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# Mechanical properties of a marginal soil stabilized with various additives

## Propriétés mécaniques d'un sol marginal stabilisé avec divers additifs

**Natalia Perez**

*Infrastructure Department, Mexico, nperez@imt.mx*

**Paul Garnica**

*Center for Innovation & Infrastructure Research, Mexico*

**ABSTRACT:** This paper shows the results of unconfined compression and resilient modulus of a high compressibility clay that was stabilized with five additives. The additives were two polymers, calcium oxide, cement and cement with a zeolite. The properties of the natural soil are shown as a reference. The results indicated that polymers are not efficient in stabilizing clays. Calcium oxide does improve the unconfined compression strength and resilient modulus. But cement and cement with zeolite provide the highest values for both parameters.

**RÉSUMÉ :** Cet article présente les résultats de la compression non confinée et du module résilient d'une argile à haute compressibilité qui a été stabilisée avec cinq additifs. Les additifs étaient deux polymères, de l'oxyde de calcium, du ciment et du ciment avec une zéolite. Les propriétés du sol naturel sont indiquées à titre de référence. Les résultats indiquent que les polymères ne sont pas efficaces pour stabiliser les argiles. L'oxyde de calcium améliore effectivement la résistance à la compression non confinée et le module résilient. Mais le ciment et le ciment avec zéolite fournissent les valeurs les plus élevées pour ces deux paramètres.

**KEYWORDS:** soil stabilization, calcium oxide, polymers, cement, zeolite, additives.

## 1 INTRODUCTION

High compressibility clays are one of the soils usually found along the route of a road project. The way to proceed with this soil type is to remove it and treat it as a waste material. At the present time, it is desirable to utilize all materials found along the project. It is no longer advisable to continue mining materials to place them as subgrade or embankment material, since the damage to the environment continues to increase. To mitigate this, in recent years engineers have carried out several research projects proposing the recycling of materials from different types of civil works. Also, it is recommended to use the materials that are not considered to meet specifications, but mixed them with other products such as additives in order to enhance their properties. The paper presented here is related with the enhancement of a clay properties by mixing it with different additives.

## 2 BACKGROUND

Clays are one of the most researched materials in the area of geotechnical engineering and pavements. This is due to the millionaire damages generated by the volume changes they suffer. Several articles can be found in the literature where results of clays stabilized with different additives have been published. For example, Chen and Huang (2019) conducted a stabilization study with a Kenyan clay. This clay was stabilized with different percentages of lime, different percentages of volcanic ash and also combining both additives. One of the conclusions of the study was that a combination of 1% lime and 15% volcanic ash provided the best properties in terms of volume change control. Geiman et al. (2005) conducted a stabilization study of three soils and six types of stabilizers. The soils studied were two clays and one sand. Some of the conclusions for the soil-polymer were that the unconfined compression strength seems to be independent of the elapsed time between mixing and

- Cement CPC-40RS (cement: 200 kg/m<sup>3</sup>)

compaction. Also, it was observed that the soil-polymer did not increase its strength. The authors mentioned that the reason for this may have been that the samples were not allowed to dry. Another polymer stabilization study was developed by Rauch et al (2002). These researchers studied the effect of three liquid stabilizers (an ionic, polymer and an enzyme) on five soils. Three of the soils were classified as CH, one soil as MH and one as CL. The authors found that the plasticity index did not show significant changes when the soils were stabilized with polymer. With respect to expansion of the soil-polymer mixtures, it was reduced by 10% for some soils; for one soil it increased.

There are many studies of soil stabilization with lime. Little (1999) summarized some of them indicating the properties studied, standards used and results obtained. All the studies indicated that lime does improve the properties of the studied soils. For this reason, this additive has been one of the most popular in the engineering community. Cement is also a well-known product to stabilize clays as shown by many authors (Prusinski and Bhattacharja, 1999; Herzog and Mitchell, Binti, 2011, etc). As seen, all additives studied in this research have been researched in other countries. The results shown here will be part of these studies, but also they contribute to the knowledge of resilient modulus of stabilized soils.

