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Effect of early-age subfreezing temperature on grouted dowel precast concrete wall connections

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HIGHLIGHTS

- Effect of subfreezing temperature on grouted dowel connections was explored for the first time.
- Bond strength was proportional to compressive strength square root after early-age subfreezing.
- Bond stress-slip response was unchanged after exposure to early-age subfreezing conditions.
- Initial normal temperature curing period was crucial for grout's compressive strength gain.

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ABSTRACT

During cold weather precast wall construction, in-situ heating of the grout used in grouted dowel connections is usually conducted for short periods of time. Hence, early-age exposure to subfreezing conditions may affect the quality of the grout and subsequently the bond strength of the connection, which can compromise structural integrity. In this study, grout specimens typical of that used in precast wall construction were initially cured at ambient conditions for one day and then placed inside a walk-in environmental chamber at subfreezing temperatures. The hardened grout properties and bond strength of the connection were examined and compared to that of specimens cured at ambient temperature. The compressive strength of the grout was monitored at temperatures of 1°, −10° and −20 °C. The effect of subfreezing exposure on the mechanical properties, hydration process and pore size distribution of the grout were examined. It was found that early-age subfreezing curing temperatures reduced the compressive strength of the grout, leading to increased dowel embedment length to achieve bar fracture. The bond strength of the connection remained proportional to the square root of compressive strength, even subsequent to early-age exposure to subfreezing temperature.

1. Introduction

Precast concrete load-bearing wall panels have become a popular choice for low-, medium-, and high-rise construction in North America. This structural system is advantageous owing to its repetitive nature, which allows for mass production of high quality precast elements in an environmentally controlled factory, as well as its rapid and cost-effective erection, even under undesirable weather conditions. However, a primary concern in precast concrete wall construction is the reliability and ease of installation of the panel connections, since this directly influences structural integrity and stability.

Most designers prefer using emulative connections since they are less labor intensive, and thus more economical. Such connections also do not usually require costly experimental evidence to satisfy special code acceptance. In particular, the grouted dowel connection has become a commonly used emulative connection in precast concrete wall panel construction. It utilizes longitudinal reinforcing bars protruding from the lower wall panel and grouted into corrugated steel ducts in the upper wall panel, as shown in Fig. 1.

In cold climates, subfreezing temperatures can prevail for long periods of time, which can significantly slow or halt concrete construction. The ACI Committee 306R-10 defines cold weather as a period of three or more successive days when the average daily air temperature drops below 4 °C and does not exceed 10 °C for more than one-half of any 24-h period [1]. Concrete must reach a compressive strength of 3.5 MPa before exposure to subfreezing temperatures; failure to do so will result in significant reduction of both the strength and stiffness of the concrete. Winter construction of cast-in-place concrete requires the heating of large areas for

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NOTATION

d_b	bar diameter, mm (in.)
f'_g	grout compressive strength, MPa (psi)
f_s	axial bar stress, MPa (ksi)
f_y	bar yield stress, MPa (ksi)
l_d	embedment length, mm (in.)
l_d/d_b	normalized embedment length
P	axial force at failure, kN (kip)
R_s	strength ratio
s_{max}	bar slip at failure, mm (in.)
u_b	average bond stress at failure, MPa (psi)
$u_b/\sqrt{f'_g}$	normalized bond stress
δ_y	yielding displacement, mm (in.)
δ_u	ultimate displacement, mm (in.)
μ_Δ	ductility ratio

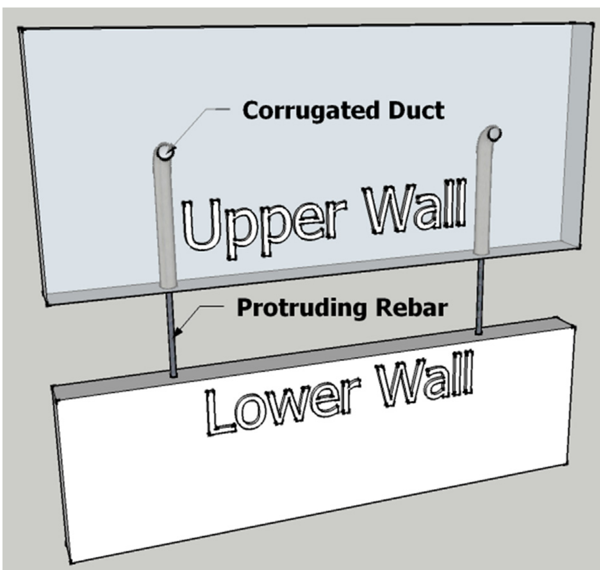

Fig. 1. Typical grouted dowel connection.

