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Influence of carbonate content on the stress–strength behaviour of neogene marls from the betic cordillera (Spain) in *cu* triaxial tests using a quasilinear elastic (hyperbolic) model

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ABSTRACT

The stress–strain behaviour of 135 samples of calcareous silt and clay soil, known as marl, from three quarries is presented and discussed in connection with its adjustment to a hyperbolic non-elastic constitutive model. The marl samples were classified and identified, following conventional soil-mechanics procedures and tested under triaxial CU (consolidated undrained) stresses. Also the carbonate, sulphate, and soluble salts contents were analysed by chemical and X-ray methods. Considering the obtained strength parameters and chemical compositions, a high correlation between the carbonate content and the parameters of the hyperbolic model, was observed, indicating a parallel increase in the brittle behaviour, and carbonate content, with a slight increase in bearing capacity. Nevertheless, when all the samples were considered, the parameters of the hyperbolic model seemed not to be clearly related to the carbonate content, this being interpreted as expressing a hyperbolic model influenced not only by the carbonate content but also by several other variables such as the percentage of fine particles or the dilatationing behaviour of the soil particles expressed by the dry density. Given the extensive use of marly soils in the construction of earth dam cores and slope banks, the main interest of the results is to present new insights into its mechanical behaviour not usually considered in common engineering practice.

1. Introduction

The study of the mechanical properties of the calcareous silt and clay (marl) cropping out in the Neogene of the Betic Cordillera (southern Spain) and Tetouen (northern Morocco), on both sides of the Mediterranean, leads to different contributions concerning: the effect of expansive clays and the activity of the fine soil fraction; the influence of the carbonate content on the plasticity behaviour of the marls and their strength properties; the problems arising with the engineering classification of marls; and, finally, the proposal of an appropriate method for the chemical analysis of the carbonate content. These studies were based on the sampling of marly soils in the Neogene basins of Granada (Spain), Tetouen (Morocco) and also in three quarrying sites in the Guadix-Baza Neogene basins (Spain) where this marl was extracted for the construction of three earth dams. (El Amrani and Chacon, 1996; El Amrani et al., 1998, 2000; Lamas et al., 2002, 2005).

The geology and engineering geology of the marls in both study areas was described (El Amrani and Chacon, 1996; El Amrani et al., 1998). An inverse correlation was shown between the carbonate content and dispersion index and swelling behaviour, while a direct correlation between carbonate content and shear strength was established from the study of 171 samples of cohesive calcareous soils. Compaction increases the shear strength and the clay fraction activity while the sulphate content augments susceptibility to weathering (El Amrani et al., 1998).

These samples were taken in the field following the instructions detailed in ASTM technical norm E-4 (2004). For the preparation of undisturbed samples in laboratory, the necessary number of samples were previously cut up, not only for triaxial but also for confined compression tests, splitting apart enough amounts for other tests. The sampling zones were selected by direct application to quarry fronts of some dam-project technical requirements concerning the construction of impervious embankment cores (PG-3, 2004), disregarding those quarry fronts not fulfilling these requirements. Therefore, the selected quarries have similar lithologies and the soil extracted for the construction of core of earth dams shows compositions in between the acceptable maximum and minimum values of different physical parameters.

Also, an inverse correlation between the clay content and the residual friction angle was found. The carbonate fraction of the marlsoil had a significant influence on the residual friction angle, and there was a threshold of 25% of carbonate contents, above which the value of ϕ'_r increased until the clay fraction and the percentage of

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smectite within that fraction tended to increase the residual cohesion value. It was proved that the presence of smectitic clay as dominant constituent produces a low value of residual shear strength, associated with high fragility in unconsolidated undrained tests, as reported by Lamas et al. (2002), although this parameter was not correlated because of the similarity in minor smectitic clay content among the available samples. Also it has been proved that the degree of compaction of the soil and, therefore, the initial porosity has a direct influence on the effective residual friction angle ϕ'_r (El Amrani et al., 2000; Lamas et al., 2002).

The existing engineering classifications fail to provide an adequate response to clay minerals and, especially, carbonate content of the marls and, thus, none of these systems satisfactorily explains the different behaviour of the marls studied (Lamas et al., 2002).

Despite the large number of experimental methods available to determine the carbonate content in soils, a comparative analysis of the three most commonly used methods (flame photometry, the Bernard calcimeter, and EDTA complexometry) indicates that the accuracy of the method is a function of the carbonate concentration in the sample to be analysed and the Bernard calcimeter has been demonstrated to be the most suitable method for analysing carbonates in soils (Lamas et al., 2005).

This paper provides a more detailed study of the relationships between the strength properties of marls tested in CU triaxial compression, and the carbonate content. For that purpose, samples from the above-mentioned three quarrying sites for earth dams in the Guadix-Baza basins were selected (Granada province, Spain; Figure 1) with increasing carbonate content.

In order to analyse changes in parameter values in these soils of known type and density, the results concerning the stress–strain behaviour are fitted to a quasilinear elastic or hyperbolic model which is considered appropriate to address problems involving stress and strain prior to failure (Kondner and Zelasko, 1963; Wong and Duncan, 1974; Duncan, 1980; Duncan and Chang, 1980).

