Methodologies for the Geological–Geotechnical Characterisation of Weathering Profiles of Granite: A Case Study

Rita Lamas, Isabel Fernandes, Jorge Espinha Marques, and António Viana da Fonseca

Abstract

Engineering works, especially those carried out in an urban environment, generally concern shallow depths in which soil or weathered rock mass is present. The assessment of a rock mass weathering grade relies on chemical and mechanical features related to the degradation of the mechanical properties and the increase of permeability. This study aims at improving the existing knowledge on the description of rock masses' weathering grade by indexing different weathering grade, namely, regarding mineralogical composition, fabric and microstructure, and its influence on the geomechanical parameters that the project of foundations and, in particular, the geotechnical structures demand, specifically, for the numerical modelling with view to constructive solutions. The permeability, deformability, and resistance of weathering horizons are underlined, and physical properties are to be evaluated closely related to the geological characteristics already mentioned. Given the environmental concerns to which society and the scientific community are increasingly alert, the final work will include new radiological measurements in the granite rock mass of the Porto urban area, which are added value to the geological and geomechanical knowledge of rock masses.

Keywords

Granite • Weathering profiles • Pedological characterisation • Geological–geotechnical characterisation • Porto granite

1 Introduction

Weathering profiles can vary widely in the area and in-depth in the same rock mass. The spatial variability and weathering intensity depend on the rock mineralogy and texture, the discontinuities, the topography, the climate, and the groundwater conditions. The description of such profiles gave rise to proposals for the classification of weathering grade classes based on colour, friability, modifications of mineralogical composition, and microfracturing. Several authors, institutions, and technical associations proposed their weathering grade classifications. However, the ISRM classification (1978, 1981, 2007) is universally used for rock masses and considers five weathering grade (W_1–W_5) and one grade corresponding to residual soil (W_6). A similar description is found in GSE (1995) for intact rock, which is very useful for obtaining correlations with the laboratory mechanical tests.

The influence of weathering grade on petrographic, physical, and mechanical characteristics has been studied by several authors in different lithologies (e.g., Irfan and Dearman 1978; Viana da Fonseca 1996; Arel and Tuğrul 2001). According to Letto et al. (2018), the geomechanical and mineral-petrographic properties of the rocks decrease with the weathering grade increase. Therefore, the weathering profiles' mechanical characterisation must be made for the rock masses for geotechnical purposes. Knowledge of the index properties, as listed in González de Vallejo and Ferrer (2011), which can be evaluated in laboratory tests, enables the classification of intact rocks, while field tests are

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usually needed for the characterisation of rock masses according to various technical criteria.

For the Portuguese granitic rock masses, widely outcropping in the country, the hypothesis arose that radon gas could be used as a plotter for geological materials' transformation processes, both due to weathering or when subjected to stresses (Koike et al. 2015). Pereira et al. (2017) showed a possible relationship between weathering grade in granitic rocks and exhaled gas concentration.

The Granite of Porto presents weathering profiles in which the entire range of weathering grades (W_1–W_5) is found and a variable and erratic thickness of residual soil (W_6). The main objective of this work is to present the methodologies which are used in the research being carried out, aiming to establish correlations between the geological characteristics of Granite of Porto, namely, the weathering grade, mineralogy, geochemistry, porosity, and microstructure, with the hydraulic and geomechanical properties of the rock mass, namely, the parameters of stiffness and shear strength of the granite for the various weathering grade.

The present work aims to present the methodology of the work developed in the scope of the ongoing research project. Results are not available yet and are planned to be published soon.

2 Methodology

In order to thoroughly characterise the geological–geotechnical variability of the Porto granite weathering profiles, it is fundamental that the amount of data is sufficiently broad. Furthermore, it is necessary to conduct tests that consider the mineral and chemical composition and determine the physical and mechanical properties for better characterisation. Thus, in order to carry out this study, a strategy was defined: first, the selection of sites for sampling, followed by the careful sampling and preparation of specimens; finally, the laboratory and in situ testing. For the first step, it was essential to take advantage of new excavation works in Porto city due to its extensive urban network. Moreover, the lack of outcrops available, namely, the excavation for constructing a building in the D. João I block in the city centre (Fig. 1), complemented a former sampling during the site investigation works for Metro do Porto tunnels, underground stations, and other infrastructures.

