing the N°10, N°40, N°200 mesh, the plastic characteristics and the group index were considered. Tables 8 and 9 represent the first and second soil samples respectively, the group symbol and group name are shown in the case of SUCS classification and in the case of AASHTO the group classification and group index are shown.

Table 8. Soil Classification – M1

SOIL CLASSIFICATION	
ASSHTO	A-4 (1)
	Silty Soils
SUCS	Light clay and gravel type with sand (CL)

Table 9. Soil Classification - M2

SOIL CLASSIFICATION	
ASSHTO	A-6 (12)
	Clay soils
SUCS	Light sandy clay (CL)

3.4. Modified Proctor

The compaction results of the first and second soil samples are represented in Figure 5 and Figure 6 respectively according to ASTM D 1557 [19]. The soil of the second sample presents a higher degree of compaction than the first sample, having a value of 1.935 g/cm^3, in addition to requiring less optimum moisture. According to [13], for soils with a high clay content, soil moisture-density curves turn out to be more inclined than granular soils, as shown in Figure 6.

3.5. California Bearing Ratio

All CBR tests were performed in accordance with ASTM D 1883 [20]. Table 10 and Table 12 show the CBR calculation results of the first and second soil sample respectively without any additive with the 3 compaction energies of 55, 26 and 12 blows, these values were found for 0.1" and 0.2" penetration. It can be noticed that the first sample has a higher resistance compared to the second sample because the strength in the first sample is 42.4% higher than the second sample, this is due to the existence of its higher granular content due to its granulometry.

Table 10. CBR Calculation – M1

N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.915	1.814	1.737
Corrected Strength	kg/cm^2	0.1"	5.000	4.060	2.720
		0.2"	9.720	8.320	4.510
CBR Index	%	0.1"	7.12%	5.79%	3.81%
		0.2"	9.19%	7.92%	4.31%

