EFFECT OF CEMENT AND LIME ON PHYLLITES RAW MATERIALS FROM SE SPAIN

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It has been previously found that the compacted phyllites did not display an important swelling on soaking at low stresses, as a consequence of its low specific surface and low water-retention ability. This material exhibited good compaction properties and, consequently, low water permeability plus a stiff response on loading. Nevertheless, despite the low porosity attained on the dry-side compaction, the material underwent some collapse on soaking at stresses greater than 100 kPa. Lime and cement addition as stabilisation products have been studied to reduce soil activity, and therefore, its expansivity. The results obtained in the experiences on stabilizations of phyllites-cement and of phyllites-lime improve the capacity amble of the soil. It is demonstrated in this investigation that the most suitable stabilization can be found by addition of 5 wt% cement. Thus, the composite is more impermeable and shows a high resistance to the vertical efforts of compression. For the same reason, the stabilization discards with lime despite the lower relative cost as compared with cement, since a proportion of 3 wt% seems enough to reach the index of capacity amble demanded according to PG-3, managing together to reduce substantially the plasticity of the raw phyllite material.

Keywords: *Phyllites; Permeability; Expansivity; Stabilisation; Lime; Cement*

EFECTOS DEL CEMENTO Y DE LA CAL EN MUESTRAS DE MATERIALES QUE CONTIENEN FILITAS PROCEDENTES DE SE DE ESPAÑA

En trabajos preliminares se ha encontrado que las filitas compactadas no sufrian una expansión importante cuando eran saturadas de agua, como consecuencia de su escasa capacidad de retención de agua y de su baja superficie específica. El material registró buenas propiedades de compactación, como consecuencia de su baja permeabilidad al aumentar la carga aplicada al suelo. Sin embargo a pesar de la baja porosidad el material registro un colapso cuando se consolida por encima de 100 kPa y dentro del lado seco. La cal y el cemento han sido usados como estabilizantes químicos para reducir la actividad del suelo, y por tanto su expansividad. Los resultados obtenidos muestran que las estabilizaciones de filitas con cemento y filitas con cal han mejorado la resistencia al punzonamiento del suelo, aunque la más conveniente es la que incorpora el 5% de cemento, ya que presento una alta resistencia a compresión uniaxial y una baja permeabilidad. Por esta misma razón se descarto la estabilización con cal, apesar de que con sólo el 3% se alcanza la resistencia al punzonamiento exigida en el PG-3, logrando además reducir la plasticidad del suelo.

Palabras clave: *Filitas; Permeabilidad; Expansividad; Estabilización; Cal; Cemento*

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1. Introduction

Phyllites at the Alpujarra region (Andalusia, Spain, provinces of Almería and Granada) have undergone several en-masse movements as a consequence of sliding and/or flow processes. These movements are conditioned, among other factors, by the dipping angle of the slopes, and the low shear strength and the humidity of the material (Alcantara-Ayala, 1999). The occurrence of expansive phenomena may also cause serious problems in arid-climate regions. In such regions, the clay is so dry that even a small amount of water supply can lead to major swelling (Lamara et al., 2005; Al-Rawas et al., 2005). During the 90s, residential buildings built on clay phyllites (Vicar – Almería, Spain) sustained severe damages due to water uptake.

On this point Garzón et al., 2010 found the development of swelling strains of a dry-side compacted material at Modified Proctor (MP) and at low vertical stresses. Despite the presence of some clay minerals (illite) and the interstratified phase illite-smectite in the raw phyllite, the densely MP compacted phyllite did not display notable swelling on soaking at low stresses, as a consequence of its low specific surface. Nevertheless, this expansivity limits its use in earth constructions were low stresses are envisaged, such as road subgrades.

On the other hand, well-established techniques of soil stabilization are often used to obtain geotechnical materials improved through the addition of cementing agents, such as cement, lime, asphalt, etc (George et al., 1992; Miller and Azad, 2000; Seco et al., 2011; Castro-Fresno et al., 2011). If the by-product has attributes superior to those of original material with a similar cost, it becomes an attractive alternative in soil engineering. As a result of previous research, several methods have been proposed to apply some industrial additives to increase the properties of the raw soils (Gidley and Sack, 1984; Kamon and Nontananandh, 1991; Attom and Al-Sharif, 1998; Kolias et al., 2004; Basha et al., 2005).

