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Note

Effect of lime on stabilization of phyllite clays

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ABSTRACT

This paper represents a new advance in the study of engineering properties and material applications of phyllite clays. Considering their potential use as construction materials for structures subjected to low stress levels, this laboratory research investigated the stabilization and improvement in engineering properties of a Spanish phyllite clay achieved by the addition of 3, 5 and 7 wt.% lime. Geotechnical properties investigated include the consistency limits, compaction, California Bearing Ratio, swelling potential and water-permeability. The phyllite clay–lime mixtures had good compaction properties and very to extremely low permeability-coefficient values, with a semi-logarithmic correlation between increasing permeability and increasing proportion of lime additive. The addition of 3 wt.% lime was sufficient to reach the index of capacity amble specified in the Sheet of Technical General Prescriptions for Works of Roads and Bridges PG–3 (Spanish Highways Agency, 2008), significantly reducing the plasticity index value, with the compacted mixture undergoing no swelling under soakage. The required pavement thicknesses for the raw phyllite–clay material and the phyllite clay–lime mixtures are compared and discussed. Potential applications for phyllite clay–lime mixtures include for pavements/road subgrade, earth construction, building materials and for impermeabilization purposes.

1. Introduction

Well established soil improvement and stabilization techniques for clayey soils by the addition of cementing agents (e.g. lime, cement, asphalt, coal waste, ash, etc.) are often used to obtain engineering materials having superior properties/performance (Attom and Al-Shariff, 1998; Basha et al., 2005; Castro-Fresno et al., 2011; Di Sante et al., 2014; George et al., 1992; Gidley and Sack, 1984; Kamon and Nontananandh, 1991; Kolias et al., 2005; Miller and Azad, 2000; Modarres and Nosoudy, 2015; Seco et al., 2011). Soil type, application and environmental conditions can significantly influence the choice of technical methods and procedures employed, as well as the resulting characteristics of the treated soil. Hence, prior to the application of soil improvement/stabilization procedures, an accurate characterization of the local soils and an understanding of local conditions for a given country are deemed mandatory (Ali, 2004). For instance, expansive phenomena may cause serious problems in arid climates, whereby the supply of water from any source is liable to cause ground heave in soils or rocks possessing swelling potential (Al-Rawas et al., 2005).

Phyllite clays or 'phyllites' are rocks (metamorphosed to a low extent) of slate clay materials that are found in vast areas around the world. Phyllites belong to the foliated and platy group composed of tabular and elongated minerals (the lamination and foliation make them break along planes) and they are thinly bedded. Phyllites contain an abundance of fine grained phyllosilicates, which gives them an unctuous feel, and the existence of preferential cleavage makes them easily breakable into thin sheets (Adom-Asamoah and Owusu-Afrifa, 2010; Alcántara-Ayala, 1999; Garzón et al., 2009a; Lonergan and Platt, 1995; Oliva-Urcia et al., 2010; Ramamurthy et al., 1993; Sanz de Galdeano et al., 2001; Valera et al., 2002). In a recent paper, de Oliveira et al. (2015) considered phyllite as a 'granulated metamorphic rock', citing previous work performed by Arnold et al. (1998). However, Arnold et al. (1998) considered phyllite as low-grade metamorphic rock, classified as greenschist facies with thin-shaly foliated texture, formed from pelitic rocks. de Oliveira et al. (2015) studied the effect of the substitution of hydrated lime with Brazilian phyllite on mortar quality. They concluded that the contribution of the phyllite to mortar quality was lower than that of the lime and, therefore, produced a reduction in mortar quality, rather than improving it.

The present investigation concerns the stabilization and improvement in the engineering properties/performance achieved for Spanish phyllite–clay material by the addition of lime. The addition of lime stabilizes clay, although the percentage of lime content required changes with clay type/minerals. Hence, the proper design of clay–lime mixtures includes careful identification of pertinent soil characteristics and a well-developed experimental testing program aimed at identifying the appropriate mix proportions to achieve the required material properties/performance. Composite materials having attributes superior to those of the original soil (clay), but produced with low or at similar

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relative cost, are an attractive proposition for applications in the construction and building industries.

Due to their good compaction properties and very low permeability, traditional uses of phyllites in southeast Spain have been for very specific purposes, including: as cover for and to impermeabilize roofs and the central area of ponds; as core material in zoned dam/reservoir construction; and for waste landfill applications (Alcántara-Ayala, 1999; Castillo, 2010; Garzón et al., 2009a, b; Garzón et al., 2010; Lonergan and Platt, 1995; Sanz de Galdeano et al., 2001). A systematic program of testing was performed on materials sampled from several phyllite–clay deposits located in the Almería and Granada provinces (Andalusia Region, Spain) by Garzón et al. (2009a); Garzón et al., 2009b; Garzón et al., 2010). The materials had good compaction properties and, hence, low water-permeability values and stiff response on loading. Despite the low porosity attained for dry-side compaction, the material underwent some collapse settlement on soaking at stresses greater than 100 kPa. At low applied stress, the compacted material did not display important swelling on soaking (despite the presence of active clay minerals) on account of its low specific surface and low water-retention ability. Nevertheless, the expansivity of these phyllite clays limits their used in some applications, such as earth construction where low stress levels are envisaged; e.g. as road subgrade material.

Recently, we reported on new phyllite clay–cement composites having improved engineering properties and material applications (Garzón et al., 2015). In the present paper, we present the experimental findings of an original investigation performed to examine the improvement in engineering properties/performance of Spanish phyllite–clays achieved by the addition of up to 7 wt.% lime. The main focus of this research was to investigate the effectiveness of lime addition in producing a reduction in the phyllite clay activity (i.e. decrease its plasticity index value), and therefore its expansivity, in order to meet regulatory requirements for its potential use as road subgrade material. The engineering properties of the phyllite clay–lime mixtures investigated include their consistency limits, compaction, California Bearing Ratio, swelling potential and water-permeability. The required pavement thicknesses for the raw phyllite clay and phyllite clay–lime mixtures are also compared and discussed. To the authors' knowledge, this is the first international report presenting such data for phyllite clay–lime mixtures.