In order to minimise the samples disturbance, among the several existing sampling techniques, the block sampling method was selected, using excavation and manual moulding. This method is the most recommended for residual soils, while for un-weathered rock, the ideal sampling is obtained by drilling with continuous coring.

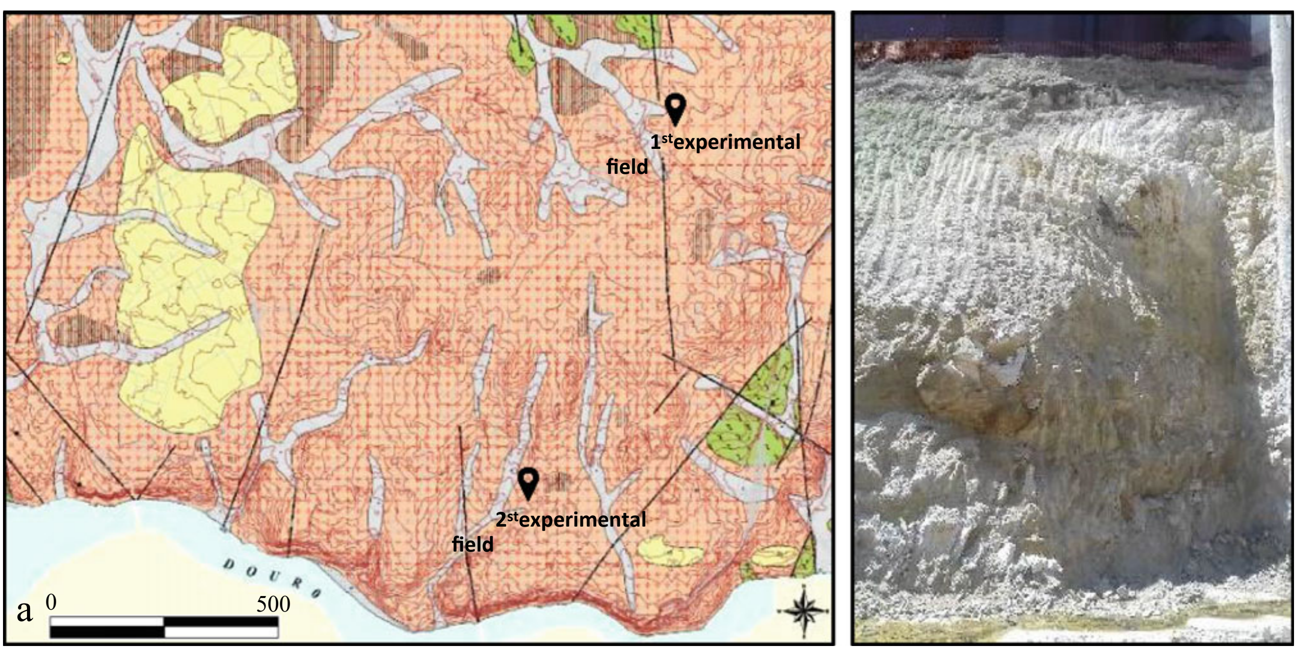

Fig. 1 Excavation works in Porto City: **a** Location of two experimental fields (adapted from COBA 2003); **b** Stone-wall in the D. João I city block

2.1 Pedological Characterisation and Associated Trials

The pedological characterisation is based on the FAO soil classification system—World Reference Base for Soil Resources (FAO 2015), using the internationally accepted FAO guidelines for soil description—Guidelines for Soil Description (FAO 2006)—to describe soils and their characteristics (Table 1).

2.2 Mineralogical and Geochemical Properties

For evaluating the mineralogical and textural characteristics, the petrographic analysis of thin sections, X-ray diffraction, and scanning electron microscopy are used (Table 2).

2.3 Physical Properties

The evaluation of physical properties includes water content, porosity, voids index, unit weight, and rock permeability. In addition, the size distribution and the consistency limits (Atterberg limits) are determined for the residual soils. Finally, in Table 3, the properties and respective standards, considering the need to apply the soil geotechnical classifications.

