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Exploratory investigation of grouted bar-in-duct connections under direct tensile load

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HIGHLIGHTS

- Bond behaviour of grouted connections under monotonic tensile loading was explored on 22 full-size specimens.
- Grouted connections behave quite differently from bar-in-concrete model assumed in design codes.
- Varying embedment length did not affect bond stress and slip, but influenced failure mechanism of connections.
- Model was calibrated and accurately predicted experimental results.
- Enhanced understanding of behaviour of connections acquired, showing need for revisions in relevant design code provisions.

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ABSTRACT

Grouted dowel connections are widely used to resist tension induced by in-plane straining actions and to provide ductility to precast concrete load bearing wall structures. Yet, such connections have not yet been duly investigated. Current design code and standard provisions treat it similar to a simple bar-in-concrete detail. The present study reports the findings of 22 full-scale tests undertaken to examine the bond behaviour of grouted connections under monotonic tensile loading. The examined test parameters included the bar embedment length, bar material and corrugated duct. Results indicate that grouted connections behave quite differently from the bar-in-concrete model assumed in design codes, primarily due to the confinement mechanism of the duct, which provides restraint to lateral expansion of the grout. Varying the embedment length seemed to affect both the bond stress and slip, but did not influence the failure mechanism of the connections. The experimental results were used to calibrate two well-known bond-slip analytical treatments, predictions of which appear to be in good agreement with experimental results. The experimental and analytical findings provide an enhanced understanding on the behaviour of such connections, highlighting the need for revisions in future relevant design code provisions.

1. Introduction

Grouted reinforcing bar connections (commonly known as grouted bar-in-conduit or corrugated duct connections) are versatile ties widely used in precast construction to resist tensile loads. The connection is attractive due to its simple application, forgiving tolerance, and weld elimination. It is generally comprised of a large diameter reinforcing bar (usually 25 mm or greater) projected from one panel and grouted into a metallic duct placed in the other, as shown in Fig. 1. Despite their increased use in precast wall construction, a limited number of studies have been devoted to study the behaviour of such connections.

The use of grouted connections in precast wall buildings generally satisfies one of two requirements: (i) structural integrity (Section 16.2.5 in the ACI 318-14), which prevents progressive collapse [1]; and (ii) as a ductile device used to yield when subjected to large in-plane deformations. Currently, the grouted length of the connections is determined per the provisions of ACI 25.4.2.3 based on the minimum development length in tension. The minimum specified development length of a No. 8 bar is 1070 mm for a 28 MPa concrete and the minimum embedment length of any bar

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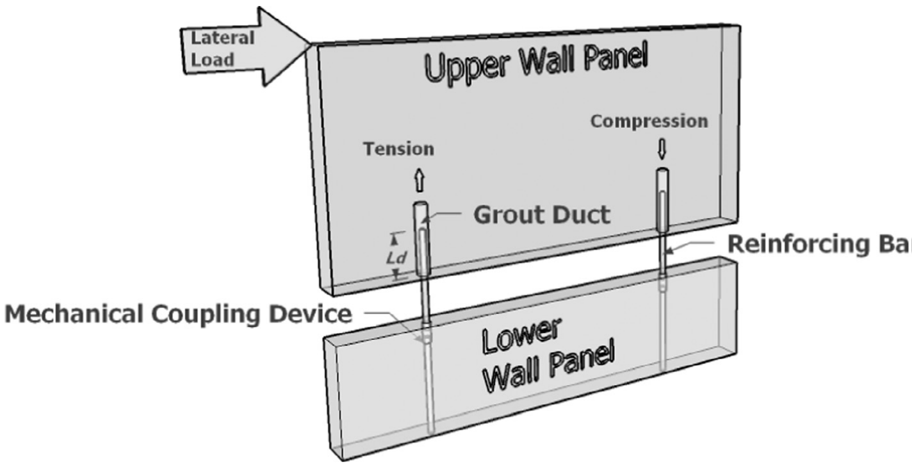

Fig. 1. Grouted reinforcing bar connection and its use in precast walls.

should not be less than 305 mm [1,2]. This usually results in excessive grouting lengths and introduces a plane of reduced stiffness at the interface between the connection and the wall [3]. A recent study by the present authors emphasized the differences between grouted connections and the current code treatment [4].