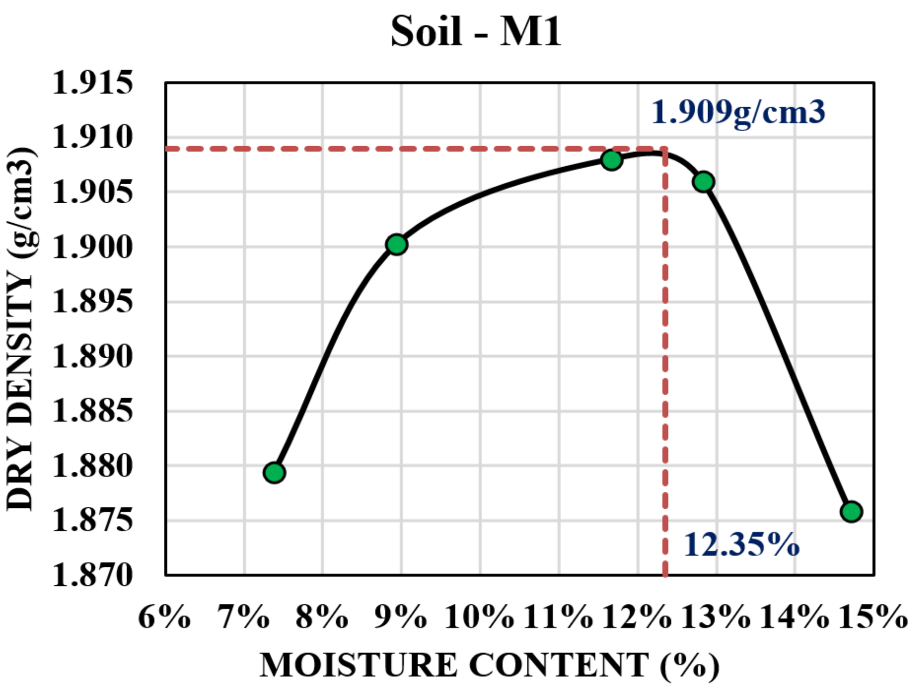

Figure 5. Soil moisture-density curve – M1

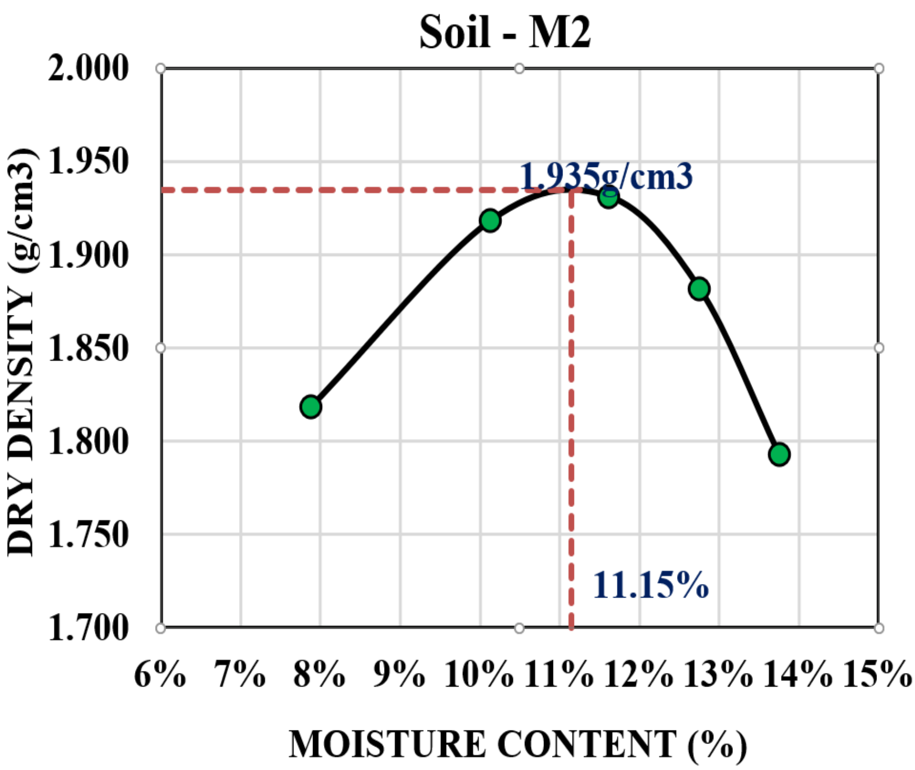

Figure 6. Soil moisture-density curve – M2

Table 11 and Table 13 show the summary of the CBR calculation of the first and second samples respectively without any additive, subsequently the CBR index at 95% compaction was found for both 0.1" and 0.2" penetration using the CBR curve, it is observed that the CBR index of the first sample is higher by 51.8% at 0.1" penetration at 95% compaction than the second sample, this is because the gravels give higher shear strength. Both samples do not meet the minimum CBR value of 6% required by the MTC [3] for road application.

Due to the low bearing capacity of the first and second samples shown above, percentages of PET were added at 0.5%, 1.0%, 1.5% and 2.0%. First, the optimum PET particle size to be used was determined. Table 14, Table 15, Table 16, Table 17 and Table 18 show the CBR calculations between the sieve ranges of 3/4"-1/2", 1/2"-3/8", 3/8"-1/4", 1/4"-N °4 and N °4-N °8. All these analyses were done with the first soil sample using 1% PET.

Table 11. CBR 100%, 95% – M1

Test		
CBR	0.1"	0.2"
100%	7.12%	9.19%
95%	5.77%	7.88%

Table 12. CBR Calculation – M2

N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.929	1.821	1.762
Corrected Strength	kg/cm^2	0.1"	3.510	3.180	2.730
		0.2"	4.410	3.980	3.410
CBR Index	%	0.1"	4.21%	3.74%	3.19%
		0.2"	5.03%	4.47%	3.81%

Table 13. CBR 100%, 95% – M2

Test		
CBR	0.1"	0.2"
100%	4.21%	5.03%
95%	3.80%	4.52%

Table 14. CBR Calculation – M1-1% PET (3/4”-1/2”)

			Test N °1		
			3/4" passing and 1/2" retained		
N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.853	1.754	1.681
Corrected Strength	kg/cm^2	0.1"	5.25	4.62	3.12
		0.2"	9.82	9.03	5.37
CBR Index	%	0.1"	7.41%	6.55%	4.42%
		0.2"	9.25%	8.58%	5.08%

Table 15. CBR Calculation – M1-1% PET (1/2”-3/8”)