extended periods of time, and typically includes the use of accelerating admixtures to ensure the development of adequate compressive strength. However, such methods can significantly increase cost, while making it difficult to maintain superior quality control.

A major advantage of precast concrete construction is that it can continue throughout adverse weather conditions, including cold weather, since the structural elements are cast and cured in a quality controlled precast plant. However, the grouted dowel connection requires the in-situ placement of fresh grout. In cold weather construction, the entire floor is blanketed and heated during grout mixing and pouring. Usually, the heating is stopped after one day, and the connection is exposed to subfreezing temperatures, before the grout is fully cured. This could affect the bond strength of the connection, and possibly the overall structural integrity.

The authors could not retrieve any studies in the open literature examining the effect of subfreezing curing conditions on the bond strength of grouted dowel connections. However, Gardner and Poon [13] investigated the effect of 2 °C curing on the bond strength of concrete, and concluded that the bond strength was affected proportionally to the square root of the compressive strength, irrespective of the temperature or cement type. Most existing research work has focused on the effect subfreezing exposure on the compressive strength, since the latter is used in the ACI (2014) [2] equation (25.4.2.3) to determine the bar development length.

Results of several studies generally indicate that the compressive strength gain of concrete was adversely affected by early-age exposure to subfreezing temperatures. For instance, Klieger [16] found that curing concrete at −4 °C resulted in significantly lower 28-day compressive strengths by 13% and 70%, for concretes made with Type I and Type III cements, respectively. Gardner [12] showed that curing concrete at 0 °C had adverse effects on the compressive strength of concrete, contradicting earlier work which determined that no adverse effects were observed when cured at 2 °C [13] and 0 °C [14]. Furthermore, the magnitude of strength loss of concrete cured in cold weather varied significantly between studies. In two separate investigations, high-strength concrete incorporating silica fume and fly ash was cured in −5 °C ocean water, resulting in 7-day strengths of 37% [15], and 81% [17]. Such inconsistent results demonstrate the importance of testing the actual grout mixture to be used in precast wall panel construction, while accurately replicating the subfreezing conditions to be experienced in the field.

2. Research significance

Since a typical precast concrete wall structural system depends primarily on the performance of grouted dowel connections, it is crucial to understand how early-age exposure to subfreezing temperatures will affect the grout and the connection's bond strength. It has been widely accepted that the bond strength of concrete is directly proportional to the square root of its compressive strength [32], even at low temperature curing [13] and in the case of frost damage [27]. Since grouted dowel connections are used in a variety of precast structures including beam-column joints in hybrid frames [24] and bridge bent caps [30], the research conducted herein on the effect of subfreezing exposure on grouted dowel connections could be extended to the winter construction of various precast structures including buildings and bridges.

3. Experimental investigation

Full-scale precast concrete wall panels are typically braced for one week. Hence, the focus of this study was on the properties of the grout in the first 7 days. The grout used in this study was a commercially available, pre-packaged, non-shrink grout containing well-graded fine aggregate and fly ash. One 25 kg bag was mixed with 3.75 L of water to achieve a fluid consistency with a specified 7-day compressive strength of 30 MPa, as indicated by the manufacturer. All materials were stored, cast, and cured at ambient laboratory conditions (T = 23 ± 1 °C). After one day of curing at ambient conditions, the specimens were moved to a temperature-controlled environmental chamber preset at the specified temperature until the testing date. The internal temperatures of the grout cylinders and pullout specimens were monitored at subfreezing temperatures with probes carefully placed at the center of the cylinders and pullout specimens; temperature readings were taken every 10 min for 7 days. The control specimens