## 3 THE MATERIALS

To carry out the research, a CH soil was utilized. The clay was stabilized with 5 additives:

- Polymer 1. A white viscous liquid. It was mixed with the compaction water; the polymer was calculated as 8% of the compaction water.
- Polymer 2: A brown liquid (50 ml per each kilogram of solid additive) added together with a solid additive (1% regarding dry mass of soil).
- Quicklime. 4% regarding dry mass of soil.
- Cement CPC-40RS (200 kg/m<sup>3</sup>) and zeolite

- Water: Tap water for all additives

#### 4 TEST PROCEDURES

To evaluate index properties, compaction and unconfined compression, ASTM standards were utilized. Resilient modulus testing was executed by following the NCHRP 1-28A protocol. The evaluation of the additives was done only with unconfined compression and resilient modulus tests. They were carried out as follows:

##### 4.1 Specimens preparation

To prepare the specimens, the following procedure was followed:

- The soil was mixed with the additive and immediately the compaction was carried out.
- For natural soil, compaction water added, mixed and stored during 24 hours.
- After mixing and storage (in case storage was needed), the specimens were compacted. For this, a mold of 71 mm diameter and 144 mm height was utilized. The specimen was compacted in 8 layers; in each layer a certain number of drops were applied (in order to achieve the maximum dry unit weight) with a hammer of 1-kilogram mass and 30.5 cm drop height (Figure 1).



Figure 1. Specimen compaction.

- To proceed, the dimensions and weight of specimens were taken.
- The testing was carried out after the conditioning was achieved (0, 7, 14, 28 days of storage; 7, 14, and 28 days of drying or 7, 14, 28 of storage followed by 14 days of wetting and then 14 days of storage).
- The wetting and drying was carried as shown in Figure 2. After wetting or drying, samples were wrapped with plastic and allow them to stay in this state during 14 days.

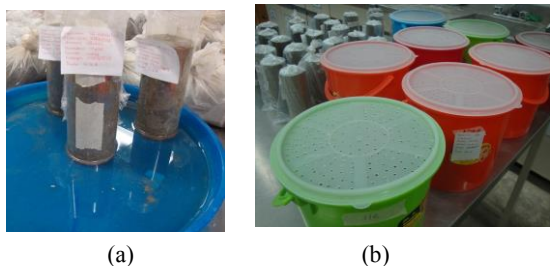


Figure 2. Wetting and drying of soil samples.

It is important to mention that wetting was through capillary flow; the drying was done by placing the specimens inside containers; the lids of the containers have small holes, such that the drying can take place slowly. This avoids cracking of samples.

#### 4.3 Resilient modulus test

Figure 3 shows the triaxial test equipment utilized in this research. The resilient modulus tests were conducted in accordance with the NCHRP 1-28A test protocol. According to this protocol, the resilient modulus test for subgrade soils consists of applying a cyclic-haversine shaped load for a duration of 0.2 seconds and a rest period of 0.8 seconds. During the test, 16 sequences with different states of stress were applied.



Figure 3. Triaxial equipment.

#### 5 RESULTS

##### 5.1 Index properties

Table 1 shows the properties of the test soil.

Table 1. Index properties of soil.

Characteristic	Value
Classification (USCS)	CH
Liquid limit (%)	91
Limit plastic (%)	33
Plasticity index (%)	58
Specific gravity	2.48
Passing 200 sieve (%)	96.17

##### 5.2 Compaction curves

To prepare the specimens, the Proctor compaction curves were first evaluated. Figures 4 to 6 show the compaction curves for natural soil, soil-limeand soil-cement. The curve for soil-cement-zeolite was assumed to be the same as the soil-cement. On the other hand, the specimens of soil-polymers were compacted taking into account the characteristics of natural soil.

##### 5.3 Unconfined compression test

Unconfined compression tests were carried out by following the procedure ASTM D 2166. According to this procedure, the sample is placed in the loading machine and a load is applied at a rate of 0.5-2%/min. In this research, the rate was 1.2%/min. The test was finished when the maximum load was observed; at the end of the test, the specimen was disintegrated to obtain samples to determine the final water content.

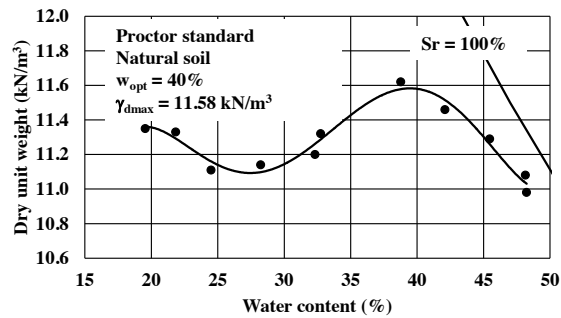


Figure 4. Proctor compaction curve of natural soil

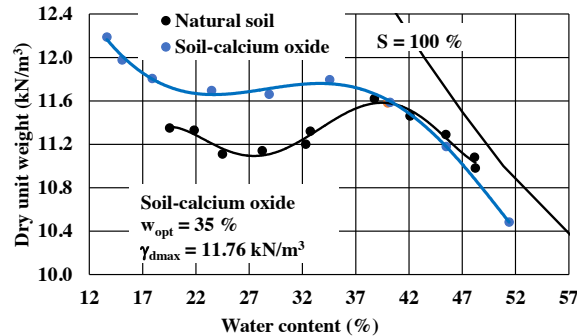


Figure 5. Proctor compaction curve of natural soil and soil-calcium oxide.

