

# Evaluation of the geotechnical behaviour of a volcanic soil wall with additions of lime and cement against landslides

C Davila<sup>1</sup>, R Vera<sup>2</sup>, L Pacheco<sup>3</sup> and G Duran<sup>4</sup>

1,2 Bachelor, Universidad Peruana de Ciencias Aplicadas, Lima, Perú

3 Part time profesor, Universidad Peruana de Ciencias Aplicadas, Lima, Perú

4 Full time profesor, Universidad Peruana de Ciencias Aplicadas, Lima, Perú

E-mail: <sup>1</sup>u201322301@upc.edu.pe, <sup>2</sup>u201414317@upc.edu.pe, <sup>3</sup>pccilpac@upc.edu.pe,

<sup>4</sup>gary.duran@upc.edu.pe

**Abstract.** The construction of earth walls can be a significant response to prevent the next landslides from reaching the road and avoid accidents. Therefore, a material of the same slope was used and reinforced with mixtures of lime and cement, with this same reinforced material a mechanically stabilized hypothetical earth wall (MSE) was developed. An analysis of the original slope was developed to check if there was a possible failure through its safety factor. Then, a hypothetical wall was developed with a floor reinforced with mixtures, in order to assess its overall safety factor and its maximum landslides. According to the results, in principle it was determined that the dosage M-3 / C-4-4 improves in a range of 30% to 37% the friction angle. In addition, it was found that a reinforced wall, that is to say with Lime and cement additions, presents a better behaviour. In its effect, its displacements are about 8 mm and have a global factor of 1.23.

## 1. Introduction

Surface erosions and landslides are the products of the various gravitational forces that occur in situ, especially in steep slopes and / or on hillsides forming granular soil. Consequently, the soil with a low degree of compactness has a minimum resistance to any destabilizing force causing surface detachment (landslides), the behavior is mainly due to the gravitational predominance of granular soils[1]. In Peru there are several areas with problems of instability of slopes and / or slopes, and we refer to the Moquegua region that presents land roads on rugged terrain, high rainfall and this adds to the lack of infrastructure to anticipate damage caused for a type of landslide, to this is added, the predominant soil in the southern part of Peru, mostly of volcanic origin. In reality the origin, of most of these types of soil, belong to outcrops of sedimentary rocks (sandstones and siltstones), so that in rainy seasons they are easily removed as detritus flows. In sum, these volcanic soils within their characteristics are found to have low density and large grain porosity [2]. Geotechnical engineering offers solutions for various problems that occur in slopes. As mentioned, there are structural and non-structural methods, in this first solution are presented that leads to the development of steel frame systems, gabions, concrete blocks, improved soil walls, etc. Mechanically Stabilized Walls (MSW) is geotechnical structures that highlight the use of armed land to form a supporting wall. These types of structures have an advantage in terms of structural strength, durability of the material, mitigates environmental damage and the security it provides to the road network [1]. According to mentions that despite having certain advantages, these structures have failures if they are not evaluated correctly. In an analysis of a sample that was Mechanically Stabilized Walls (MSW), about 65% of walls were identified with heights between 4-12 m that failed. For the stabilization of the bases of a soil, different



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

types of binders are used, tales such as lime or cement; these aggregates when finished mixing, devices such as filling empty spaces and particle binding; these particularities improve the strength parameters of the material; to be more exact the angle of friction and cohesion. This document will evaluate the geotechnical conditions of the proposal for a structure of a Mechanically Stabilized Earth Wall (MSW), in addition, that this material will be composed of a mixture of lime and cement.

**2. Experimental Program**

*2.1. Materials*

*2.1.1. Granular Soil*

The material of the area that will make up the earth wall is located in the Moquegua region, Peru; of the departmental highway MO-154 its sexagesimal coordinates are as follows 16°44'23.2"S 71°00'18.3"W. The physical properties of the granular soil were identified and investigated in accordance with the technical standards. ASTM. The next table (Table 1) will show the characteristics (figure 1).

**Table 1** Basic characteristics

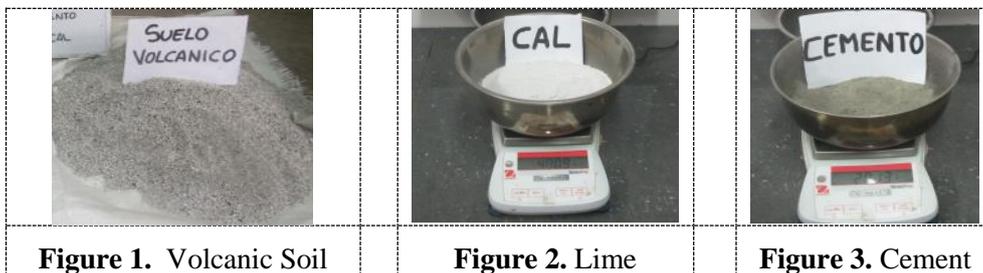
Mixture	LL (%)	LP (%)	IP (%)	SUCS	AASHTO	PUS. (kg/cm <sup>3</sup> )	compacted unit weight (kg/cm <sup>3</sup> )	% Retained 200
<b>M-1</b>	N.P.	N.P.	N.P.	SP	A1-b	0.887	1.06	0.11

*2.1.2. Cement*

The cement used is the Portland Type I of the Pacasmayo brand; it was acquired in Promart department stores (figure 3).

