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Behaviour of post-installed adhesive anchors in natural stone

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HIGHLIGHTS

- Experimental research on chemical anchors in natural stone.
- Embedment length of chemically post-installed threaded rods in basalt, sandstone and limestone support.
- Evaluation of the reliability of theoretical formulations in the literature valid for concrete.
- Investigation on the applicability of numerical models for the prediction of the bearing capacity of the anchor.
- High impact of the paper on the knowledge about adhesive anchors in natural stone given the lack of data on the topic.

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ABSTRACT

This work is based on the results of an experimental research related to chemical anchors in natural stone. The specific goal is to achieve the minimum embedment depth for chemical anchoring of post-installed threaded rods in basalt, sandstone and limestone support, by using epoxy resin. The reliability of theoretical formulations in the literature valid for concrete is evaluated. The applicability of some numerical models for the prediction of the bearing capacity of the anchor is then investigated, whereas the theoretical formulations are not feasible.

1. Introduction

In most countries of the world, the building stock is ageing and needs continuous maintenance or repair. Moreover, the majority of existing constructions is deficient in the light of current knowledge and design codes. The problem of the structural deficiency of existing constructions is especially acute in seismic regions, as, even there, seismic design of structures is relatively recent. The direct and indirect costs of demolition and reconstruction of structurally deficient constructions are often prohibitive; furthermore they entail a substantial waste of natural resources and energy. Therefore, structural retrofitting is becoming increasingly widespread throughout the world.

Additional consideration can be made concerning masonry. Masonry was, in the past, and is, today, one of the most commonly used materials throughout the world for the construction of low rise buildings.

Even though the history of past earthquakes has shown that masonry buildings suffered the high damage and accounted for the loss of life, they constitute almost the entirety of the historic centre constructions. The stonework is largely widespread in different countries and despite the variety of materials and techniques used, it has recurring problems regarding both the vulnerability to seismic actions and the applicability of reinforcement techniques.

There are many types of remedial measures that can be implemented on masonry buildings in order to improve their dynamic characteristics. In particular, in the context of the retrofitting of existing buildings, a great development has been achieved with the use of anchoring systems, understood as real structural elements.

The anchoring systems, in particular those with chemical anchors, are commonly used in plain or reinforced concrete

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structures but also in structures in lightweight material, such as wood and brick, and in masonry constructions to rigidly couple different structural elements. A variety of metal elements are usually involved in the anchoring system, normally steel elements (stirrups, longitudinal or shear reinforcement bars, threaded rods). The adhesive component of the system is generally resin, that usually found application in the structural strengthening and retrofitting of existing elements and in the addition or connection of new structural elements to other already existing.

Three types of resins for building are the most widespread on the market:

- vinyl with polyester, for anchoring of medium grip on walls in concrete, stone, bricks and hollow bricks, ideal for use in enclosed spaces because of their low toxicity;
- polyester with or without styrene, for specific, especially on masonry, anchors drilled through the use of the special cage ("sock") that prevents the propagation through the voids of the masonry itself;
- epoxy, especially for hard anchorage on concrete elements, which generally are given as two part epoxy adhesive, chemical and heat resistance, good-to-excellent mechanical properties.

Nevertheless the specific legislation on the architectural heritage does not allow the use of resin on historical and monumental buildings, but suggest the usage of special mortars, there is a wide range of situations in which the use of chemical anchoring is more suitable than mortar, especially in the case of anchoring systems on rocks or high resistance supports. Such is the case of all the masonry buildings that are not under a preservation order or listed buildings.

However, for the last twenty years, such retrofitting techniques for masonry structures have been developed and practiced, but rarely validated with experiments and numerical modelling. Specifically, while a number of studies, both theoretical and experimental, concerns the behaviour of concrete anchors, the lack of data concerning the behaviour of chemical anchors in natural stone is incontrovertible.

A wide literature exists on the experimental behaviour of concrete anchors in terms of pull-out strength and anchor depth determination, as reported in [1–3].