2. The nonlinear elastic hyperbolic constitutive model

The nonlinear elastic constitutive models simulate stress–strain soil behaviour by considering the elastic parameters as depending on the stress state and the accumulated deformation. The hyperbolic model (Kondner and Zelasko, 1963), modified by Duncan and Chang (1980) to fit it to the c and ϕ soil-strength parameters of the Mohr–Coulomb equation and to the finite-element analysis (Domaschuk and Valliappan, 1975), depends in the model of Duncan and Chang (1980) only on the stress state and model's parameters, such as the bulk module K, the shear module E_t and also the Poisson ratio ν. The coefficients necessary to define the model depend on the failure criteria. The main advantage of the model of Duncan and Chang (1980) is usually a best fit to the laboratory data because it permits the variation of the Poisson ratio during the analysis, attaining critical values in the stress deviation and volume change throughout the different stages of the analysis, as it is usually observed in real materials. Nevertheless, there are a number of

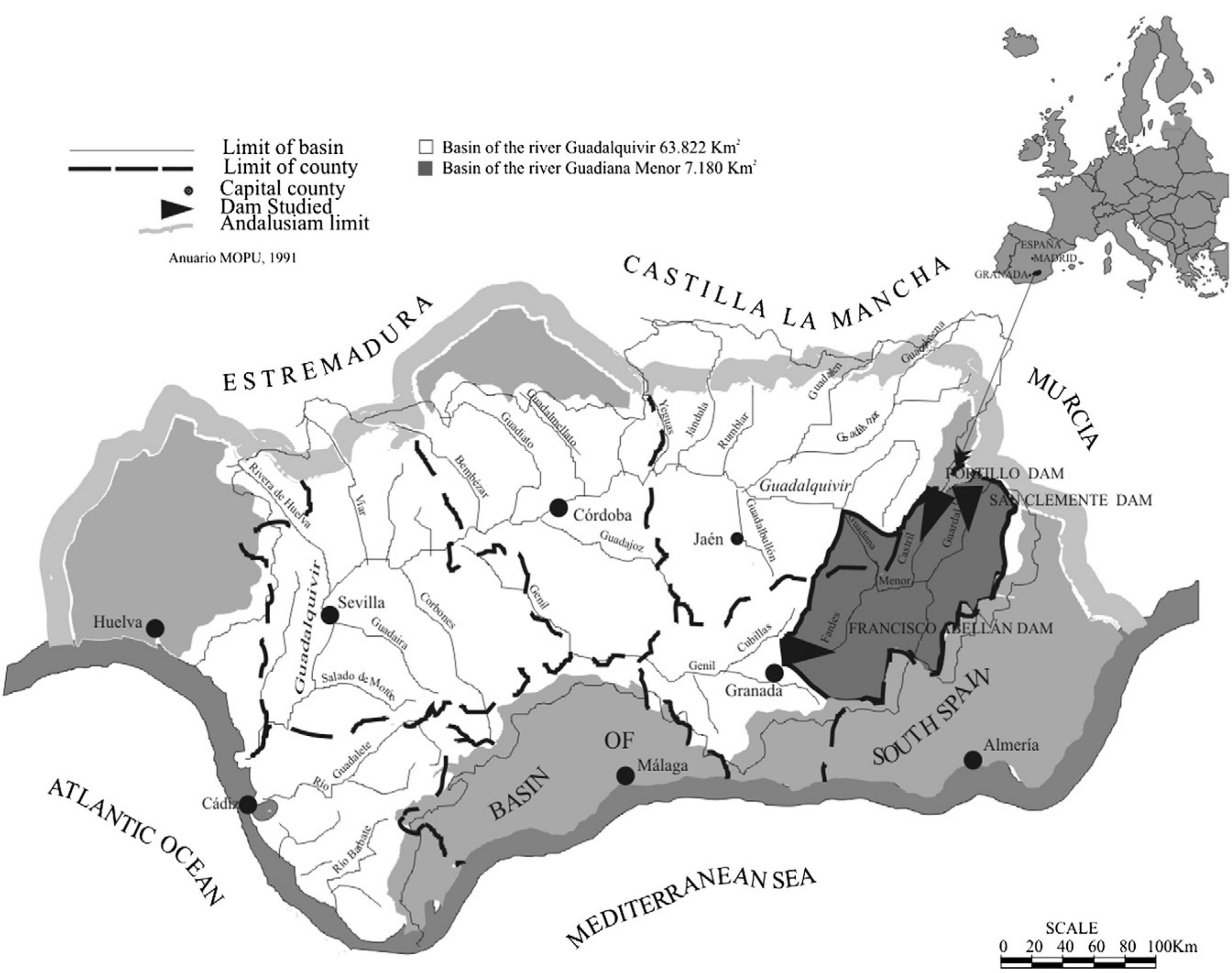

Fig. 1. Setting of the sampling area.