*2.1.3. Lime*

Lime in use is a compound made up of traces of calcium carbonate, calcium hydroxide and particles of disintegrated rocks. The lime was acquired from the department store of Promart brand "Martell"(figure 2). According to NTP 339.176 the potential Hydrogen (pH) It was performed to find optimal lime content, since this pH should not exceed 12.4 so that it has so that the mixture does not have high acidity content [3].



**Figure 1.** Volcanic Soil

**Figure 2.** Lime

**Figure 3.** Cement

*2.2. Mix Preparation*

First mixtures were prepared according to the following table (Table 2), in order to perform the modified Proctor tests and to find the right combination to continue with the tests. Then, it developed shear strength of soil by direct shear test, for the same dosage and the best combination was sought to use its parameters in the plaxis models.

**Table 2** Dosage of mixture and Symbology

Mixture	Soil (%)	Lime (%)	Cement (%)	Simbology
<b>Volcanic Soil</b>	100	0	0	M-1
<b>Mixture 1</b>	100	4	2	M-2/C-4-2
<b>Mixture 2</b>	100	4	4	M-3/C-4-4
<b>Mixture 3</b>	100	4	6	M-4/C-4-6
<b>Mixture 4</b>	100	4	8	M-5/C-4-8

### 3. Methodology

#### 3.1. Laboratory Test

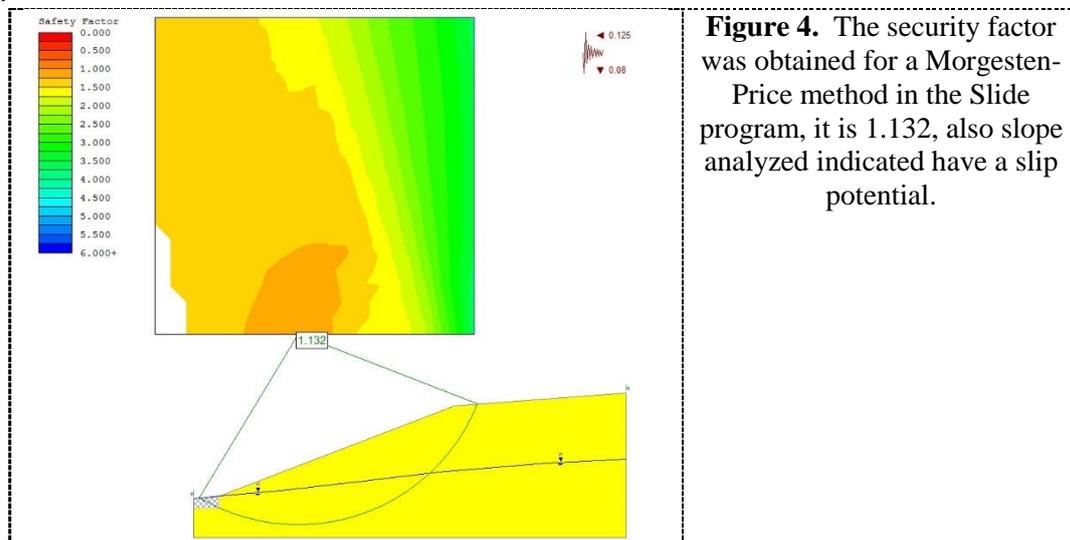
To know the physical properties of Sandy soils and the mixtures were performed the following tests:

**Table 3** Tests made to found the geotechnical properties

Test Name	Norm
Standard Test Method for Particle-size Analysis of soils	NTP 339.128 (ASTM D422)
Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort	NTP 339.141 (ASTM D1557)
Standard Test Method for Direct Shear Test of Soils Under consolidated Drained Conditions	NTP 339.1171 (ASTM D3080)

#### 3.2. Slope

The geological, hydrogeological and mechanical data of the slope were necessary for the elaboration of this investigation. This data will be used for numerical modeling using Slide V 6.0 for the processing of a safety factor [4]. The slope has 2 strata, the smaller one which belongs to the road (MO-154) and the larger one dimension belonging to the land (T-1), the parameters of shear resistance to cutting (friction angle) are 33 and 38 degrees respectively, and the cohesion for both cases is zero. Due to the presence seismic of our study region it should have been added PGA information our design, this is understood as the Horizontal Maximum Acceleration and vertical within the, this parameter was got of the Peruvian Technical Norm of resistance seismic E0.30. With all the data, in addition of the different natural soils characteristics indicated, it will proceed to the modeling of the slope.



