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A Retrospective View of EMM-ARM: Application to Quality Control in Soil-Improvement and Complementary Developments

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Abstract

The EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method) is a technique that allows the continuous measurement of the E-modulus of a given material under test, since the instant in which it is cast into the testing mould. The technique has been initially developed in 2008-2009 and it is particularly useful to monitor the hardening process of cement-based materials or any similar materials that can be cast into a mould and endure significant stiffness changes since early ages. EMM-ARM is based on the identification of the resonant frequency of the testing mould, which evolves along time due to the hardening process of the tested material, and then the E-modulus of the tested material can be inferred with basis on the dynamic equations of motion of the testing system. Even though the method has been originally devised to test concrete, it has quickly been extended to other materials such as mortar, cement paste, stabilised soils and even epoxy resins. In the particular case of stabilised soils, the method has been successfully applied to both cement-based stabilization and lime-based stabilization. This paper intends to provide a wide perspective of the several evolutions that EMM-ARM has endured throughout its applications to stabilised soils, namely in regard to: (i) mould geometry and material; (ii) sampling procedures for in-situ application; (iii) excitation and modal identification techniques; (iv) systematic application to several mix formulations and comparative evaluation of hardening kinetics. Indeed, one of the foremost applications of EMM-ARM in the context of soil stabilization is the capability to provide real-time data about the stiffness of the material, allowing the users to take early decisions in regard to the expectable stiffness that a recently improved soil will predictably attain. This readily available information can have strong economic impacts in the case of rejection of a given stabilised layer.

Keywords: EMM-ARM, Soil stabilization, E-modulus,

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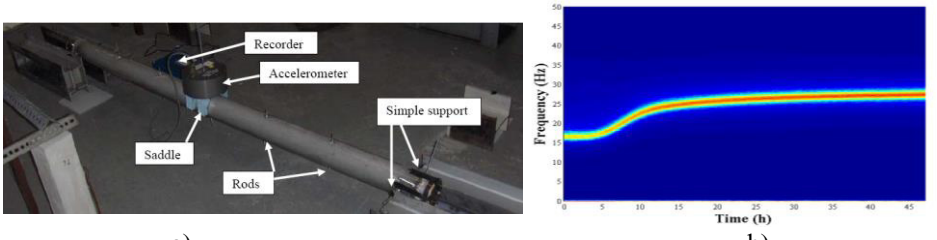
1 Introduction

The stiffness (or deformability) of foundation soils is considered to be of utmost importance for design and for the actual service life of structures (Puppala, 2008, Atkinson, 2000). In view of this relevance, the soil stabilization with chemical additives is a technique frequently used in the improvement of the geo-mechanical properties of underlying soils as an alternative to soil substitution (Jackson *et al.*, 2007). However, as there are no general performance-based dosage methodologies established on rational criteria (Viana da Fonseca *et al.*, 2009) soil stabilisation is usually preceded by a laboratory mixture formulation and the assessment of mechanical properties (as the E-modulus) is performed by quality control tests (Gomes Correia *et al.*, 2009).

A line of research related to this field applied to the specialized study of stiffness of stabilised soils has been opened in 2010 at the University of Minho with the MSc thesis of J. Silva (Silva, 2010) and has been prolonged since then in a PhD work by the same author. This line of research has been leveraged by the EMM-ARM (Elasticity Modulus Measurement through Ambient Response Method).

The EMM-ARM is a technique that allows the continuous measurement of the E-modulus of a given material under test, since the instant in which it is cast into the testing mould. EMM-ARM is based on the identification of the resonant frequency of the testing mould, which evolves along time due to the hardening process of the tested material. The E-modulus of the tested material can be inferred with basis on the dynamic equations of motion of the testing system.

EMM-ARM was initially developed for performing measurements in concrete in 2008-2009 by Azenha (2009), and since then it has been under continuing developments and improvements targeted to concrete and cement paste in the scope of the PhD work of J. Granja (Azenha *et al.*, 2012b, Granja *et al.*, 2014, Granja & Azenha, 2015b, Granja & Azenha, 2015a). In its original implementation (see photo in Figure 1a), EMM-ARM consisted of a test beam, composed of a 92mm/100mm hollow acrylic tube filled with concrete, having ~2m span and being simply supported by rods at its extremities. The encouraging results obtained for the pilot experiment in concrete (Azenha *et al.*, 2010) led to additional developments in the study of cement pastes (Azenha *et al.*, 2012a) with small cantilevered composite beams that allowed very clear identification of the resonant frequency of the tested specimens as shown in Figure 1b. Since then, improvements have been made at several levels for the study of concrete (Azenha *et al.*, 2012b, Granja & Azenha, 2015b, Granja & Azenha, 2015a), cement paste (Granja *et al.*, 2014) and even epoxy resins (Granja *et al.*, 2015).



a) b)

Figure 1. a) Testing arrangement in the initial implementation of EMM-ARM for concrete; b) Typical frequency plot obtained in cement paste testing.

The thriving environment of developments of EMM-ARM in regard to freshly cast materials such as concrete and cement paste was accompanied by significant distinct and complementary developments targeted to the specific case of stabilised soils, which pose specific challenges in regard to sampling and to the quite distinct (smaller) stiffness that they present, thus demanding for specific developments. This paper intends to provide an integrative description of the main developments and achievements obtained for testing of stabilised soils, in particular concern to the test setup, the modal identification procedures, the sampling and even its validation and systematic application. The conclusions elaborate on the practical applicability of EMM-ARM, together with the challenges that the developing team currently tackles and foresees.