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Experimental and analytical study on precast concrete dowel connections under quasi-static loading

M. Elsayed [a], F. Ghrib [b], M.L. Nehdi [a,*]

[a] Department of Civil and Environmental Engineering, Western University, London, ON, Canada
[b] Department of Civil and Environmental Engineering, University of Windsor, Windsor, ON, Canada

HIGHLIGHTS

- Grouted dowel connections tested under quasi-static loading for the first time.
- Calibrated Frictional Model gave satisfactory predictions of experimental results.
- Developed empirical model captured grout damage due to cyclic excitation.
- Rational and accurate design tool for grouted dowel connections is proposed.
- Proposed tool is more accurate than current unrealistic bar-in-concrete model.

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ABSTRACT

To create composite behaviour in precast concrete panel construction, grouted dowel connections are widely used owing to their simplicity and ability to divert damage from panels during excessive deformation. Yet, current design codes treat this connection as a bar-in-concrete idealization, disregarding the sleeve confinement and composite behaviour of the assembly. Moreover, the performance of this connection under cyclic excitation is yet to be explored. In this study, full-scale grouted dowel connection specimens mimicking actual field conditions were tested to failure under quasi-static loading. Experimental findings revealed that, regardless of the strain level, grouted connections consistently failed in a pull-through mode by shearing of grout between the lugs of the bar. For all dowel embedment lengths, the load capacity of connections depended primarily on the connection seams of the sleeve, and not on the hoop strain level developed in it. Measurement of the hoop strain values allowed calibrating the Frictional Model, which yielded satisfactory predictions of the experimental results. An empirical model was developed using the experimental results to capture the grout damage due to cyclic excitation, thus providing a rational and accurate design tool for grouted dowel connections in composite panel precast concrete wall construction.

1. Introduction

Grouted reinforcing bar-in-conduit connections, or simply grouted connections, are composite connections often used to connect a variety of precast concrete elements. The connection is comprised of a large-diameter reinforcing bar grouted into a corrugated duct, bridging the horizontal joint between two vertically stacked walls. Grouted connections provide a straight force path extending along the height of a precast wall, reducing the risk of brittle failure. Two of the most common schemes of these connections are illustrated in Fig. 1, with detail 1 being the most prevalent. It is shown that bond is the main mechanism through which grouted connections achieve composite action.

Currently, grouted connections are designed in accordance with the recommended development length in tension of ACI 318-14 (Sections 25.4.2.3), which treats the connection as a bar-in-concrete scheme. A recent study questioned the efficacy of this assumption and showed that grouted connections did not suffer sudden splitting failures owing to the passive confinement effect of the duct [1]. In the absence of dedicated design provisions that reflect the composite action between the corrugated duct and the grout, designers and precast fabricators tend to over-design these connections, thus increasing field grouting operations. For example, the recommended development length of a 25-mm bar is typically 1200 mm for a concrete with a compressive strength, f'_c of 27

* Corresponding author.
E-mail address: mnehdi@uwo.ca (M.L. Nehdi).

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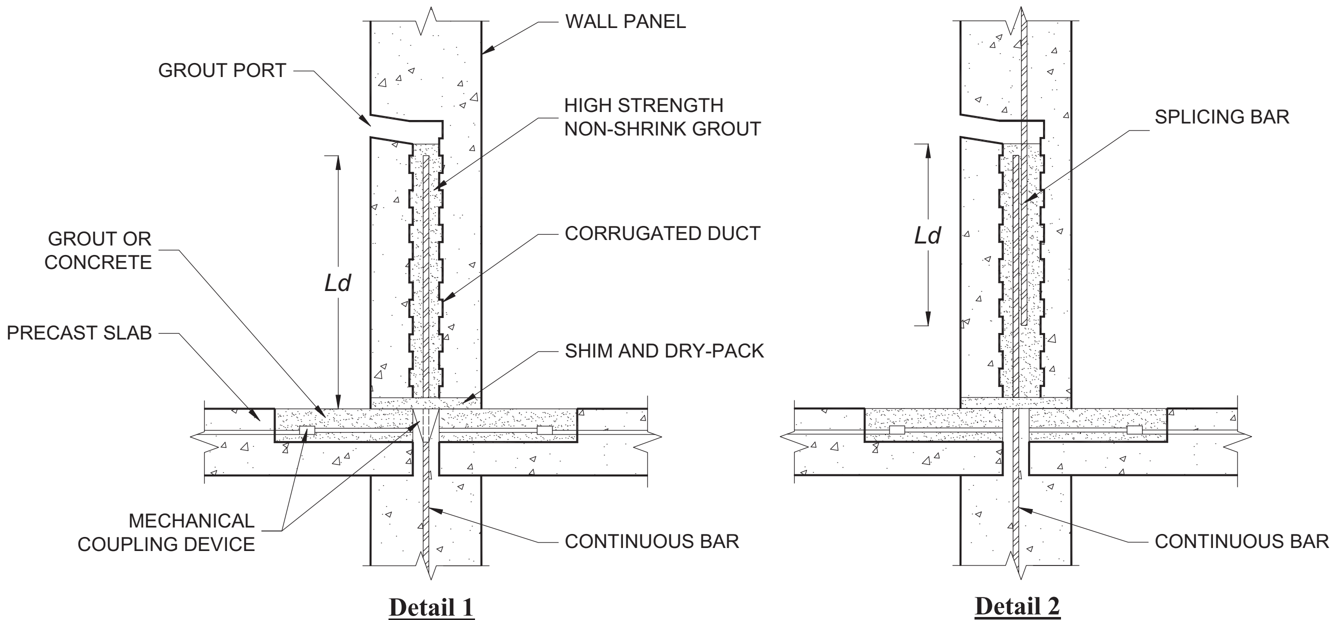