**3.3. Reinforced Soil Wall**

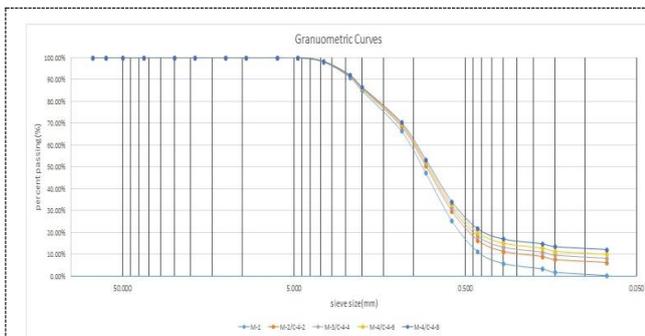
Armed Earth walls also known as Mechanically Stabilized Walls (MSE) is a construction system that has many advantages such as improved strength and stability of the structure, durability of the materials used, better resilience, aesthetics, limited environmental footprint and profitability. Numerical modeling is a useful tool that allows the analysis of complex systems, such as the interaction of structural elements and soil. In this way, with the “PLAXIS” program, the analysis of the mechanically stabilized wall can be performed in order to obtain the deformation and stress behavior generated [5]. For the pre-dimensioning, the percentage of the slope is 38%, the height of the wall is 3.00 m and a lower base of 2.00 m, for better construction process, geotextiles were placed for each 20 cm high block and bracing the main. On the other hand, for the selection of the floor material that will comprise the wall, the mixture M-3 /C-4-4 was chosen, since it is the dosage that best responded to the tests and presents a better behavior.

**4. Analysis and results**

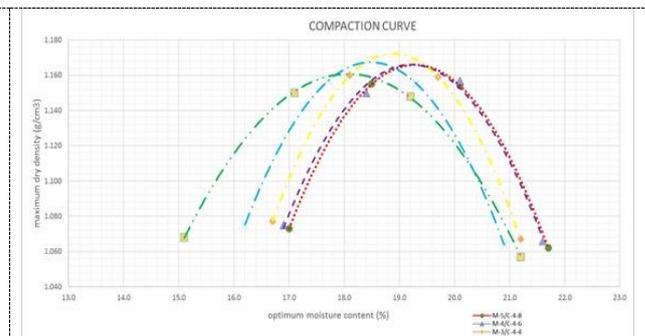
It was determined in the granulometry tests that varied with respect to the M-1 sample; this will be shown in the following table and the granulometric curves in Figure 2. This is due to the fact that by introducing lime into the sample it works for the rearrangement of particles and cement as a binder of these, this increases its coefficient of uniformity and reciprocally the coefficient of curvature.

**Table 4** SUCS classification of natural soil and mixture

classification	SUCS
M-1	SP
M-2/C-4-2	SP-SM
M-3/C-4-4	SW-SM
M-4/C-4-6	SP-SM
M-5/C-4-8	SM



**Figure 5.** Granulometric curves of volcanic soil and mixtures



**Figure 6.** Compaction curves of volcanic soil and mixtures

In the modified Proctor test, improvements of maximum dry density with respect to the natural soil were obtained; this because the binders interact with the soil as grain binders in the M-1 sample, also the addition of lime allows the rearrangement of particles and covers the empty spaces of said sample.

**Table 5** Maximize dry density and optimal moisture content of natural soil and mixtures

	M-1	M-3/C-4-4	M-3/C-4-4	M-4/C-4-6	M-5/C-4-8
<b>MDS(g/cm<sup>3</sup>)</b>	1.161	1.167	1.172	1.168	1.165
<b>OCH (%)</b>	18	18.4	18.8	19.1	19.2

With the data obtained from the shear tests, the fault envelopes for dosing were performed (Figure. 5) where the friction angle and cohesion parameters for each dosage will be obtained from the direct shear tests (table 6.)