2. Experimental

Select phyllite–clay samples were sourced from Berja, Almería, Spain. In its natural state, this material has a very low gravimetric water content ranging 1–2% (mean of 1.8%), a void ratio (volume of voids to volume of solids) value of ~0.39 and a dry density of 2.03 Mg/m^3 (Garzón et al., 2010). The representative bulk phyllite–clay sample used in the present investigation was oven dried at 105–110 °C to constant mass, allowed to cool to ambient laboratory temperature (20 °C), disaggregated, and then sieved to obtain the fraction passing the 20-mm sieve (grading curve for which is presented in Fig. 1).

Garzón et al. (2010); Garzón et al., 2015) reported the predominant silica-alumina chemical composition of these phyllite clays, with typically 45–50 wt.% of silica and 22–24 wt.% of alumina. Minor amounts of other oxides were also found present, such as CaO (1.7–4.4 wt.%), MgO (2.8–3.4 wt.%), Na_2O (1.8–2.4 wt.%), K_2O (3.3–3.9 wt.%) and iron oxide as Fe_2O_3 (8.3–9.4 wt.%). The mineralogical composition) of these samples was determined by X-ray powder Diffraction (XRD) as chlorite and illite (main clay minerals), quartz and some minor aluminosilicates, potassium feldspar and an interstratified phase with phyllosilicates, which was identified as mixed-layer illite–smectite or possible chlorite–smectite. The loss in dry mass of a representative test-specimen of the natural material after 1 h of thermal treatment at 1000 °C ranged 6.8–7.0 wt.%, which was associated with phyllosilicates having structural OH groups (i.e. chlorite, illite and interstratified phase).

The lime used in preparing the soil mixtures was a powdered sample of industrial hydrated lime material (96 wt.% passing the 125 μm sieve), which had a calcium hydroxide content of 92 ± 2 wt.% and a gravimetric water content <1.5%.

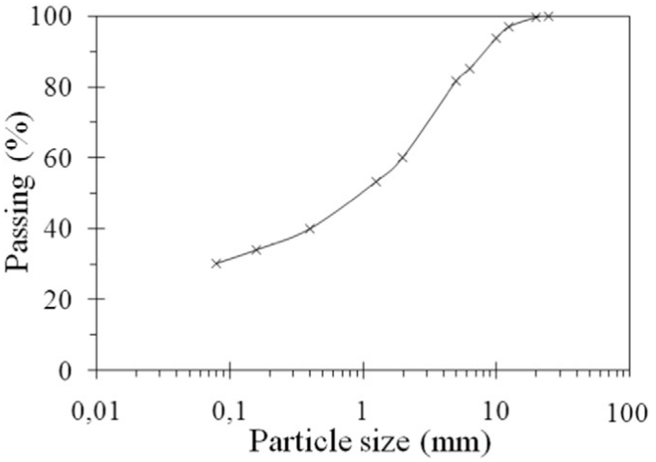

Fig. 1. Grading curve for fraction of disaggregated phyllite–clay sample passing the 20-mm sieve.

In preparing phyllite clay–lime mixtures (at 3, 5 and 7 wt.%) for investigation, a sample of the phyllite–clay material passing the 20-mm sieve was dry mixed with the lime material in the required proportions for a 1-h period to achieve homogeneity. Deionized water was then added to sub-samples, as necessary, in order to prepare test materials having a range of water contents.

The raw phyllite clay and phyllite clay–lime mixtures were characterized by their liquid limit, plastic limit and plasticity index values, following standard procedures (ASTM D4318-05: ASTM, 2005), in order to investigate their change in activity with increasing proportion of lime additive. These tests were performed on the fraction of the test materials passing the 425 μm sieve, as required by the given standard.

The modified Proctor (MP) compaction behaviors of the phyllite–clay fraction passing the 20-mm sieve, and its mixtures with lime, were determined in accordance with ASTM (2014). Further, California Bearing Ratio (CBR) tests were performed on the MP-compacted specimens after they had been allowed to soak in a water bath for 4 days (ASTM, 2014). The CBR test is used to evaluate the potential strength of subgrade, sub-base and base course materials for use in the design of road and airfield pavements. The swelling potential of the MP-compacted specimens was also determined from the measured change in longitudinal (axial) dimension of compacted soil cylinders under soakage (ASTM, 2014).

The water-permeability coefficient values of the raw phyllite clay and phyllite clay–lime mixtures were determined at constant confining stress and controlled-gradient conditions using a triaxial cell apparatus. The test-specimens were MP compacted slightly on the wet side of the optimum water content for compaction, allowed to cure in a wet chamber for a 7-day period and then saturated in the triaxial cell apparatus by back pressure steps to achieve a Skempton B coefficient value ≥0.95, with the permeability-coefficient value determined for a mean effective confining pressure of 50 kPa.

Finally, Peltier's (1969) formulation (Eq. (1)) was used to calculate the overall thickness (E, in cm) of the flexible pavement that would be required for road linear work construction employing the raw phyllite clay and phyllite clay–lime mixtures.

$$E = \left(100 + 150\sqrt{P}\right)/(CBR + 5) \tag{1}$$

where P is the maximum wheel load (in tonne), estimated at 3 tonne. Refer to Dal-Ré (2001) for some worked examples on the use of Peltier's formulation for the design of rural roads.