			Test N°2		
			1/2" passing and 3/8" retained		
N°Hits			55	26	12
Specific Dry Weight	g/cm^3		1.861	1.761	1.691
Corrected Strength	kg/cm^2	0.1"	5.31	4.81	3.24
		0.2"	10.81	9.67	5.73
CBR Index	%	0.1"	7.55%	6.84%	4.53%
		0.2"	10.25%	9.14%	5.41%

Table 16. CBR Calculation – M1-1% PET (3/8”-1/4”)

			Test N°3		
			3/8" passing and 1/4" retained		
N°Hits			55	26	12
Specific Dry Weight	g/cm^3		1.864	1.765	1.699
Corrected Strength	kg/cm^2	0.1"	5.43	4.92	3.25
		0.2"	11.37	10.17	6.05
CBR Index	%	0.1"	7.65%	7.04%	4.62%
		0.2"	10.74%	6.62%	5.74%

Table 17. CBR Calculation – M1-1% PET (1/4”-N°4)

			Test N°4		
			1/4" passing and retained N°4		
N°Hits			55	26	12
Specific Dry Weight	g/cm^3		1.862	1.763	1.693
Corrected Strength	kg/cm^2	0.1"	5.34	4.87	3.25
		0.2"	10.92	5.73	5.83
CBR Index	%	0.1"	7.57%	6.92%	4.63%
		0.2"	10.28%	9.19%	5.54%

Table 18. CBR Calculation – M1-1% PET (N°4- N°8)

			Test N°5		
			N°4 passing and retained N°8		
N°Hits			55	26	12
Specific Dry Weight	g/cm^3		1.857	1.757	1.692
Corrected Strength	kg/cm^2	0.1"	5.17	4.73	3.18
		0.2"	10.37	9.36	5.56
CBR Index	%	0.1"	7.33%	3.67%	4.46%
		0.2"	9.80%	8.81%	5.27%

Table 19 shows the summary of the five CBR tests at 1% PET at 100% and 95% compaction at 0.1" and 0.2" penetration according to ASTM D 1883 [20], it is observed that the most unfavorable result is with the 3/4"-1/2" sieves having a low value of 6.63%, the optimum was between the 3/8"-1/4" sieves achieving 7.11% CBR at 0.1" penetration at 95% compaction.

Table 19. CBR 100% y 95% – M1-1% PET

	CBR	0.1"	0.2"
Test N°1	100% MDS	7.41%	9.25%
	95% MDS	6.63%	8.72%
Test N°2	100% MDS	7.55%	10.25%
	95% MDS	6.92%	9.30%
Test N°3	100% MDS	7.65%	10.74%
	95% MDS	7.11%	9.82%
Test N°4	100% MDS	7.57%	10.28%
	95% MDS	7.05%	9.42%
Test N°5	100% MDS	7.33%	9.80%
	95% MDS	6.81%	9.00%

Table 20 shows the percentage increase of the CBR resistance of the five tests carried out previously compared to the standard sample of 5.77%, it is observed that test N°3 achieves a gain of 23.22%, this being the highest of all, so PET particles between 5mm-10mm will be used.

Table 20. % CBR Increase -95%

N°Test	PET SIZE		CBR	% CBR Increase
	PASSING	RETAINED	5.77%	
Test N°1	3/4"	1/2"	6.63%	14.90%
Test N°2	1/2"	3/8"	6.92%	19.93%
Test N°3	3/8"	1/4"	7.11%	23.22%
Test N°4	1/4"	N°4	7.05%	22.18%
Test N°5	N°4	N°8	6.81%	18.02%

Once the appropriate PET particle size was found, CBR tests were performed with the 4 percentages of PET in relation to the dry weight of the soil according to ASTM D 1883 [20]. Table 21, Table 22, Table 23 and Table 24 present the CBR calculation results of the first sample at 0.5%, 1.0%, 1.5% and 2.0% PET respectively.