Raynor *et al.* [5] investigated the behaviour of grouted connections used in hybrid frames using short bar embedment lengths under monotonic and cyclic pull-out loads. They concluded that bars embedded in corrugated ducts behave differently from their non-ducted counterparts, primarily due to the confinement effect of the duct. Steuck *et al.* [6] performed pull-out tests on grouted connections used in bridge bent cap structures, where a large diameter bar (No.10, 14, and 18) is customarily used. The corrugated duct generated confinement sufficient to suppress splitting failures of the concrete. Similar studies on bridge bent cap structures were conducted by Brenes *et al.* [7] and Matsumoto *et al.* [8] who explored various configurations of the connection and reached similar conclusions. Balleri and Riva [9] showed that grouted connections used in column-footing assemblies have favourable ductility compared to that of monolithic assemblies, attributing this to the additional confinement effect of the duct. Although there is agreement among the limited number of studies on the additional confinement imparted by the corrugated duct, quantitative supporting evidence has often not been provided.

Most of the published literature on grouted connections pertains to its use in bridge bent cap structures. Bond is not measured directly and is known to be sensitive to several influential factors such as the cover-to-bar ratio, testing configuration, material properties, and confinement. Hence, the relevant sparse experimental results and associated models cannot be directly extrapolated to the specific case of grouted connections used in precast walls. Accordingly, the present study is a dedicated experimental methodology to address these knowledge gaps. The specific objectives of this paper are: i) provide quantitative and qualitative experimental evidence on the behaviour of grouted connections in precast walls; ii) examine the behaviour of grouted connections equipped with Fibre Reinforced Polymer (FRP) bars that can be used in non-seismic application; and iii) develop and calibrate suitable analytical treatments to explain the behaviour of these connections.

2. Experimental program

In the present study, 22 full-scale pull-out tests were carried out to investigate the behaviour of grouted bar-in-duct connections. A summary of the experimental parameters is given in Table 4. The main test parameters were:

- **Embedment length**: anchored lengths of 6, 8, 10 and 12 d_b (where d_b is bar diameter) were chosen to explore the bond over short and medium anchorages.
- **Bar type**: the bars tested included Grade 60 and Grade 100 rebar, Glass FRP, and Basalt FRP. Bars were selected to examine the bond behaviour of grouted connections under different bar strain domains and the associated effect on the bond (e.g. Grade 60 (plastic bar strain); Grade 100 (elastic bar strain); FRP (elastic bar strain)). Exploring the effects of different strain levels and surface treatments of bars responds to specific construction needs. For example, ductile bars were studied for use in panels subjected to large tensile and ductility demands. FRP bars were considered in light panels to satisfy structural integrity requirements.
- **Duct**: specimens with and without ducts were considered to investigate the role of the corrugated duct. Specimen details, materials properties and test methodology are presented below.

2.1. Materials properties

Self-consolidating concrete having average 28-d compressive (ASTM C39 [10]) and splitting tensile strengths (C496/C496 M [11]) of 50.6 MPa and 4.9 MPa, respectively was used to cast the specimens. Its mixture proportions are shown in Table 1. A high-strength non-shrink grout with an average 28-d compressive strength of 39.3 MPa and tensile strength of 6 MPa was used. Mechanical properties of the concrete and grout are summarized in Table 2. The mechanical properties of the various bars measured per ASTM guidelines [12] are reported in Table 3. The dowel bars used included Grade 60 and Grade 100 rebar along with GFRP

Table 1
Concrete mixture proportions.

Materials	Per 1 m^3
CSA Type 30 Cement	435 kg
Sand	842 kg
14 mm aggregate (round)	842 kg
Water	200 Litres
Air	5%
Air Entrainment/Lubricant	20 ml/100 kg cement
High Range Water Reducer	630 ml/100 kg cement
Total	2,322 kg