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Experimental results on mechanical behaviour of metal anchors in historic stone masonry

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HIGHLIGHTS

- Pull-out tests were carried out to characterize the adhesive behaviour of anchors.
- Adhesive fastenings seemed to present better results than the mechanical ones.
- Prediction formulas for axial forces were more appropriate for adhesive fastening.

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ABSTRACT

Ancient buildings constructed in stone masonry often deteriorate and partially collapse, with only their façades and/or lateral walls remaining. This work provides a study of the mechanical behaviour of anchors used as connections between existing walls and new members, for purpose of strengthening of historic stone masonry buildings. The paper addresses a comparative analysis between an experimental campaign and analytical formulations for ultimate load prediction. To obtain practical results, pull-out tests were carried out with adhesive and mechanical metallic anchors in stone masonry walls constructed in laboratory. The results allow conclusions on the most efficient connections in terms of adhesion.

1. Introduction

Many existing historic buildings are made of coursed and rubble stone masonry, and experience structural damage arising from internal or external factors, such as the action of environmental agents or earthquakes, leaving only their façades. In order to prevent these from collapsing, due to their historical, architectural or other value, temporary or permanent structural shoring is often proposed, or new structural members, interconnecting with these old façades, are constructed to preserve them [1].

Anchoring systems between historic masonry and a new structure can be made in various ways, and using a wide range of materials. The type of fastener depends mostly on two aspects: a) should the façade serve as an element for supporting the load within the new construction, load-bearing fasteners will be used; b) should the façade be braced by the new structure, only supporting its own weight and with the wind load acting directly upon it, restraint-only fasteners will be used [2]. Fasteners may utilize through fixing systems or anchors. The latter are the object of this work and include: bonded anchors, expansion anchors or undercut anchors [2]. The Construction Fixings Association has published a guidance note [3] supporting the identification of the types recommended for masonry. According to this publication, only bonded anchors and thin-walled sleeve expansion anchors types are recommended for brick and stone masonry. In the case of stone masonry, with certain limitations, it is possible to adopt shield expansion and undercut anchors.

There are two generic types of bonded anchors, one using resin, also known as a chemical anchor, and the other using cement based matrixes. In addition, there are two types of resin anchor systems: capsule based and injection systems. In the capsule system, when an anchor rod is inserted, the various capsule components are mixed together. The injection system contains two compartments that are mixed in a special mixer nozzle, which pumps the mixture into the hole drilled for the anchor. Cementitious anchors use a cement based grout to bond the anchor [3]. Grout is a fluid material with similar properties to mortar or

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concrete, which performs well at high temperatures and in humid conditions [2]. Both connections require a curing period to attain resistance; this period is shorter in chemical anchors. Resin bonded anchors, generally used when a fast setting time is required, work with small diameter drill holes (typically 10 to 25% larger than the diameter of the fastener); while in anchors using grout, the drill hole diameter should be between 150 and 200% of the fastener diameter [4].

Expansion anchors widen in their installation and fall into two categories: torque controlled and deformation controlled. In the torque controlled, the movement of tightening the nut or bolt activates the expansion mechanism, whereas the degree of expansion in the deformation controlled is determined by the relative displacement of the expansion cone within a sleeve. Undercut fasteners resemble small pegs and expand at the lower end [2]. In general, mechanical anchorage is based on friction between the sides of the hole and the fastener lugs for the transfer of loads. Fig. 1 illustrates the main types of anchors recommended for brick and stone masonry, according to the guidance note of The Construction Fixings Association [3].

The present paper presents an experimental campaign investigating the behaviour of steel anchors in stone masonry. The objective is a comparative analysis, in terms of ultimate load, between the results of pull-out tests, using two types of anchoring systems with metallic fasteners (anchors bonded with resin and cementitious grout, and mechanical anchors) fixed on stone masonry walls constructed in a laboratory, and the results of analytical values from literature.

Anchors are required to resist forces in two directions. Pull-out forces are those that act in the direction of the axis of the fastener, while shear forces are those that act at right angles to the axis of the fastener. To assess the anchors performance, the pull-out laboratory tests for the stone masonry metallic fasteners were conducted in two ways: firstly, with the pulling actuator positioned in the direction of the fastener axis and, secondly, with the actuator inclined 30° from that axis.