The application of principles of soil stabilization requires an understanding of local conditions for a given country (Ali, 1992; Bell, 1996; Attom and Al-Sharif, 1998; Al-Rawas et al., 2005). The soil found locally may differ in imperative aspects from soils tested in other ones. Soil type and climatic conditions affect the characteristics of stabilized soil materials, as well as technical method and procedures. Therefore, previous accurate characterization of the local soils prior to the application of the stabilization procedures is mandatory.

In the present paper, the possibility of improving clay phyllite soils from Berja (Almería, Spain) is examined. This sample contain phyllites as the main component (phyllite soils). The effects of lime and cement in a proportion in the range 3-9 wt% on the consistency, density, strength and permeability of the residual phyllite-soils produced by these additives have been studied.

2. Material and methods

A systematic experimental programme was envisaged to study the changes undergone by the clay phyllite material studied by Garzón et al. (2010) during lime or cement stabilisation at different proportions (3%, 5% and 7% mass basis for lime; 5%, 7% and 9% for cement). This programme was devoted specifically to reducing soil activity (decrease of the plasticity index), and therefore its expansivity, for its potential use in road subgrades. The cement and lime used were the following: a) cement CEM V/A 32.5 N/mm^2 (UNE-EN 197-1:2000), b) lime (calcium hydroxide content: 92±2 wt%), water content <1.5 % and particle size less than 125 µm in a proportion of 96 wt%.

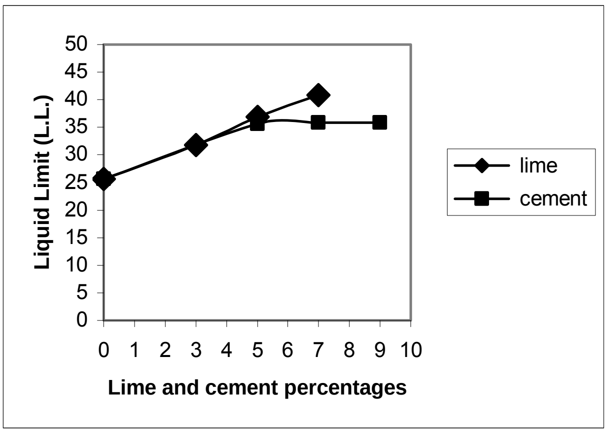
Stabilised materials were characterised by their consistency limits in their remoulded states (ASTM, 2006) to detect the reduction of the activity of the material. In addition, the MP-compaction properties in terms of optimum water content and maximum dry density achieved were also studied for the different lime and cement contents. The stabilisation study ended by the characterisation of the California Bearing Ratio (CBR) (penetration test according to ASTM Standard), uniaxial compression strength tests and permeability in equipment triaxial on original and stabilised soil samples (following ASTM Standard).

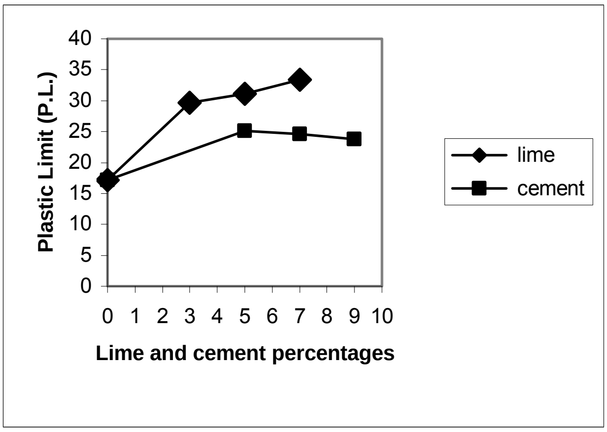
3. Results and discussion

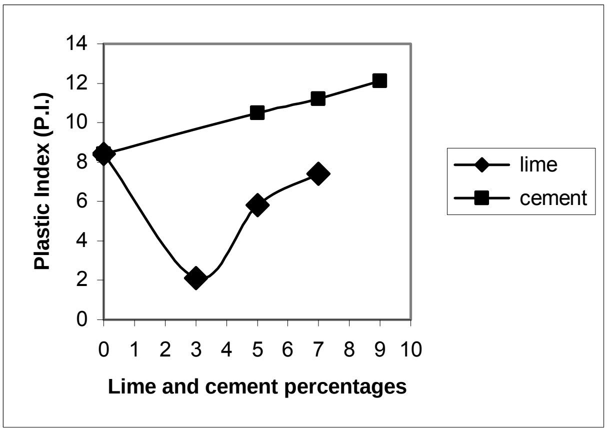
This section discusses a set of interesting results on the cementitious binder stabilisation, lime and cement additions, of compacted phyllites in view of their potential use as construction materials in earth structures submitted to low stresses, such as those underlying a pavement structure.

