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Long Term Cyclic Response of a Soil-Cement Mixture: Experimental Study and Modelling

Fabrizio Panico[1] and António Viana da Fonseca[1]

[1]*CONSTRUCT-GEO, Faculty of Engineering (FEUP), University of Porto, Portugal.*

fabrizio.panico@fe.up.pt, *viana@fe.up.pt*

Abstract

Soil and granular materials stabilization with hydraulic cements is an interesting solution as stiffness and strength are highly improved. It is especially attractive when high traffic loads with considerable number of passages are expected and high mechanical properties of subgrade soils are required. Furthermore, such improvement allows reducing the amount of natural soils to be disposed for the fact of being rehabilitated, with significant environmental and economic advantages. Many authors have studied the cyclic behaviour of soils and soft rocks and others have studied soil-cement mixtures under static conditions. However, few studies have been published on soil-cement mixtures in cyclic conditions, particularly with a high number of cycles.

The purpose of this paper is to analyse the behaviour of some mixtures of cement-treated soil subjected to long term cyclic loading in order to contribute to the identification of rational criteria for design of subgrades for transportation infrastructures. The soil used is a well-graded silty sand remoulded from the weathered horizons of Porto granite, the most common rock in the north-western region of Portugal. The cement added to the soil varied in four percentages from 0 to 7% of mass of the uncemented soil. For each of these cement contents, two specimens were moulded with two initial void ratios. The study included an extensive set of long-duration drained cyclic triaxial tests, performed under stress-controlled conditions using an automatic hydraulic system with cells containing high-precision internal axial and radial strain gauges.

The scope of the triaxial cyclic tests is to study the evolution of the accumulation of permanent strain in cemented and uncemented specimens subjected to cyclic loading.

Keywords: Soil–cement mixtures, Soil improvement, Subgrade layers, Cyclic Triaxial tests, Porosity/cement ratio, Constitutive modelling

1 Introduction

The improvement of soil by the addition of hydraulic cement as an alternative to traditional techniques in geotechnical engineering is a very interesting solution. Due to the growing constraints imposed by environmental issues, the use of large amounts of soil has been conditioned. Moreover, the

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costs of transport of such quantities have more and more increased over the years. Another problem related to untreated soils is the degradation of subgrades in highway-pavement and railway-track support systems, giving rise to high maintenance costs and reduced serviceability. The main causes of deterioration are the accumulation of plastic deformation and the resilient cyclic deformation leading to pavement cracking by fatigue.

Soil and granular materials stabilization with hydraulic cements is an interesting solution as stiffness and strength are highly improved by the treatment. It is especially attractive when high traffic loads with considerable number of passages are expected and high mechanical properties of subgrade soils are required. Furthermore, such a mixture allows reducing the amount of natural soil to be used, with environmental and economic savings. Many authors have studied the cyclic behaviour of soils and soft rocks and others have studied soil-cement mixtures under static conditions. However, few studies have been published on soil-cement mixtures in cyclic conditions and with a great number of cycles (e.g. Viana da Fonseca et al., 2013). It is also interesting to note that although European Committee for Standardization (CEN) has already concluded a standard on "Cyclic load triaxial test for unbound mixtures" (CEN, 2004) there is still a lack in the equivalent for hydraulic bound mixtures.

The present paper presents a study of the behaviour of some mixtures of cement-treated aggregate subjected to long term cyclic loading in order to contribute to the identification of rational criteria for design of subgrades for transportation infrastructures. The basis of this experimental study is formed by a complete set of triaxial cyclic tests with a large number of cycles (up to one million), performed in a stress-controlled press suitable for cyclic loadings.

Through the use of proper instrumentation the axial and volumetric deformations were registered in order to study the evolution of the accumulation of permanent strain during cyclic loading and infer possible trends.

2 Material Description

The soil used in this study is a remoulded well-graded silty sand originated by the weathering of Porto granite, the most common rock in the north-western region of Portugal. The soil in its natural state was described in detail by Viana da Fonseca (2003) and Viana da Fonseca et al. (2006). As shown by Viana da Fonseca (2003), this soil in its natural state has some variability in the grain distribution curve, even if extracted in the same site.

Because of this non homogeneity (typical of residual soils), other authors [Rios (2011), Amaral (2012)] who have studied this soil in remoulded conditions, decided to correct the soil grain distribution curve in order to obtain a consistent research work and to meet the Portuguese specifications for soil-cement mixtures. Such a correction was adopted in the present paper. Some corrected grain distribution curves used are shown in Figure 1.

This soil is classified as a silty sand (SM) according to the unified classification system (USCS - ASTM, 1998) being a very well graded soil. The results of the physical identification tests are shown in Table 1.

γ_s (g/cm^3)	D_{50} (mm)	C_u	C_c	ω_L (%)	ω_P (%)
2.72	0.25	113	2.72	34	31

Table 1: Physical parameters of the soil

Being γ_s the particle unit weight, C_u the uniformity coefficient, D_{50} the largest diameter for 50% of passing particles in weight, and C_c the curvature coefficient.

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