The methodological approach includes a short literature review and an experimental campaign including: a) definition of the laying mortar to be used in the laboratory constructed walls; b) characterization of the materials used; c) construction of the stone masonry walls; d) execution of diagonal and uniaxial compression tests and pull-out tests on masonry; and e) analysis of the results, including a comparative evaluation between experimental and analytical values. The present work allows to choose the most efficient anchor in terms of adhesion to stone masonry, using mechanical and bonded fastenings.

2. Theoretical aspects of metallic anchors subject to tension and shear

The use of anchors is usually associated with features such as: the stabilization of cracked or deformed masonry; the connection between new and existing structures or structural members; the transfer of tensile forces, for example, during construction; the strengthening of walls and foundations; and the strengthening to support dynamic loads [5].

Strengthening masonry with the use of metallic anchors subject to tension has occurred for centuries and is often accepted in the conservation of cultural built heritage and in operations arising from repair and strengthening. Below, analytical expression of the estimated values of capacity of anchors to tensile and shear forces are presented. These have been obtained from formulas for pull-out tests, and are available in different norms. A large number of underlying models was specifically developed for concrete; however, analogies may be made for stone masonry. The formulas address the predicted load resulting from tensile tests and combined tensile and shear tests. Tables are presented for the chemical and mechanical anchors selected for this work.

It is noted that the theoretical basis given is associated with the experimental study developed, which consisted of only one anchor per wall, located at its centre and at a large distance from the edges.

2.1. Resistance to tensile loading

The analytical formulation for tensile loading was established according to the mode of potential anchor failure, namely: a) steel anchor failure; b) cone failure in the substrate; c) pull-out failure; d) combined pull-out and substrate cone failure; e) splitting failure (cross section) and f) blowout failure [6,7], as shown in Fig. 2.

The anchor capacity depends on the properties of the existing materials and on the technology applied [5]. The characteristic anchor resistances' (N_{Rk}) formulas given below consider the main modes of failure, according to the bibliographic research, using adhesive anchoring. Detailed information regarding the expressions and symbols used may be found in the specific references.

For metal failure, referenced in this article as T1, the characteristic resistance, for concrete and masonry are

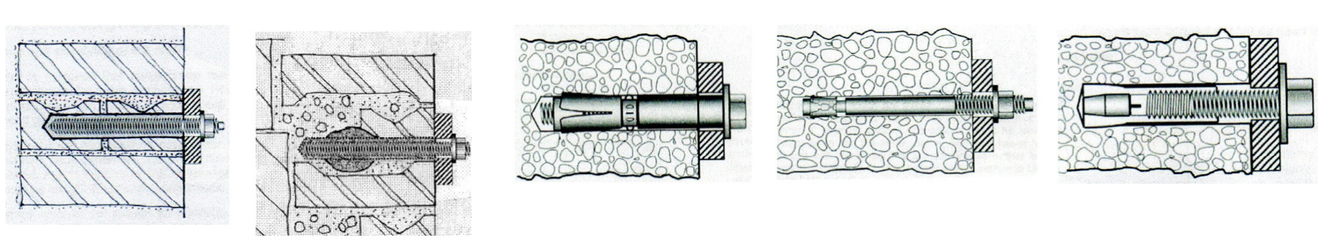
$$N_{Rk} = 0.75.A_s.f_u \tag{1}$$

$$N_{Rk} = 0.90.A_s.f_y \tag{2}$$

The T1 characteristic resistance is provided by the effective cross section of the bolt (A_s) and the steel ultimate tensile strength (f_u). [8–11]. ACI 318 recommends using a coefficient of 0.75 [9], while ACI 530 proposes using yielding strength (f_y) rather than ultimate strength and applying a reduction coefficient of 0.90 [12]. Anchor steel failure is rarely seen in masonry applications, and occurs in cases in which anchorage depth and masonry resistance are significant [13].

For cone failure (T2), most studies involve concrete as substrate. The characteristic resistance is calculated by [8]

$$N_{Rk} = \mathrm{k}.(f_{ck\ cube})^{0.5}.h_{ef}^{1.5}.(A_{c,N}/A_{c,N}^{0}) \tag{3}$$



(a) (b) (c) (d) (e)

Fig. 1. Bonded anchors: (a) capsule-type bonded anchor for resin; (b) injection-type bonded anchor for resin and grout. Torque-controlled expansion anchors: (c) thick-walled sleeve; (d) through bolt. Deformation-controlled expansion anchors: (e) [3].