Figure 1 summarises the main results for consistency limits in their remoulded state for different soil-binder mixtures (natural soil 3%, 5%, and 7% mass basis for lime; 5%, 7%, and 9% for cement). As readily noted in the figure, the effect of lime stabilisation is some reduction of the plastic index as a consequence of the considerable increase in the plastic limit with lime addition –with greater changes than those undergone by the liquid limit. This slight reduction of the plastic index is expected to decrease the activity of the material and, consequently, its sensitivity to water changes. Despite that these results agree with those reported by Lopez-Lara *et al*. (1999), Ola, 1977 on lateritic soil and Bell, 1996 on laminated clay, further research needs to be done and complement these results to understand this slight reduction in plastic index and the real benefit of lime stabilisation in controlling the swelling capacity of the compacted material. In addition, the present results also show that

Figure 1: Results of Atterberg limits: for clay phyllite soil, soil+lime and soil+cement mixtures.

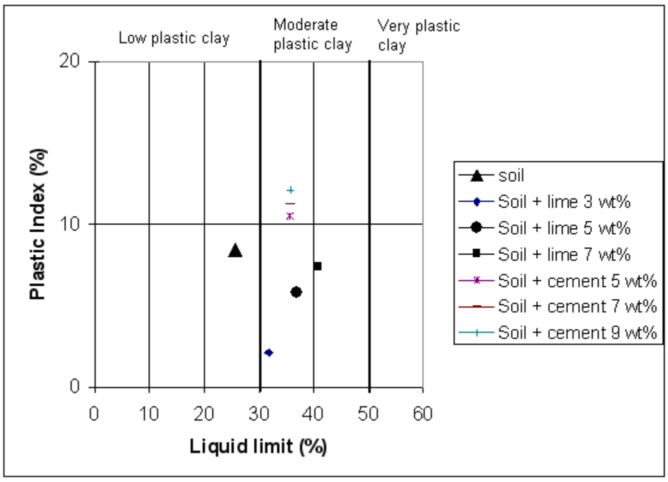






lime percentages over 3 wt% are scarcely effective in reducing the plasticity index, which has also been corroborated by Ayuso (1982). On the contrary, the addition of cement does not contribute to the reduction of the activity and, therefore, it appears not as effective as a binder compared with lime to stabilise the soil and reduce its sensitivity to water changes. Figure 2 shows the above results positioned on the Holtz and Kovacs (1981) diagram. It can be observed the change to low-plastic to moderate-plastic produced by addition of lime and cement, as well as the change induced by addition of the larger proportion of cement (9 wt%) to the phyllite sample, with a relative higher plastic index (12,1) as compared with all these.

Figure 2.- Position of clay phyllite soil, soil-lime and soil-cement samples on the Holtz and Kovacs, 1981 diagram.

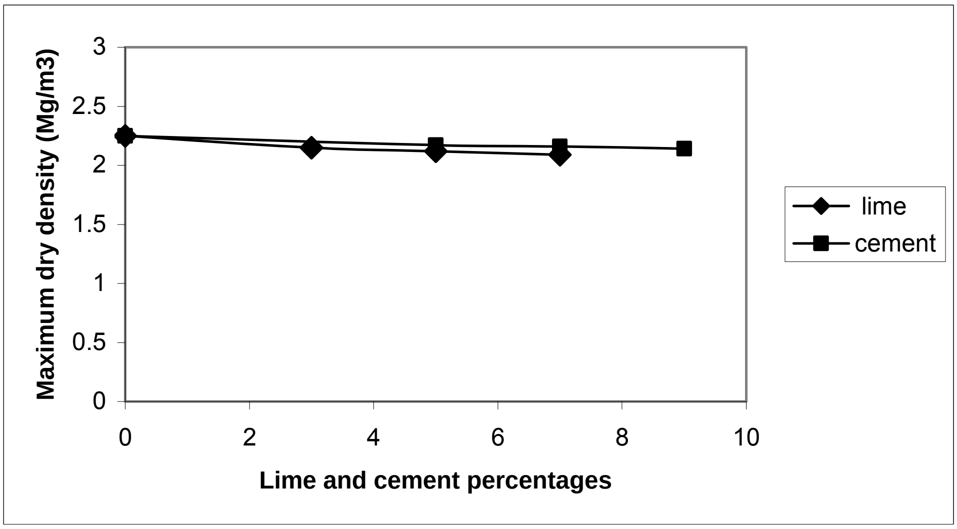


The MP compaction results in terms of optimum water content and maximum dry density achieved by the different binder proportions are summarised in Figure 3.