The structural soundness of concrete reinforced with chemically bonded anchors have been studied by means of the use of acoustic emission techniques in [4]. A number of experimental investigations concerning concrete are also coupled with theoretical formulations for predicting the ultimate tension load [5–8], or the strength under shear load [9]. Moreover, experimental and theoretical predictions have been compared with numerical simulation by using elastoplastic finite-element analysis in [10], the 3D Microplane Concrete Model in [11] in the case of anchor bolts with large embedment depths, an elastic analysis in [12]. A detailed definition and characterisation of suitable adhesive material models for finite element analysis is given in [13]. Theoretical models for concrete have also been validated by Cook in [10], analytical and numerical support for the practical prediction of the strength of epoxy-grouted anchor bolts in reinforced concrete is provided in [14], while the pull-out behaviour of an imperfectly bonded anchor system is studied in [15]. The prediction of the tensile capacity of single adhesive using neural networks is attempted in [16]. Moreover, the extension of these concepts to Fiber Reinforced Polymer anchor can be found in [17,18], among others. In [19] the factors affecting the pull-out strength of steel rods bonded into precast concrete panels are investigated. The tensile behaviour of post-installed chemical anchors embedded to low strength concrete is studied in [20] and their response under cyclic load is analysed in [21]. Finally, the bond strength of chemical anchor in high-strength concrete is investigated from the experimental and numerical point of view in [22].

The literature drastically shrinks about other materials, such as wood. Cimadevila and co-authors presented a novel anchoring system using threaded steel rods glued into wood [23,24]. In the same way few paper are available, in the author knowledge, concerning stone materials. Some information can be found in [25] about the mechanical behaviour of anchorages for reinforcing marine stone structures subjected to sea waves, while the experimental investigation on mechanical and chemical anchors in masonry wall subject to pullout load and torque is reported in [26]. A few other references can be found in the field of rock mechanics and tunnelling technologies. In [27] the influence of the grout properties on the pull-out load capacity of fully cement-grouted rock bolts is investigated.

The poor information regarding the behaviour of chemical anchors in natural stone has highlighted the need of wide and deep researches in this area, especially required by licensed engineers working in the field.

Aim of the research is the determination of the uni-axial strength of post-installed threaded rods in natural stone by means of Hilti Re-500 epoxy resin of the company Hilti, providing technical guidelines for the determination of the minimum anchorage length in the case of block masonry.

The goal is achieved from both the experimental point of view (through laboratory testing) and the numerical point of view (through simulations with finite element software). In the experiments three different types of stone for construction were tested, at various embedment depth and for different values of the bar diameter. The validity of theoretical models for concrete is investigated.

The following is a brief description of the organisation of the paper.

Section 2 provides a general overview about chemical anchoring systems. In Section 3 there is a description of the materials that were used for both experimental and numerical studies concerning post-installed adhesive anchors in natural stone. Section 4 reports the results of the experimental investigations on chemically bonded anchoring systems in different stone types. Section 5 provides an overview of the theoretical models for the failure mechanisms of chemical anchors in the literature and section 5.2 the comparison between the theoretical prediction and the experimental results. In Section 6 the numerical simulation of the experimental tests in Section 4 is described and compared with test data. In Section 7 a specific algorithm based on the Strong Discontinuity Approach for the prediction of the cracks in brittle material is applied as an explanatory example of the failure mechanism. Some conclusions close the paper.

2. The anchoring system

In the past, traditional systems of fastening devices consisted of mortar to be applied after practising an hole of appropriate size on the wall.

Such systems are now almost entirely abandoned in favour of a widely used new generation of anchors. These modern fastening systems that use mechanical or chemical anchors, such as plastic or metal dowels, adhesive capsule or injectable resin mortar, require preliminary procedures, from the realisation of a single hole in the support by means of impact drill to the compressed-air cleaning of the hole.

The range of applications extends the anchors for attaching organs of various types to reinforced concrete, plain concrete, very compact stone walls, solid brick walls, semi-solid and perforated walls or heavy concrete blocks.