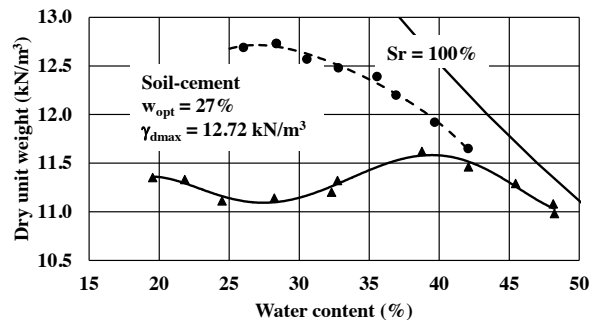


Figure 6. Proctor compaction curve of natural soil and soil-cement.

### 5.3 Unconfined compression strength

Results of unconfined compression indicate that lime, cement and cement-zeolite are the most effective additives to improve the strength of the clay (Table 2; Figures 5, 6 and 7). However, it is also important to note that the strength obtained in soil stabilized with cement or cement and zeolite are similar, showing that most of the improvement is due to the cement.

Table 2. Unconfined compression summary.

Condition	Unconfined compression strength (kPa)					
	NS	P1	CO	SCZ	SC	P2
0A	152	144	598	958	667	237
7A	181	163	1273	2935	2738	296
14A	150	300	1368	3111	3367	305
28A	321	323	1184	4220	3570	296
7S	381	404	1488	3579	3899	504
14S	785	475	1374	3879	3876	501
28S	785	537	2104	4019	4165	555
7-14-14	23	31	1267	5138	5480	105
14-14-14	47	47	1364	4387	4546	58
28-14-14	47	40	1495	4807	4259	75

NS: Natural soil; P1: Polymer 1; CO: Calcium oxide; SCZ: soil-cement-zeolite; SC: soil-cement and P2: Polymer 2

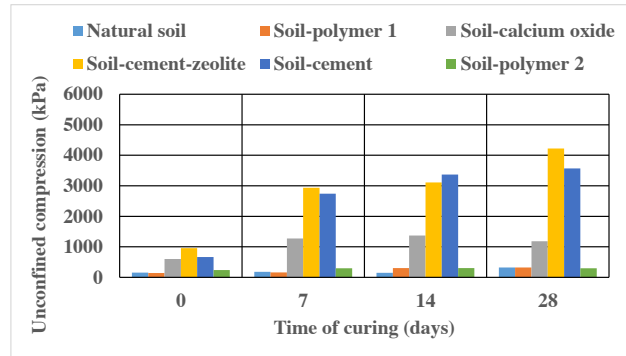


Figure 7. Results of unconfined compression for different curing times.

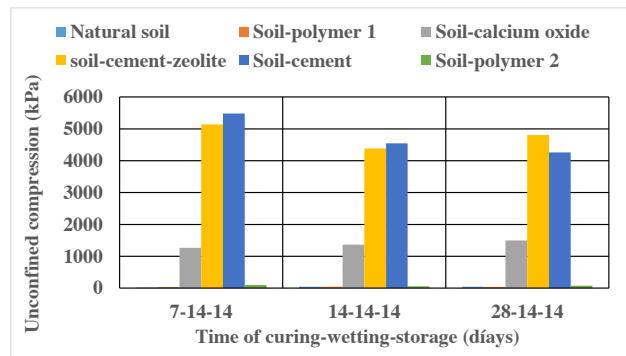


Figure 8. Results of unconfined compression for samples that were wetted after storage time.

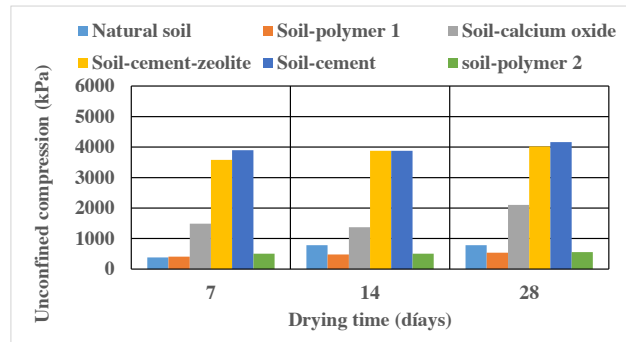


Figure 9. Results of unconfined compression for samples that were dried.