Fig. 1. Common schemes of grouted connections used in precast walls.

MPa. Such excessive grouted lengths could result in a wall panel with reduced stiffness because excessive deformations can result in spalling of the concrete along the length of the corrugated duct [2]. Despite its extensive use in precast wall structures, a dearth of information on grouted connections currently exists in the open literature, particularly under cyclic loads.

For instance, a single study was found in the open literature directly addressing this type of connection under cyclic loading. This investigation conducted by Raynor et al. [3] studied grouted connections typically used in hybrid precast frames (small cover/diameter ratio). The specimens were subjected to a constant amplitude and variable displacement history. The bars had short embedment and the specimens were sufficiently confined. Their experimental results indicate that bond stresses due to cyclic loads are 10–70% less than those from monotonic loading, depending on the level of slip. It was shown that grouted duct connections behave differently from their bar-in-concrete counterparts. However, the reported data in this study were mostly qualitative and lacked experimental evidence on the real failure mechanisms.

Other studies on precast walls having grouted connections briefly reported on some behavioural aspects of these connections. For example, Seifi et al. [2] tested under cyclic loading precast walls having grouted connections that use 16 mm bar and a grouted length of 37.5 d_b. The panels did not suffer premature failure and displayed favourable ductile behaviour characterized by panel sliding via yielding and elongation of the connection reinforcement. Other studies acknowledged the ductility and favourable energy dissipation of grouted connections. However, large embedment lengths were used in such studies and no information pertaining to the bond of the connections was reported [4–6].

When a deformed bar is pulled/pushed under a cyclic load, adhesion is first lost, then mechanical bearing of the ribs is the primary mechanism of bond. The line of action of the bearing force resultant is approximately 30° [7]. This value strongly depends on various influential parameters, including the geometry of the lugs, confinement, and the characteristics at the cement-aggregate interface. The exact value of θ is not known and remains a matter of great contention in the open literature. This concept was originally proposed by Lutz and Gergely [8] and experimentally verified by others. For example, Cairns and Jones [22] observed an inclination angle of 45°. Similar observations were made by Goto [23], who observed that the initiation of cracks at the bar-concrete interface occurred at an angle of approximately 60°. More relevant experimental studies on precast concrete connections reported similar findings. For example, Steuck et al. [9] reported conical grout break-out failures forming an angle of 45–60° with the longitudinal axis of the bar in grouted connections. Ameli and Pantelides [10] and Parks et al. [11] reported similar break-outs with an angle of 45° in grouted splice sleeves.

The amount of damage accumulation is strongly dependant on the strain range of the cycles and the type and rate of loading [12,13]. The escalating slip due to constant amplitude cyclic loading decreases after the first few cycles. According to the Palmgren-Miner Hypothesis, the relationship between damage accumulation and number of cycles is linear at a certain load level. To further induce slip, loading should approach or exceed that in the previous cycle [7,14]. Transverse reinforcement can delay the occurrence of splitting failures resulting from cyclic loads. If sufficient restraining action is provided, the failure can shift from splitting to pull-out failure [15,16]. The relationship between the anchored length of the bar and the number of cycles to pullout is not understood quantitatively. Per the ACI 408.2R guidelines, the anchored length is proportional to the total number of cycles required to achieve a pull-out failure [7].

Considering the current knowledge gaps and lack of data, the cyclic behaviour of grouted connections is explored in the present study through a carefully designed experimental methodology. The primary objectives are fourfold: i) devise an experimental scheme that eliminates the spurious effects known to be associated with bar bond testing; ii) explore the cyclic behaviour of grouted connections under realistic specimen and loading conditions; iii) provide quantitative evidence on the confinement of the corrugated sleeve and exploit this information to calibrate a frictional model; and iv) develop an empirical equation capable of predicting the capacity of the connection under a desired level of stress in the dowel and compare it with a similar model developed by the authors for grouted connections under monotonic loading [1].