



Review

Evaluation of the grout injectability and types of resistance to grout flow



Fernando Jorne*, Fernando M.A. Henriques

Departamento de Engenharia Civil, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal

HIGHLIGHTS

- Void size distribution of the porous media affects grout injectability.
- Darcy's law and front resistance are inadequate to model grout injection.
- A new additional resistance called resistance of suspension is created.
- Pre-wetting the porous media reduces the overall resistance to grout flow.
- Tomography showed density gradients along the porous media.

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ABSTRACT

Grout injection is an efficient technique commonly used for structural consolidation of multi-leaf stone masonries, which often present high porosity (especially in the inner core) due to the presence of internal voids. Since porosity and void size distribution are not constant within masonry, the efficiency of grouting varies along the injection. Thus, it is essential to study the injectability of grouts in porous media with different characteristics along the height of injection. To evaluate the efficiency of grout injection this work used 11 different porous media, in the shape of small scale cylinders. For each porous medium, grout injection velocity and injected mass were measured. The reliability of various rules of thumb used to check grout injectability was also verified.

From the injection tests different resistances to grout penetration were detected, created by the porous medium to the flow. The knowledge of these resistances is crucial to estimate the grout penetration in the internal voids. In contrast with literature, the injection tests show that Darcy's law and front resistance are not adequate to estimate the grout injection. Therefore, an additional resistance is introduced (resistance of suspension – R_s). This resistance, as well as the overall resistance to grout flow are reduced when the pre-wetting of the porous medium (before grout injection) is done. The performance of the grout injection performance was also analysed in the hardened state with ultrasonic tomography.

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Abbreviations: PM, porous medium; SP, superplasticizer.

* Corresponding author.

E-mail address: fjorne@fct.unl.pt (F. Jorne).

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1. Introduction

The grout injection is an efficient technique commonly used for structural consolidation of multi-leaf stone masonries, which often present low compactness (due to the presence of internal voids and cracks) and inadequate links between the internal and external leaves [1–4]. Thereby, this type of masonry walls is not monolithic in the lateral direction, making the wall brittle especially when external forces act in the horizontal direction [5]. Thus, the seismic resistance associated to this type of masonries is low. However, through grout injection, the continuity and homogeneity of a damaged masonry is recovered and the cohesive strength of the structural elements is increased. Therefore, there is an improvement of the mechanical behaviour of the masonry and a potential increase of seismic resistance. Furthermore the morphology and load-bearing system of the masonry do not suffer significant changes.

Grouts are mixtures of binder with water, with or without special additives. Their design as well as the method of application must fulfil a series of performance requirements, namely injectability, bond strength and compatibility. For that purpose, a profound survey of masonry internal sections is required. It should be known the construction type, the materials and the dimensions of the masonry, as well as the size (the nominal minimum width – W_{nom}), percentage, connection and distribution of voids [5–7].

In what concerns the nature and composition of the masonry materials, the grouts must show compatibility with the original material in terms of chemical, physical and mechanical characteristics in order to fulfil with Charter of Venice [1,8]. Thus, it should be underlined the importance of selecting appropriate raw materials for the grout composition, taking into account the properties of the masonry to be injected. For this reason, hydraulic lime was the binder chosen instead of the cement [9,10].

As regards injectability (related to the penetration and diffusion capacity of the grout), permeability, voids size distribution and water absorption of the media particles are the most important properties of the porous media – PM [11]. Depending on the grain size distribution of PM particles, the parameters referred have different influence on injectability. Thus, it is necessary to characterize all parameters of the PM so that the injection capacity of the grout can be estimated [12]. In this paper to evaluate the injection performance of the grouts in function of the PM, small scale models (cylinders created in laboratory) already used in previous works have been used [12–14]. Nevertheless, in this study the granulometry of each PM is not constant along the height of injection. The aim was to evaluate the grout injectability in PM filled with different layers (with different grain size distributions) and different permeabilities and voids distribution along the PM. It was also analysed the reliability of various rules of thumb to check the injectability of a grout in a given PM. Furthermore, it was possible

to detect the resistances created by the PM to the grout during the flow. The knowledge of these resistances is crucial to estimate the grout penetration in the internal voids of a PM, allowing to detect when a grout is not injectable in a particular PM.

According to [8,15], Darcy's law clearly shows a partial inadequacy to model the injection tests. Indeed, the use of Darcy's law led to faster injections through the PM than the experimental results. This suggested that the overall media resistance was underestimated when using this theory. In fact, there is an additional resistance to the grout flow that is ignored by Darcy's law, which is due to the granular nature and the ability to establish bonds of the cementitious grouts. The referred authors implemented in their works the theory of a physical resistance at the fluid (grout) front, called front resistance. This resistance emphasizes the importance of the permeability and granulometry of the front layer. The authors concluded that when this kind of resistance is overcome, it is easier for the rest of the grout to flow through the same front layer. Nonetheless, the injection tests carried out in this work showed that this front resistance is not adequate to model the grout injection. So, an additional resistance was introduced (resistance of suspension – R_s). This resistance depends on the size of the grout solid particles, the size of the voids of the front layer and the void size distribution of the layers already injected.

Taking into account that the grout injection can occur under various environmental conditions, pre-wetting was done before grout injection. Indeed, it is not expected that masonries are always dry. Some authors [7,15,16] argued that this procedure is able to improve the penetration of the grout inside the PM. Since water content of the PM is a parameter that has influence on the grout injectability, its influence was taken into account for the determination of R_s .

In addition to the fresh state, the grout injection performance was also analysed in the hardened condition. Through tomography, it was also assessed the grout injection capacity in different PM. As concluded in other works [14,17–19], sonic and ultrasonic tomography may be used to detect voids (evaluating the homogeneity) and to evaluate the efficiency of grout injection. In fact, as observed in [20] the results of tomography were in accordance with visual inspections, which confirms how useful this technique can be to locate non injected areas inside the cylinders that were not visually apparent, and thus to control the effectiveness of grout injection technique.

This research gives continuity to the papers [12,14,20] where the performance of the grout injection was analysed (in fresh and hardened state). In this paper, the main aims are: the study of grout injection in PM with different grain size distributions along the injection, the evaluation of Darcy's law and front resistance in grout injection tests and the creation of an additional resistance to the grout flow (R_s), allowing a more accurate evaluation of the injection.

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