According to these results, the addition of both lime and cement induce a slight decrease in the dry density and an increase in the optimum water content, when it is compared to the results presented for the untreated phyllite. These results are consistent with those presented by Ola (1977); Kezdy (1979); Ayuso (1982); Bell (1996); Miller and Azad, 2000. The slight decrease in the dry density is explained due to the lower solid density of the binder used, as well as to the higher rigidity of the treated soil skeleton. The slight increase in the optimum moisture water content is a consequence of the increase detected in the liquid and plastic limits with binder addition. It should be noted that Ola (1977) associated changes of this kind to a puzzolanic reaction, i.e. a chemical reaction, between the clay minerals and lime addition. Such a process can be operating in the present case.

The stabilisation study continues with the results reported in Table 1, in which a considerable increase in the penetration properties (California Bearing Ratio, CBR) was found in stabilised soil samples. Again, proportions larger than 3 wt% for lime and 5 wt% for cement are not so effective in increasing CBR. It is not yet clear how to explain this considerable increase, and the associated changes in the consistency limits induced on clay phyllite stabilization, which could be also associated to mineralogical characteristic of the phyllite sample, where illite and interstratified phase illite-smectite were found (Garzón et al., 2010). At the same time, stabilization of phyllite soil with both lime and cement additions produces the dissapearing of the expansion phenomenon or swelling of the original untreated material (see Table 1).

Figure 3. Results of Modified Proctor (MP) test for clay phyllite soil, soil+lime and soil+cement mixtures.



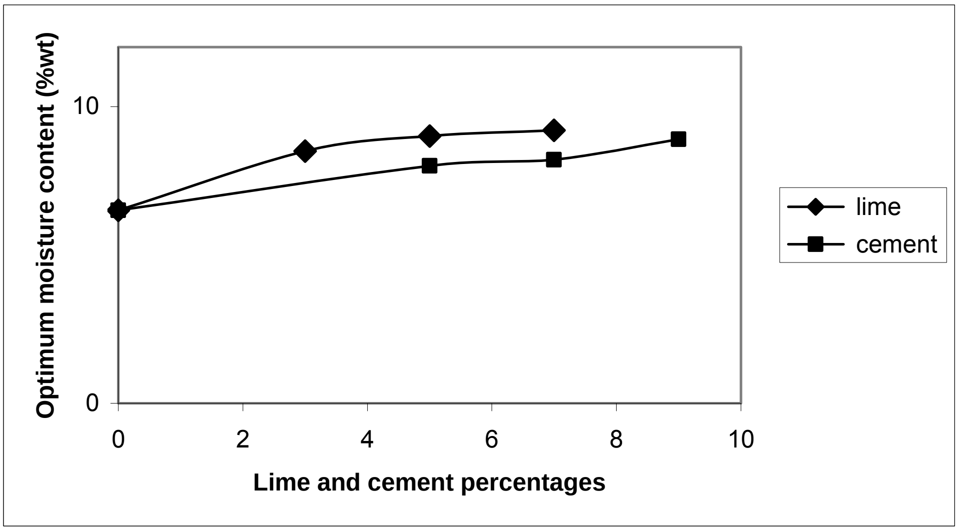
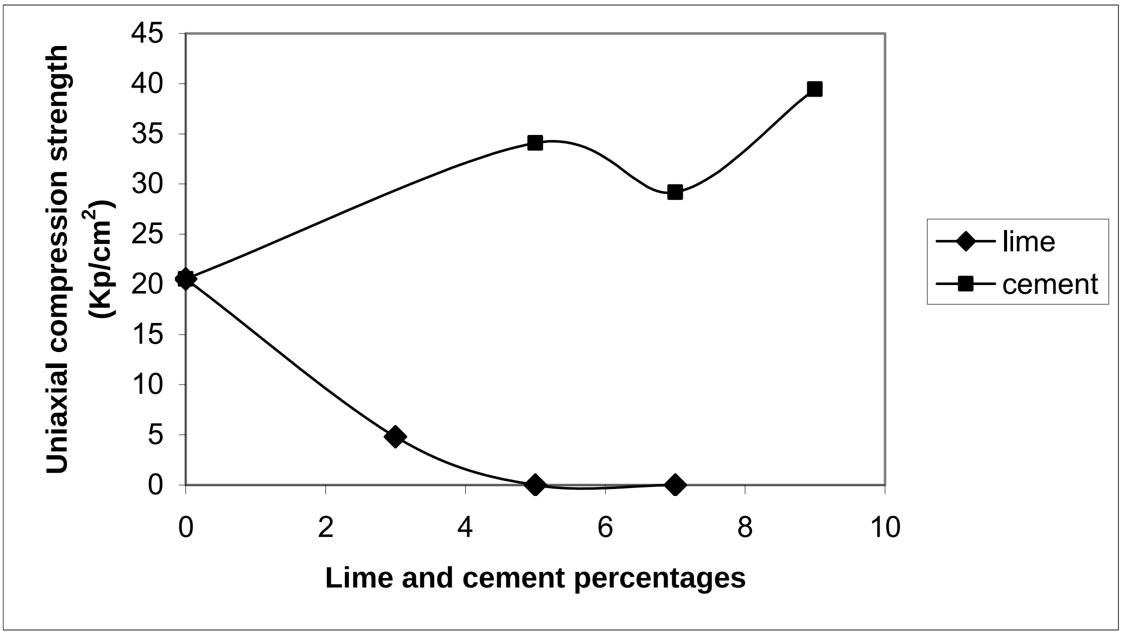


