COMPREHENSIVE REVIEW OF FACTORS AFFECTING STRAND BOND

Canh N. Dang, Department of Civil Engineering, University of Arkansas
Cameron D. Murray, Department of Civil Engineering, University of Arkansas
W. Micah Hale, Department of Civil Engineering, University of Arkansas
Jose′ Marti-Vargas, ICITECH, Universitat Politecnica de Valencia

ABSTRACT

Proper bond between the prestressing strand and the concrete is essential in prestressed concrete members. Inadequate bond can reduce the shear capacity and flexural capacity of a prestressed member. Strand bond is influenced by many factors that are not directly addressed in current design codes. These factors can be divided into three groups. The first group includes the characteristics or properties of the concrete. This includes properties such as concrete compressive strength, concrete modulus of elasticity, composition, and type of concrete. The second group includes the strand properties. This includes strand surface condition (presence of lubricants and chemical residues) as well as strand location and the number of strands. The final group is testing conditions, including method of prestress release and time dependent effect. Data collected from the literature and from testing conducted at the University of Arkansas were used to investigate which properties of these three groups have the greater influence on strand bond. Factors that have a major effect, such as concrete compressive strength and strand surface condition, are proposed for inclusion in the prediction equations. Otherwise, factors that have a minor influence should not be considered in the equations.

Keywords: Pretensioned Concrete, Transfer Length, Development Length

INTRODUCTION

In prestressed concrete, the prestressing force is transferred from the strand to the adjacent concrete by the bonding of the strand and concrete. The bond performance guarantees that the strand and concrete work well together. When tension stress occurs in the strand, it tends to move in the same direction with applied force. The relative movement of strand will be prevented by the bonding of the two materials. The bonding is controlled by a number of factors. Adhesion, Hoyer's effect and mechanical interlocking are recognized as major factors contributing to bond. However, the variability and unpredictability of friction, discontinuities of the concrete due to cracking, and interaction of Hoyer's effect and mechanical interlocking cause difficulties on qualifying the bonding stress.

Currently, there is no way to directly measure the bonding stresses in prestressed concrete. It can be indirectly determined by measuring embedded length of strand. The bond stresses can be divided into two components: transfer bond stress and flexural bond stress. The transfer bond stress occurs when strands are released (or detensioned) and transmits the prestress to the concrete. In other words, the strands are firmly anchored to the concrete via operating of the transfer bond stress. The flexural bond stress occurs when the applied loads increase strand stress. Generally, the transfer bond stress is specified by the transfer length, which acts in transfer region, and the flexural bond stress is determined by the flexural bond length, which acts in the flexural bond region. Development length is the sum of transfer length and flexural bond length.

The length of the transfer region is from the point of zero stress in the strand to the point of effective stress (f_{se}). At the time of release, stress in the strand is the initial release stress (f_{si}). However, at the end of the transfer region, strand stress is equal to the effective stress (f_{se}), which is smaller than the initial release stress (f_{si}) due to elastic shortening. The effective stress in prestressing strand is constant beyond the transfer region. In the transfer region, the prestressing stress increases linearly, and transmits to the concrete via transfer bond stress. Concrete stress also proportionally increases and achieves compression stress (f_{ce}) at the end of the region. In other words, the transfer bond stress is a "bridge" to transmit prestress from the prestressing strand to the concrete in the transfer region. From the standpoint of bonding stress, it is governed by three factors; adhesion, Hoyer's effect and mechanical interlocking. Hoyer's effect is the most effective near the end of specimen because of the large decreasing of stress in the prestressing strand, from the initial stress (f_{si}) to zero, that causes large frictional resistance in the transfer region. This effect will reduce as stress in the strand increases, and disappears at the end of the region. The mechanical interlocking acts in a different way; its influence is more active while the Hoyer's effect is less. At the end of the transfer region, the impact of mechanical interlocking is fully responsible for the transfer bond stress.

The flexural bond stress depends on the external loading. When the loading is small, there are no cracks in the flexural region, so the flexural bond stress is quite small. When the loading increases, the prestress in the tensile fiber is invalid and cracks are formed due to low tensile strength of concrete. At the location of cracks, the flexural bond stress is zero and the strand receives all stress form adjacent concrete. Thus, the strand stress is greatly increased at the location of cracks. In segments of concrete, which are located between cracks, the flexural bond stress is still valid and resists the slip of strand throughout the concrete segments. In each segment, the mechanical interlocking is a main factor contributing to bonding between strand and surrounding concrete. The formation of cracks significantly influences the strand stress.