**Table 6** Friction angle for each dosage

	M-1	M-2/C-4-2	M-3/C-4-4	M-4/C-4-6	M-5/C4-8
<b>Ø</b>	38.1	44.5	49.6	49.0	46.7
<b>Cohesion</b>	0	0.14	0.24	0.25	0.27

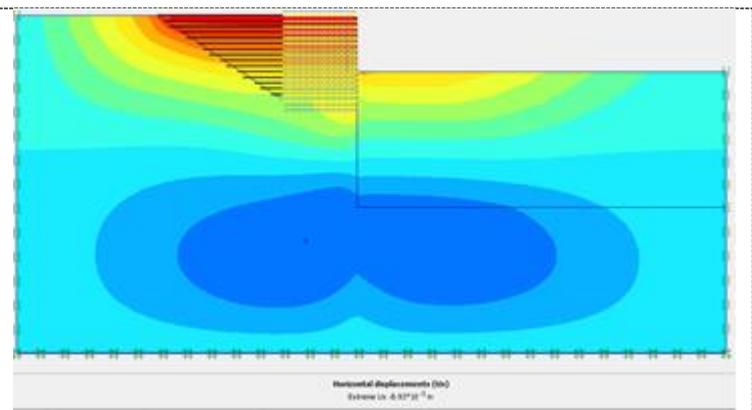


**Figure 7.** it was obtained that the percentages of 4% lime and 4% cement obtain a better performance in combination with the soil. The resistance parameters, in this case the increase in the friction angle for the M-2 / C-4-2 mixture is improved by 17%, with the mixture of M-3 / C-4-4 and M-4 / C-4-6 of cement its friction parameter improves by 30% compared to the natural one. Finally, with a mixture of M-5 / C4-8 the friction increases by 23% in relation to the natural soil.

The results of the modeling carried out in the Plaxis program for a ground wall with the combination M-3 / C-4-4 indicate that for the horizontal displacements (Figure. 8) of the vertical face on the wall it presents a maximum horizontal displacement 8.93 mm. Finally, the global security factor (Figure. 7) has a value of 1.2343, which according to “AASHTO LRFD Bridge Design and AASHTO LRFD Bridge Construction Specifications” establishes a global Safety Factor that is 0.75 for defined geotechnical wall parameters and slope that do not support structural elements.



**Figure 8.** Global safety factor of the wall



**Figure 9.** Horizontal Displacement in Reinforced Wall

### 5. Conclusions

- The maximum optimum density of the mixture M-3 / C-4-4 increases by 0.011 g / cm<sup>3</sup> with respect to M-1, this because the binders interact with the soil as grain binders in this sand,

Additionally to adding them Fine to soil composition, these results are expected given the type of soil of the M-1.

- In the tests of direct shear, the maximum resistance to the shear stress was presented when the horizontal displacement is 2.25mm. When the normal stress applied is 49kPa, the shear strength of the M-3 / C-4-4 mixture compared to natural soil (M-1) increased from 38.5kPa to 79.3kPa, in the same way when the stress Normal applied is 98.1kPa increased from 76.3kPa to 138.9kPa and when normal effort is 196.1kPa increased from 153.9kPa to 253.9kPa
- The friction angle of the optimum mix M-3 / C-4-4 has an efficiency percentage of 30% with respect to M-1, this percentage was higher than the other doses.
- The safety F.S of the wall with the mixture M-3 / C-4-4 is greater than the required 0.75 being this of 1.23 reason why the wall will be in correct operation and will stop the landslides of the Slope.
- The construction of this wall contributes to the conservation of the environment, since the materials to be used do not come from the activity that most critically impacts the “Quarry exploitation” environment. However, quality control in a construction process is of vital importance in terms of the optimal dosage presented and the compaction that must reach the maximum dry density determined in the laboratory.

## References

- [1] R. M. Koerner and G. R. Koerner, “A data base, statistics and recommendations regarding 171 failed geosynthetic reinforced mechanically stabilized earth (MSE) walls,” *Geotext. Geomembranes*, vol. 40, pp. 20–27, 2013.
- [2] S. Yokohama, “Effects of compaction conditions on undrained strength and arrangements of soil particles for Shikotsu volcanic soil,” *Volcan. Rocks Soils - Proc. Int. Work. Volcan. Rocks Soils*, 2015, no. September, pp. 103–104, 2015.
- [3] G. Odar *et al.*, “Stabilization method with lime in subgrades for rigid pavements designed by AASHTO 93 in road projects with the presence of bofedales Método de estabilización con cal en subrasantes para pavimentos rígidos diseñados por AASHTO 93 en proyectos viales con presencia de bofedales,” no. July 2019, pp. 24–26.
- [4] H. Ghiassian, M. Jalili, and D. Kasemi, “Model study of sandy slopes under uniform seepage and reinforced with anchored geosynthetics,” *Geosynth. Int.*, vol. 16, no. 6, pp. 452–467, 2009.
- [5] T.-L. Chau and T.-H. Nguyen, “Study the influence of adherence edge to steel strip and soil interaction in Mechanically Stabilized Earth Wall with a self-made strip,” *Lect. Notes Civ. Eng.*, vol. 54, pp. 757–762, 2020.