The results also indicate that polymers are not a suitable additive at least for this clay.

It is worth to mention that in pavements water is a key in the behavior of materials. Usually, if materials absorb water, they lose strength, however, in this case, if clay is mixed with lime, cement or cement and zeolite, even if the material gains water, the strength is not reduced but rather seems to increase.

### 5.4 Resilient modulus

The results of resilient modulus are summarized in Table 3 and they are also shown in Figures 10, 11 and 12.

The results indicate that resilient modulus for natural soil and soil with polymers is similar. And for this parameter, cement, cement-zeolite and lime seem to provide similar resilient modulus values. For 0, 7 and 14 days of curing, lime provide larger values of resilient modulus compared to that of soil-cement (Figure 10).

Table 3. Resilient modulus summary.

Condition	Resilient modulus (MPa)					
	NS	P1	CO	SCZ	SC	P2
0A	38	37	163	96	101	57
7A	58	52	256	206	186	64
14A	63	59	208	181	196	74
28A	61	62	203	212	224	71
7S	80	68	159	147	189	102
14S	131	124	141	158	144	113
28S	98	115	135	174	126	215
7-14-14	4	7	222	329	287	18
14-14-14	7	8	222	293	375	11
28-14-14	8	10	225	284	241	11

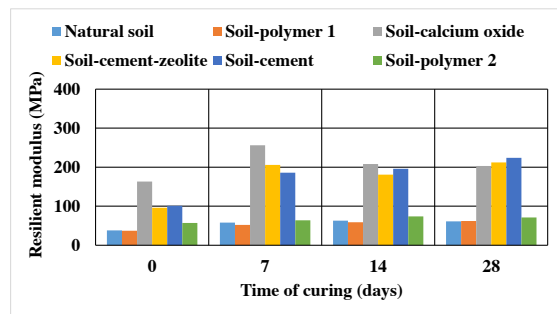
Resilient modulus for  $\sigma_d = 97$  kPa and  $\sigma_3 = 14$  kPa

Figure 10. Results of resilient modulus for different curing times.

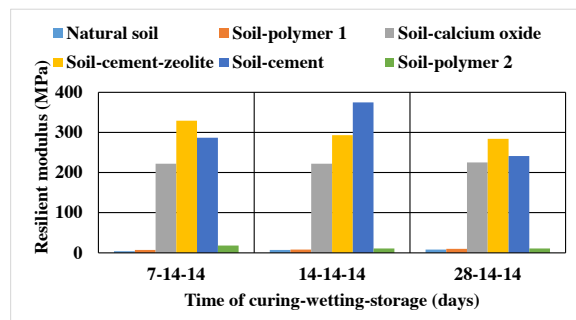


Figure 11. Results of resilient modulus for samples that were wetted after storage time.

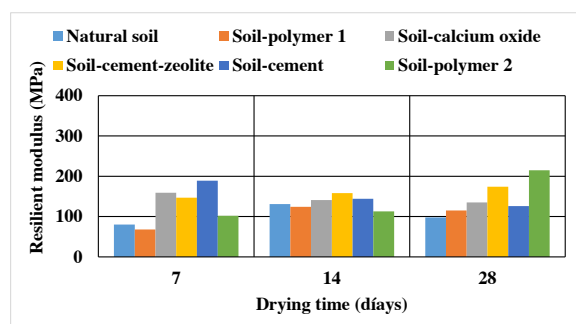


Figure 12. Results of resilient modulus for samples that were dried.

For the samples that were wetted, it seems that the stiffness (in terms of resilient modulus) is not affected by the absorption of water. Water seems to have an opposite effect, that is to say, the resilient modulus is increased compared to values obtained in samples that were storage (Figure 11). For the condition of drying, again, lime, cement and cement-zeolite provide the largest values of resilient modulus. The exception is the case of polymer 2 for 28 drying, this gave the highest resilient modulus, it should be checked to be sure that this value is correct.

## 6 CONCLUSIONS

The evaluation of additives is an important task in the area of pavements. This is because engineers are reluctant to use these products if they do not know their behavior. The study shown in this paper indicates that for the case of the clay studied, polymers are not a good option to stabilize it. Calcium oxide, cement and cement with zeolite seem to be the best option, since both compressive strength and resilience moduli are improved. In fact, even the most critical condition (when the soil absorbs water) shows that these additives make the clay less susceptible to variations in its properties due to water gain.

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