2.4 Mechanical Properties

In order to characterise the residual soil and the rock material, various mechanical properties will be determined. These tests are listed in Table 4, and the equipment used is listed.

2.5 Radiometric Methods

It is intended to use the radon accumulator method, which allows obtaining radon concentration in the samples to show the variations it presents according to the rock weathering grade. The method is based on measuring the exhalation of radon and is obtained using an Alphguard Pro2000 equipped with an ionisation chamber (University of Coimbra). Subsequently, the exhalation rate of radon is calculated.

Table 1 Methods of pedological characterisation

	Properties	Methods of determination
Field pedological characterisation	Soil profile description	Guidelines (FAO 2006)
	Unsaturated hydraulic conductivity and infiltration rates	Mini-disk infiltrometer
	Saturated hydraulic conductivity	Guelph permeameter
Laboratory pedological characterisation	Colour	Munsell Soil Colour maps
	Texture	FAO (2006)
	Bulk density	FAO (2006)
	Porosity	Volumetric ring method
	pH	pH metre–(FAO 2006)
	Electrical conductivity	Method of Benton Jones

Table 2 Methods for determining mineralogical and geochemical characteristics

Properties	Methods of determination
Mineralogy, texture, microfracture index, and microphotographic index	Petrographic analysis under optical microscope—NIKON Eclipse E400 POL (University of Porto)
Chemical analysis of major oxides and determination of the mineralogical composition	X-ray fluorescence and X-ray diffraction (University of Alicante)
High-resolution images with verification of the composition of cryptocrystalline components	SEM/EDS/EPMA-JEOL JXA-8200 (University of Lisbon)

Table 3 Methods for determining physical properties

Properties	Methods of determination
Water content	Portuguese standard NP-84 1965 (University of Porto)
Porosity, void index, and weight volume	Portuguese standard NP EN 1936 2008 (University of Porto)
Size distribution	LNEC Specification E196-1966 (University of Porto)
Consistency limits (Atterberg limits)	Portuguese standard NP-143 1969 (University of Porto)

Table 4 Methods for determining mechanical properties

Properties	Methods of determination
Seismic wave velocity (Longitudinal and transverse waves-Vp, Vs)	Laboratory ultrasonic pulse wave velocity Proceq® system—ASTM D2845-08 (Labgeo-University of Porto)
Unconfined compressive strength (σc)	Uniaxial compression test (TRIAX 500KN)-ASTM D7012-14e1 Point load tester (Controls-D550)—ASTM D5731-16 Schmidt Hammer L-Proceq (Labgeo-University of Porto)
Tensile strength (σt)	Diametrical test (Clockhouse DIX20)-ASTM D3967-16
Resistance (cohesion-c, friction angle-Φ)	Triaxial compression test-ASTM D7012—14e1 (PUC of Rio de Janeiro)
Deformability (static and dynamic elastic deformation modules: Young's modulus—*E*, Poisson ratio-*ν*)	Uniaxial compression test (TRIAX 500KN)—ASTM D7012-14e1 (Labgeo-University of Porto) Seismic test—ASTM D2845-08 (University of Porto)
Abrasiveness	Cerchar Abrasiveness Index—ASTM D7625-10 (Federal University of Viçosa)
Soil compressibility	Edometric test (Wykeham Farrance 24,251)-ASTM D-2435/D2435M-11 (Labgeo-University of Porto)

3 Concluding Remarks

The proposed programme will contribute to the evolution of knowledge globally since, in most cases presented in the literature, the evaluation is based on a limited number of tests and samples. There is a wide variety of papers regarding laboratory tests due to the need to define the best method to reflect the variability of the geotechnical properties with the granitic rock masses' weathering grade profiles.

The methodology proposed above intends to obtain a complete characterisation to establish correlations between the rock mass's geological, hydrogeological, and geotechnical characteristics. The aim is to achieve comprehensively relevant results in granitic rock masses with varying weathering grade and in residual soils with similar properties to the materials studied in the present work.

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