Table 21. CBR Calculation – M1-0.5% PET

			Test N°1		
			0.5 % of PET		
N°Hits			55	26	12
Specific Dry Weight	g/cm³		1.887	1.780	1.717
Corrected Strength	kg/cm²	0.1"	4.91	4.46	2.97
		0.2"	9.93	8.83	5.21
CBR Index	%	0.1"	7.05%	6.37%	4.21%
		0.2"	9.36%	8.35%	4.93%

Table 22. CBR Calculation – M1-1.0% PET

			Test N°2		
			1.0 % of PET		
N°Hits			55	26	12
Specific Dry Weight	g/cm³		1.864	1.767	1.694
Corrected Strength	kg/cm²	0.1"	5.36	4.84	3.21
		0.2"	10.85	9.67	5.74
CBR Index	%	0.1"	7.60%	6.84%	4.55%
		0.2"	10.17%	9.15%	5.43%

Table 23. CBR Calculation – M1-1.5% PET

			Test N°3		
			1.5 % of PET		
N°Hits			55	26	12
Specific Dry Weight	g/cm³		1.845	1.752	1.677
Corrected Strength	kg/cm²	0.1"	5.51	5.00	3.25
		0.2"	11.27	10.04	5.95
CBR Index	%	0.1"	7.82%	7.09%	4.64%
		0.2"	10.62%	9.47%	5.63%

Table 24. CBR Calculation – M1-2.0% PET

			Test N°4		
			2.0 % of PET		
N°Hits			55	26	12
P.E. SECO	g/cm³		1.823	1.727	1.662
Corrected Strength	kg/cm²	0.1"	5.27	4.76	3.18
		0.2"	10.65	9.53	5.63
CBR Index	%	0.1"	7.53%	6.75%	4.46%
		0.2"	10.08%	9.00%	5.31%

Table 25 shows the summary of the CBR calculation of the first sample for 0.1" and 0.2" penetration, it also shows the values at 95% compaction found with the CBR curve as indicated by ASTM D 1883 [20].

Table 25. CBR 100% y 95% – M1

	CBR	0.1"	0.2"
Test N°1	100% MDS	7.05%	9.36%
	95% MDS	6.52%	8.57%
Test N°2	100% MDS	7.60%	10.17%
	95% MDS	6.95%	9.32%
Test N°3	100% MDS	7.82%	10.62%
	95% MDS	7.15%	9.62%
Test N°4	100% MDS	7.53%	10.08%
	95% MDS	6.86%	9.14%

Table 26 shows the percentage increase of the CBR resistance of the first soil sample compared to the standard sample. It is observed that by adding 1.5% PET the CBR index increases by 23.91% of its initial value, being 1.5% the optimum percentage and offering greater resistance, in addition, a value of 7.15% of CBR was obtained, being higher than the minimum required 6% demanded by the MTC [3].

Table 26. % CBR Increase 95% - M1

POLYMER %	CBR Index	% CBR Increase
0.00%	5.77%	
0.50%	6.52%	12.99%
1.00%	6.95%	20.45%
1.50%	7.15%	23.91%
2.00%	6.86%	18.90%

Figure 7 shows a summary of the comparison of the CBR indices at 0.00%, 0.50%, 1.00%, 1.50% and 2.00% PET of the first soil sample at a compaction level of 95%. It is observed that the soil is improved by adding the 4 percentages of PET, but this increase in resistance was minimal.

Table 27, Table 28, Table 29 and Table 30 present the CBR calculation results of the second soil sample at 0.5%, 1.0%, 1.5% and 2.0% PET respectively in relation to the dry weight of the soil according to ASTM D 1883 [20].