The transfer length is the anchor length that guarantees a structure components work well in the service condition. The flexural bond length is the additional anchor length that is needed to achieve the nominal capacity at the ultimate stage. Generally, cracks can be formed in the flexural bond region, but not in the transfer region. If cracks occur in the transfer region, it will cause a significant increase in strand stress. The transfer bond stress is not adequate to resist the increase, and bond failures occur.

The bond behavior of prestressing strand is affected by many factors. These factors can be divided into three groups. The first group includes concrete characteristics, such as compressive strength, concrete composition, and concrete type. The second group consists of strand characteristics such as the lubrication and chemical residue on the strand surface, strand spacing, and strand location. The final group includes method of prestress release, time dependent effect.

Transfer length and development length are also affected by such parameters as strand diameter, stress level in the strand, surface condition of strand (i.e., clean, rusted, or epoxy-coated), confinement reinforcement around the strand, spacing between strands, and concrete cover below the strand layer being considered. Other parameters include concrete strength, concrete modulus of elasticity consolidation and concrete quality or consistency around the steel, and concrete creep and shrinkage. In addition, the transfer and development length is affected by the type of prestress release (i.e., gradual or sudden). Recent studies have also shown that strand bond may be affected by concrete mixture ingredients, type of coarse aggregates and types and amounts admixtures.

LITERATURE REVIEW

BACKGROUND

The relevant standards for the transfer and development lengths of prestressing strand are found in the Section 12.9 of the ACI Code[1] and Article 5.11.4 AASHTO-LRFD Specification[2] as shown in Table 1.

There is no specific requirement in the ACI Code and AASHTO-LRFD Specification for the transfer length. However, regarding calculating the nominal shear capacity of pretensioned member when subjected to web-shear cracking in the transfer region, the ACI Code suggests using 50 times of the strand diameter for the transfer length. This value corresponds to the expression $f_{se}/3$ given in Commentary Section 12.9 when f_{se} is 150 ksi. The AASHTO

Specification suggests using 60 times the strand diameter, which corresponds to the expression when f_{se} is 180 ksi.

The ACI Code and AASHTO-LRFD Specification provide the same equation to determine the development length of prestressing strand as shown in Eq. 1. This equation is equivalent to the expression as shown in Eq. 2. The first term represents the transfer length, and the second term represents the flexural bond length. The ACI Commentary mentions that Eq. 1 is established from test data from Hanson and Kaar[3], and Kaar, Lraugh, and Mass[4]. The testing program was performed on prestensioned components that used normal weight concrete, 2 in. concrete cover, bright strand, and strand diameters of 0.25, 0.375, and 0.5 in. in the 1950s and 1960s.

Table 1. Development length equations by Codes

ACI Code	$L_d = \frac{f_{se}}{3} d_b + (f_{ps} - f_{se}) d_b$	(1)
AASHTO-LRFD Specification	$L_d = \kappa(f_{ps} - \frac{2}{3} f_{se}) d_b$	(2)

where d_b is nominal diameter of strand (in.); f_{se} is effective stress in prestressed steel after losses (ksi); f_{ps} is stress in prestressed steel at nominal strength (ksi); L_d is development length (in).

CURRENT RESEARCH NEEDS

The materials used to produce pretensioned concrete specimens have greatly changed since the 1950's. These changes include the concrete properties, mixture ingredients, and strand characteristics. The ACI Code and AASHTO-LRFD Specification consider effects of strand diameter, effective stress and ultimate stress of prestressing strand in their equations. Nevertheless, there are many variables affecting the transfer and development length and they can be classified into three groups. The first group includes factors depending on concrete properties, such as concrete strength, composition of concrete mixture, consolidation and consistency of concrete around steel, concrete cover around steel, and confining reinforcement around steel. The second group consists of factors that depend on strand characteristics, such as strand diameter, strand stress level, surface condition (bright, rusty, epoxy coated), and strand spacing. The final group contains factors depending on testing conditions, such as type of loading (static, repeated, impact), method of release (gradual, sudden), and time dependent effects.

NECESSITY FOR CODE CHANGES

The Eq. 1 was implemented by ACI Committee 323 in 1963. It was established based on tests performed at the Portland Cement Association (PCA) by Hanson and Kaar[3]. The strands originally studied were Grade 250 pretensioning strands, with a guaranteed breaking strength of 250 ksi (1720 MPa). In the early of 1980's, a new type of low relaxation strand with a guaranteed ultimate strength of 270 ksi (1860 MPa), Grade 270, was introduced. The newer strands possess a ratio of cross-sectional area to perimeter larger than the strands used in the original PCA research. However, these changes had serious impacts on bond strength as well as larger essential bond strength to develop a certain strand stress. Research performed with the newer strands indicated that the current equations were not as accurate as assumed. Upon publication of these results, the Federal Highway Administration (FHWA) applied a 60% increase to the development length equation and prohibited the use of 0.6 in. strand in 1988.