Table 1. Results of CBR test for soil, soil+lime and soil+cement mixtures.

Sample	CBR 100 % MP	CBR 95% MP	Swelling
Soil	2.5	1.7	3.56
Soil + Lime 3 wt%	34.9	19.6	0
Soil + Lime 5 wt%	37.9	21.2	0
Soil + Lime 7 wt%	42.0	22.2	0
Soil + Cement 5 wt%	43.0	15.0	0
Soil + Cement 7 wt%	50.0	28.4	0
Soil + Cement 9 wt%	31.8	35.6	0

Nevertheless, when the uniaxial compression strength results are analyzed (Figure 4), they show that the lime addition produces a sudden fall of the uniaxial compression strength than that the original untreated sample, and they enclosed generates that the samples fall apart before the break. In contrast, the stabilization with cement is characterized by an increase of the uniaxial compression strength, being practically twice at 9 wt%.

Figure 4. Results of test for uniaxial compression strength (Kp/cm^2).



These results point out that the stabilization process most adapted for presenting a high strength to the vertical efforts of compression applied is the one that adds cement, so that with a percentage of cement of 5 wt % the uniaxial compression strength is 34,09 Kp·cm^{-2}. However, on having increased the cement proportions does not show a linear increase of the uniaxial compression strength, though always it remains over the range between 17,5- 28,0 Kp·cm^{-2} fixed by Dal-Ré (1994) for such a kind of stabilization. This result indicates that with minor addition of cement, the values of uniaxial compression strength can be easily reached to a minor relative cost.

Finally, it can be observed that the phyllite sample changes to a more non permeability character, i.e. the permeability decreases, when it is stabilized by addition of cement at 9 and 5 wt% (Table 2). However, the stabilization using lime provocates an increase of permeability. These results are congruent with the experimental values of compression strength. Although all these results on stabilization are of great interest for application of the clay phyllites, it is pointed out that the most economical product can be obtained by addition of cement at 5 wt % to the original sample.

Table 2: Evolution of permeability (K in m/s) of compacted clay phyllite samples with Modified Proctor and addition of cement and lime.

Sample	K (m/s)
Natural soil	1,81E-11
Soil + 5% Cement	7,42E-11

Soil + 7% Cement	3,95E-10
Soil + 9% Cement	1,39E-11
Soil +3% lime	3,53E-10
Soil +5% lime	6,21E-10
Soil +7% lime	2,41E-09

4. Conclusions

In view of the potential use of clay phyllites as construction material in earth structures submitted to low stresses, this research includes an investigation of its stabilisation with cementitious binder. The results obtained in the present work described experiences on stabilizations of phyllite-cement and of phyllite-lime to improve the capacity amble of the soil. There has been demonstrated that the most suitable stabilization is produced by addition of cement at the proportion of 5 wt% for presenting a high resistance to the vertical efforts of compression, being the composite material with a lower value of permeability and most economical. For the same reason, the stabilization discards with lime in spite of turning out to be more economic, since a concentration of 3 wt% turns out to be sufficient to reach the index of capacity amble demanded in the Sheet of Technical General Prescriptions for Works of Roads and Bridges PG-3 of the Headquarter of Roads, managing together to reduce substantially the plasticity of the soil.

Future research is now in progress to study the addition of both lime and cement to the clay phyllites with the objective of a decrease of the plasticity for determined applications. They will be matter of future reports.

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