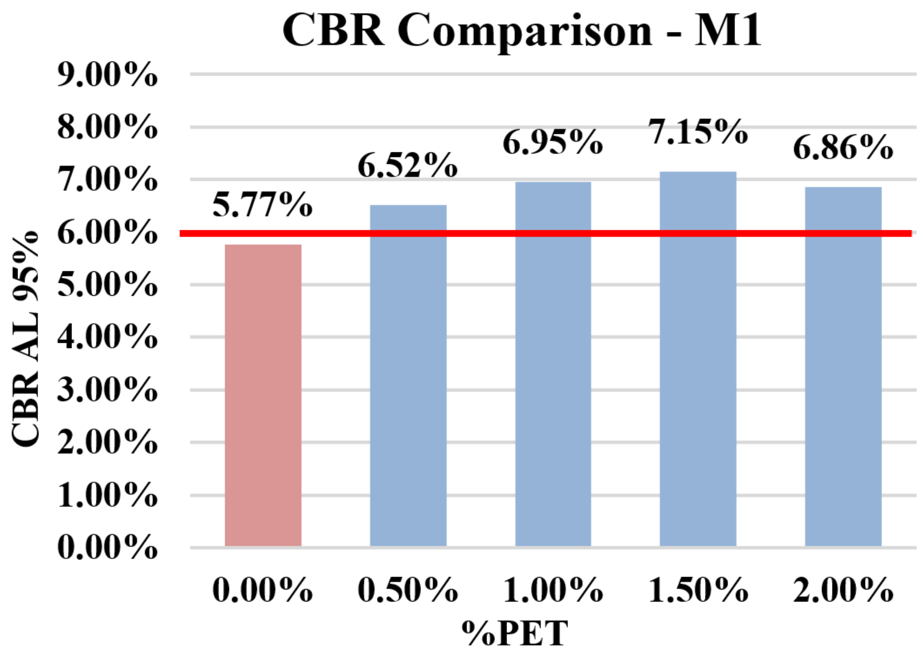

Figure 7. CBR Comparison – M1

Table 27. CBR Calculation – M2-0.5% PET

			Test N°1		
			0.5 % of PET		
N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.954	1.823	1.751
Corrected Strength	kg/cm^2	0.1"	3.31	3.11	2.23
		0.2"	6.12	5.44	3.45
CBR Index	%	0.1"	4.71%	4.42%	3.15%
		0.2"	5.75%	5.16%	3.31%

Table 28. CBR Calculation – M2-1.0% PET

			Test N°2		
			1.0 % of PET		
N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.909	1.081	1.741
Corrected Strength	kg/cm^2	0.1"	3.61	3.25	2.42
		0.2"	6.12	5.91	3.71
CBR Index	%	0.1"	5.12%	4.64%	3.43%
		0.2"	5.75%	5.63%	3.51%

Table 29. CBR Calculation – M2-1.5% PET

			Test N°3		
			1.5 % of PET		
N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.845	1.747	1.682
Corrected Strength	kg/cm^2	0.1"	3.71	3.37	2.46
		0.2"	6.93	6.15	3.93
CBR Index	%	0.1"	5.32%	4.80%	3.52%
		0.2"	6.51%	5.81%	3.72%

Table 30. CBR Calculation – M2-2.0% PET

			Test N°4		
			2.0 % of PET		
N °Hits			55	26	12
Specific Dry Weight	g/cm^3		1.883	1.784	1.713
Corrected Strength	kg/cm^2	0.1"	3.52	3.23	2.37
		0.2"	6.41	5.77	3.64
CBR Index	%	0.1"	4.96%	4.54%	3.36%
		0.2"	6.06%	5.46%	3.43%

Table 31 shows the summary of the CBR calculation of the first sample for 0.1" and 0.2" penetration, it also shows the values at 95% compaction found with the CBR curve as indicated by ASTM D 1883 [20].

Table 31. CBR 100% y 95% – M2

	CBR	0.1"	0.2"
Test N°1	100% MDS	4.71%	5.75%
	95% MDS	4.47%	5.18%
Test N°2	100% MDS	5.12%	5.75%
	95% MDS	4.72%	5.66%
Test N°3	100% MDS	5.32%	6.51%
	95% MDS	4.87%	5.92%
Test N°4	100% MDS	4.96%	6.06%
	95% MDS	4.63%	5.56%

Table 32 shows the percentage increase of the CBR resistance compared to the standard sample of the second soil sample. It is observed that by adding 1.5% PET the CBR index increases by 28.15% of its initial value, this being the higher percentage than the rest and offering greater resistance, in addition a value of 4.87% CBR is obtained, but this does not meet the minimum required value of 6% demanded by the MTC [3].

Table 32. % CBR Increase 95% - M2

POLYMER %	CBR Index	% CBR Increase
0.00%	3.80%	
0.50%	4.47%	17.63%
1.00%	4.72%	24.21%
1.50%	4.87%	28.15%
2.00%	4.63%	21.84%

Figure 8 shows a summary of the comparison of the CBR indices at 0.00%, 0.50%, 1.00%, 1.50% and 2.00% PET of the second soil sample at a compaction level of 95%. It is observed that there is little improvement of the soil by adding the 4 percentages of PET, in addition to the fact that none of the percentages of PET previously proposed improved to reach the minimum required CBR of 6%, this is due to the fact that the soil of the second sample contains a high percentage of fines compared to the first sample, in addition the latter contains a higher percentage of granular material such as gravel and sand, so the PET did help to improve the soil to achieve a 7.15% CBR as shown in Figure 7.

