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Quantification of bond performance of 18-mm prestressing steel

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HIGHLIGHTS

- A complete testing program is conducted to evaluate the bond performance of 18-mm prestressing strand.
- The bond performance of untensioned prestressing strands is examined using Standard Test for Strand Bond (STSB).
- Transfer and development lengths are measured for 12 pretensioned concrete beams.
- The bonding equations in the current design codes are applicable for predicting transfer and development lengths.

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ABSTRACT

The use of 18-mm prestressing strands has extensive advantages in building and bridge construction. Strand bond is a critical factor that constitutes the strand behavior in pretensioned concrete girders and directly affects the applicability of existing bonding equations. This study systematically examines the bond performance of 18-mm strands. The bond strength of untensioned strands was evaluated using simple bond tests. Twelve pretensioned concrete beams were additionally cast using self-consolidating concrete to assess the bond-related parameters of transfer and development lengths. The experimental results indicate the bond performance of 18-mm strands complies with the current design codes of pretensioned concrete members.

1. Introduction

The purpose of this experimental research program was to examine the bond characteristics of 18-mm, Grade 1860, prestressing strands, using different design codes. The scope was limited to verifying the surface conditions of untensioned strand specimens using simple bond tests, and measuring transfer and development lengths of 12 pretensioned concrete beams cast with self-consolidating concrete (SCC). The measured data were used to verify the applicability of the American Concrete Institute Committee 318 (ACI 318-14) [1], American Association of State Highway and Transportation Officials – Load and Resistance Factor Design – Bridge Design Specifications (AASHTO) [2], Model Code 2010 Specifications (MC-2010) [3], and Eurocode 2 (EC-2) [4] in predicting the transfer and development lengths of 18-mm prestressing strands.

Mechanical properties and bond performance of prestressing strands are significant for the design of pretensioned concrete members. The mechanical properties govern the load-carrying ability while the bond performance is critical to ensure the strands and the concrete can work as a composite material [5,6]. The American Society for Testing and Materials (ASTM) A416 [7] identifies that a 18-mm strand has a cross-sectional area of 190 mm^2, a minimum yield strength of 1675 MPa, an ultimate strength of 1860 MPa, and a minimum elongation of 3.5%. These requirements were validated for a number of strand specimens collected from different strand manufacturers [8]. However, there are no official specifications to evaluate the bond performance of 18-mm prestressing strands. The current code equations are applicable for strand diameters up to 15-mm prestressing strands.

Strand bond is the shearing stress at the interface between the strand and the surrounding concrete [9]. When the prestressing strand is in tension, it tends to move in the same direction with

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Nomenclature

A_{sp}	cross-sectional area of prestressing strand
E_p	modulus of elasticity of prestressing strand
E_{ct}	modulus of elasticity of concrete at release
L_t	transfer length or transmission length
L_d	development length
$l_{bpt,0.05}$	lower bound of transmission length
$l_{bpt,0.95}$	upper bound of transmission length
l_{bp}	basic anchorage length
α_{p1}	coefficient considering the type of release
d_b	nominal strand diameter
f_{se}	effective prestress after losses
f_{ps}	average prestress at the time for which the nominal flexural resistance of a pretensioned concrete member is required
f_{bpd}	design bond strength
f_{ctd}	lower design concrete tensile strength
f_{ctm}	concrete tensile strength at release
f_{ptd}	design strand strength
f_{cki}	concrete compressive strength at release
f_{ck}	concrete compressive strength at 28 days of age
f_{pj}	jacking stress
σ_{pi}	strand stress just after release

the applied force. If the strand bond is inadequate to prevent the movement, a premature failure tends to occur prior to pretensioned concrete members achieve the nominal flexural resistance. In design, structural engineers generally assume that the bond performance of prestressing strands is adequate, and bond-related parameters of transfer length and development length can be predicted using bonding equations specified by the codes as presented in the following sections. Therefore, the quantification of bond performance of 18-mm strands is a vital task before this type of strands is widely used in construction.

