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Review article

Bond strength of textured micropiles grouted to concrete footings

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ABSTRACT

In a previous research study the authors performed push-out tests with smooth micropile inserts grouted under varying confinement conditions. It was shown that: (i) failure always occurs at the steel-to-grout interface; and (ii) the connection capacity increases with the passive confinement. To increase the connection capacity, it is a common practice to weld steel rings on the surface of the micropile and execute grooves in the predrilled hole. Therefore, a new study is herein presented aiming to widen the conclusions already drawn by analysing the influence of most important parameters in the bond strength of textured micropiles grouted to concrete footings.

Laboratory tests were specifically designed for assessing the effect on the connection capacity of the: (i) diameter of the predrilled hole; (ii) insert's embedment length; (iii) active confinement of the footing; and (iv) treatment of the hole surface. Eighteen textured micropile inserts grouted in RC footings were submitted to monotonic push-out tests until failure. In brief, it can be stated that the capacity of the micropile-to-footing connection increases by increasing the insert's embedment length and by decreasing the hole diameter. Moreover, an adequate active confinement must be provided to achieve the required capacity.

Contents

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1. Introduction

Micropiles are usually applied to existing RC footings through predrilled holes and sealed with non-shrink grout. Detailing depends mainly on the required capacity of the connection [1–3]. It is a common practice to weld steel rings or a steel spiral around the perimeter of the micropile (see Fig. 1) in order to increase the capacity and the ductility of the connection. In this case, load is transmitted from the micropile to the footing by friction between shear rings and surrounding grout. Grooves at the hole surface (see Fig. 1) are also required to guarantee sufficient bond strength at the grout-to-concrete interface [1,4,5].

Attention must also be paid to the reinforcement of the existing concrete footing since this can be insufficient for the strengthened situation. In this case, both lateral and vertical confinement of the existing footing should be increased to assure the required connection capacity [2]. Namely, vertical prestressing is required to enhance the shear capacity, while lateral prestressing is required to enhance both shear and flexural capacities of the footings. Prestressed tendons or aramid/carbon fibres can be used with this aim.

The assessment of the bond strength of the micropile-to-grout and concrete-to-grout interfaces is vital for designing the connection between micropiles and existing footings. However, few studies are available. One of the most relevant was performed by Gómez et al. [6], using push-out tests to evaluate the connection capacity of micropiles considering smooth and textured inserts in reinforced concrete footings. Holes were drilled using a jack hammer to guarantee sufficient bond at grout-to-concrete interface. The reinforcement represented approximately 1% by volume of the concrete footing. For textured inserts weld beads were created around the perimeter of two micropiles to simulate shear rings with 150 mm spacing and a thickness varying between 10 and 12.5 mm. The authors concluded that for textured micropile inserts the connection capacity is mostly controlled by frictional effects due to the dilation caused by the relative slip at the micropile-to-grout interface. It was concluded that the use of textured micropiles increases both capacity and ductility of the connection.

In a previous research study [7], the authors performed push-out tests to evaluate the load capacity of existing RC footings strengthened with smooth micropile inserts grouted in predrilled holes. It was concluded that: (i) failure always occurs at the steel-to-grout interface; (ii) the connection capacity increases with the confinement level of the grout mass and (iii) it decreases with the increase of the grout diameter. Immediately after reaching the peak load, all specimens presented a sudden drop of the load carrying capacity, down to a residual value of less than 50% of the maximum load.

Moosavi and Bawden [8] performed shear tests on grout cylinders subjected to varying normal pressure, for which the shear strength of the cement grout was shown to increase with higher compressive strength and higher normal stresses.

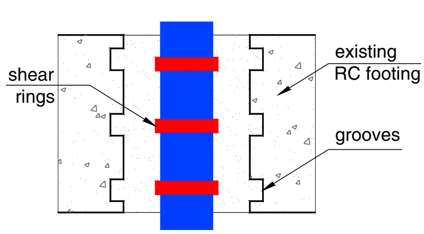

Fig. 1. Micropile to footing connections with shear rings and grooves at the hole surface.

Studies on bond strength of grouted reinforcing bars using pull-out tests also present some relevant conclusions for the investigation herein described and therefore should be referred to.

Darwin and Zavaregh [9] performed several pull-out tests of individual reinforcing bars grouted in small-diameter holes predrilled in concrete. Bond strength was shown to be insensitive to the preparation and the diameter of the hole, but increasing with bar size, cover and embedment length, presenting a nearly linear relation with the latter. Finally, it is also concluded that the bond strength increases with the square root of the compressive strength of the surrounding concrete.

Barley [10] performed several pull-out tests in grouted anchors to determine the shear capacity of confined grouts. For normal anchor grout the direct shear strength is in the range of 12–20 MPa, whereas for proprietary encapsulating grouts the direct shear strength can reach 25 MPa.

In another research program, Moosavi et al. [11] studied the bond of cement grouted reinforcing bars under constant radial pressure in a series of pull-out tests using a modified Hook cell to assess the effect of confining pressure on the bond capacity. By increasing the confining pressure, the connection capacity also increases and the radial dilation decreases. Furthermore, lower quality grouts also have decreased dilation which results in a lower bond capacity.

Kılıc et al. [12] performed 80 pull-out tests on rock bolts to evaluate the shear strength effect of grout on the bond strength at the bolt-to-grout interface of a threaded bar. The authors concluded that the bolt capacity depends on the mechanical properties of grouting materials, with failure occurring at the bolt-to-steel interface. The pull-out force increases with the Young's modulus, uniaxial compressive strength and shear strength of the grout, and a linear relation with the embedment length (until reaching the ultimate tensile strength of the bolt) is observed. It is also concluded that the water/cement ratio considerably affects the pull-out strength and that it should be between 0.34 and 0.40.

In the case of steel micropiles connected to RC footings, and from the studies previously referred to and [13–15], it can be assumed that the load transfer mechanism depends on: (1) chemical adhesion at both steel-to-grout and concrete-to-grout interfaces; (2) friction at both steel-to-grout and concrete-to-grout interfaces; and (3) bearing of the welded steel rings at the micropile-to-grout interface. Consequently, five possible failure mechanisms can be predicted: (i) bond failure at the steel-to-grout interface; (ii) bond failure at the concrete-to-grout interface; (iii) failure of the RC footing; (iv) failure, yielding or buckling of the micro-pile; and (v) a combination (of some or all) of the previous.

All design codes for RC structures, namely ACI 318 [16], EC2 [17] and MC 2010 [18], specify design expressions for both the bond strength and the anchorage length of bars embedded in concrete. However, there are no specific expressions addressing the bond strength of steel tubes grouted in predrilled holes in concrete. Furthermore, if the existing expressions are used to estimate the anchorage length of a micropile grouted in a predrilled hole, too conservative solutions are obtained, requiring a significantly deeper foundation and are generally not feasible in practice.

The study herein described focuses specifically on the behaviour of both micropile-to-grout and concrete-to-grout interfaces with textured micropile inserts aiming to quantify the influence on the bond capacity of the micropile of: diameter of the predrilled hole; insert's embedment length; active confinement of the footing; and treatment of the hole surface.

2. Research significance

Although strengthening existing RC footings with grouted micropiles is currently one of the most used retrofitting techniques, the