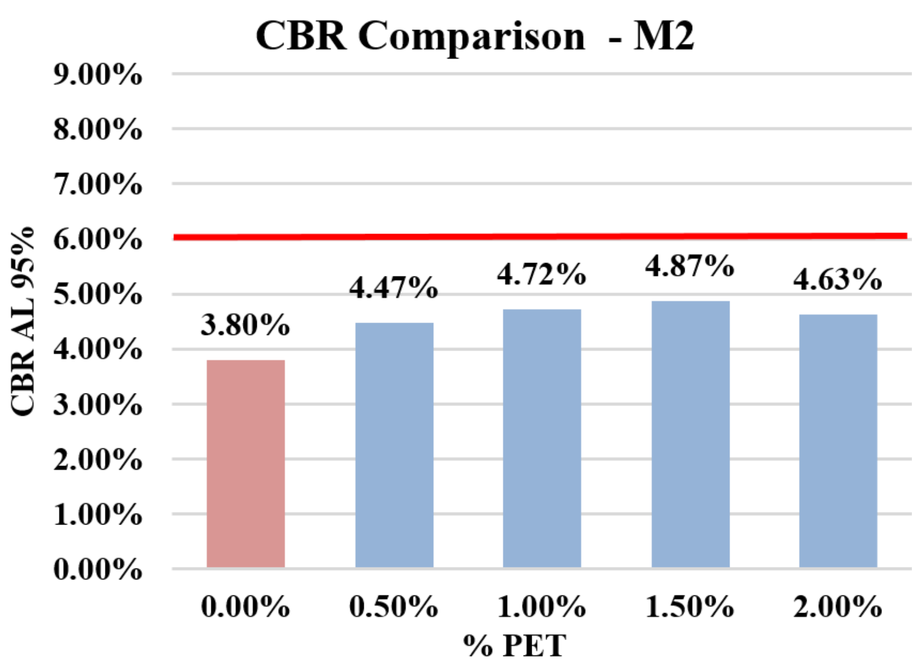

Figure 8. CBR Comparison – M2

4. Conclusions

The improvement of clay soils using recycled polymers (PET) for rural roads in Jr. La Libertad located in the district of Sicaya is a good option according to its physical characteristics that the soil has, for example, the plasticity index of the soil to be improved has to have a range between 1 to 8, also that the soil has at least 40% of granular material such as gravel and sand, it is recommended that its granulometry has a maximum of 60% of fines such as clays and silts, if it meets all of the above PET is an excellent alternative to apply as a stabilizer of clay soils for rural roads.

According to the study carried out, it is proposed to use PET of size between 5 mm to 10 mm since in the CBR test carried out with 1% PET, it was found that among all the sieves used. The optimum one was the 3/8" passing sieve and 1/4" retained sieve, achieving a value of 7.11% CBR at 0.1" penetration at 95% compaction, being the highest CBR index value than the rest of the sieves.

It is proposed to use 1.5% PET in relation to the dry weight of the soil because this percentage offers greater resistance. For the first soil sample, a CBR of 7.15% was obtained at 95% compaction at a penetration of 0.1". The CBR index obtained is greater than the minimum required of 6%. In addition, an increase of 23.91% of resistance is achieved compared to the standard sample. Regarding the CBR index of the second sample, a value of 4.87% was obtained at 95% compaction at a penetration of 0.1". In addition, there was an increase in resistance of 28.15% compared to the standard sample. For this last sample, it was not possible to obtain the required minimum of 6% CBR, this is because the second sample contained a high concentration of clay since it had a high content of fines 77. 77%, in addition to having a medium-high plastic index of 14.91%, which led to the conclusion that these values are not recommended for the application of PET as a soil improvement for rural roads.

Finally, by using recycled polymers (PET) as subgrade improvement in clay soils, an added value will be given to this material, which will help to counteract environmental pollution and generate a lower environmental impact in its application.

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