2. Literature review

2.1. Bonding equations

The current codes use different equations to quantify the transfer and development lengths of 15.2-mm and 12.7-mm strands. Transfer length is the required length for transferring the prestress in the strands to the concrete. Development length is the required length at which the concrete member achieves the nominal flexural resistance. According to the ACI 318-14 [1], the development length can be estimated using Eq. (1). In this equation, the first and second terms represent transfer length and flexural-bond length, respectively. ACI 318-14 alternatively proposes a simple transfer length equation of $50d_b$ (where d_b is the strand diameter). AASHTO [2] proposes a transfer length of $60d_b$, and the AASHTO development-length equation is identical to the ACI 318-14 equation for pretensioned concrete members having a depth less than 610 mm.

$$L_d = \frac{f_{se}d_b}{20.7} + \frac{(f_{ps} - f_{se})d_b}{6.9} \quad (f_{se}\,\text{and}\,f_{ps}\,\text{in MPa}) \tag{1}$$

where L_d is development length; d_b is the strand diameter; f_{se} is the effective stress in the prestressing strand after losses; f_{ps} is the average stress in prestressing strand at the time for which the nominal flexural resistance of a pretensioned concrete member is required.

In the EC-2 [4] and MC-2010 [3] specifications, the terms of transmission and anchorage lengths are used to define transfer and development lengths, respectively. The estimation of these parameters, however, is slightly different between the EC-2 and MC-2010 with the ACI 318-14 and AASHTO [16,17]. First, the EC-2 and MC-2010 propose the lower and upper bounds of transmission length to examine concrete stresses at prestress transfer and compute shear strength and flexural resistance, respectively. The ACI 318-14 and AASHTO equations are used as the upper bound of the transfer length. Second, the EC-2 and MC-2010 consider the effects of the strand bond conditions, release techniques, and concrete tensile strength on the transmission and anchorage lengths. This consideration can increase the accuracy in predicting these parameters.

According to the EC-2 [4] specifications, an average transmission length can be estimated using Eq. (2) with an assumption of a constant bond strength shown in Eq. (3). For 7-wire strands, the bond strength is a function of strand bond conditions and concrete tensile strength. For the ACI 318-14, the bond strength was assumed to be a constant of 2.76 MPa. In EC-2, two multipliers of 0.8 and 1.2 are used to compute the lower and upper bounds of transmission length, respectively. The lower bound is used for checking concrete stresses at release. The upper bound accounts for the increase of transmission length over time, which is dependent upon concrete properties, environmental conditions, or construction practices. The anchorage-length equation shown in Eq. (4) is computed based on the upper bound of transmission length and the assumption of a constant bond strength in the flexural bond zone as shown in Eq. (5).

$$L_t = \alpha_1\alpha_2 d_b \frac{\sigma_{pi}}{f_{bpt}} \tag{2}$$

$$f_{bpt} = \eta_{p1}\eta_1 f_{ctd,R} \tag{3}$$

$$L_d = 1.2L_t + (\alpha_2 d_b)\left(\frac{\sigma_{pd} - \sigma_{pe}}{f_{bpd}}\right) \tag{4}$$

$$f_{bpd} = \eta_{p2}\eta_1 f_{ctd,S} \tag{5}$$

where L_t is transmission length; d_b is the strand diameter; α_1 considers the release techniques (1.0 for gradual release, 1.25 for sudden release); α_2 is a strand area factor (0.25 for strands with circular cross section, 0.19 for 7-wire strands); σ_{pi} is the strand stress just after release; f_{bpt} is the design bond strength within the transfer zone at prestress transfer; η_{p1} considers the type of prestressing strand and bond situation in the transfer zone (2.7 for intended wires, 3.2 for 7-wire strands); η_1 considers the strand bond conditions (1.0 for good bond conditions [EC-2, Article 8.4.2], 0.7 otherwise); $f_{ctd,R}$ is the design concrete tensile strength at prestress transfer; $f_{ctd,S}$ is the design concrete tensile strength at 28 day of age; σ_{pd} is the strand stress under design load, which is equivalent to f_{ps} in the ACI 318-14 equation (see Eq. (1)); σ_{pe} is the effective strand stress, which is equivalent to f_{se} in the ACI 318-14 equation (see Eq. (1)); f_{bpd} is the bond strength in the flexural bond zone at the ultimate limit state; η_{p2} is a coefficient accounting for the type of prestressing strand and bond situation in the flexural bond zone (1.4 for intended wires, 1.2 for 7-wire strands); f_{ctd} is the design concrete tensile strength at 28 days of age.

The MC-2010 [3] specifications are basically similar to the EC-2, but the multipliers used to estimate the lower and upper bounds of transmission length are slightly different. MC-2010 provides a