Other agencies have addressed these concerns. The Comité Euro-International du Béton (CEB) and the Fédération International de la Précontrainte (FIP), CEB-FIP Model Code 1990 specified several modifications. Transfer length of top strand was increased approximately 40% to account "top bar effect." In order to consider the influence of prestress release method, CEB-FIP Model Code 1990 identified an addition up to 25% of transfer length when strands in prestressed components were detensioned suddenly.

PROBLEM STATEMENT

Transfer length is a significant factor in accurately predicting strand development failures (Russell and Burns[5]) because it decidedly affects the flexural and shear capacity of pretensioned beams in the ultimate limit state. Under applied load condition, cracks can occur due to bending or shear at the ends of the beam. If cracks appear and propagate in the transfer region, these can highly increase stress in prestressing strand and result in a bond slip failure. Therefore, it is vital to precisely predict the transfer length and prevent the occurring of any cracks within the transfer zone in both cases.

The development length is an essential factor for a beam to develop its nominal moment capacity. At the end of the transfer region, the strand is expected to develop the effective stress, f_{se}, which is approximately 75% (after prestress losses) of the ultimate stress, f_{ps}. Under ultimate limit state, the strand requires additional length, which is the flexural bond length, to develop the ultimate stress to achieve the nominal flexural capacity. If inadequate development length is available, the ultimate moment capacity of a beam is controlled by bond in lieu of flexure. In general, bonding failure is sudden and provides no warning signs.

As previously mentioned, the materials used in the pretensioned concrete industry have been greatly changed, and there are three groups of factors that can influence the transfer and development length. The first group that is constituted by the concrete properties, there are many contemporary kinds of concrete which are utilized, such as high strength concrete, high performance concrete, ultra high performance concrete, and self-consolidated concrete. These concretes have properties which are different than conventional concrete, and they can have positive and negative effects on strand bond. Regarding to the second group, a new generation of strands with higher guaranteed breaking strength, larger cross sections as well as different surface conditions due to alternations in manufacturing processes have strongly impacted the transfer and development length. The final group includes method of prestress release and time dependent effects.

The objective of this paper is to analyze the factors that have strong effects as well as unapparent impacts on the transfer and development length. As formerly discussed, many factors affect these lengths, but it is too complicated to incorporate them into expressions of the ACI Code and AASHTO- LRFD Specification. An approximate way to consider these effects is to investigate the major factors and incorporate them into the current Codes. Minor factors should be disregarded or need further investigations.

DATA ANALYSIS AND DISCUSSION

CONCRETE PROPERTIES AND COMPOSITION

Compressive Strength of Concrete

Concrete strength is the most important concrete property that affects transfer and development length. There are many research programs which have investigated the influences of compressive concrete strength which are shown in Table 2. The researchers concluded that increasing the concrete strength could reduce the transfer and development length. The first research was performed by Zia and Moustafa[6]. They proposed an expression for the transfer and development length that included the concrete strength. Research conducted by Abrishami and Mitchell[7] showed both the transfer and development length decreases with increasing concrete strength. In their testing program, initial strength of concrete at release, f_{ci}, ranged from 3,050 psi to 7,250 psi and 28-day concrete strength ranged from 4,500 psi to 12,900 psi. The study incorporated factors that accounted for concrete strength into the expression of transfer and development length. Cousins et al.[8] performed transfer and development length tests on normal-strength concrete with compressive strengths of 6,000 psi to 8,000 psi, and high-strength concrete, with strengths of 10,000 psi to 12,000 psi. The measured data showed that the transfer length in high-strength concrete was 25% shorter than in normal-strength. Recently, a comprehensive research conducted by Ramirez and Russell[9] investigated the effects of high-strength concrete on transfer and development length. The study also proposed a transfer and development length equation that is a function of concrete strength. The researchers also concluded that transfer and development length decreases as compressive strength increases.

Fig. 1 and Fig. 2 show the relationship between concrete strength and transfer and development length for 0.6 in. diameter strand. The plots assume a low relaxation strand with an ultimate strength of 270 ksi, an initial stress of 75% of its ultimate strength, and 20% loss of prestress. From the figures, it is apparent that the higher concrete strength, the shorter the transfer and development length.

Table 2. Development Length Equations

Research	Expression	
Zia and Moustafa (1977)	$L_d = 1.5\frac{f_{si}}{f'_{ci}}d_b - 4.6 + 1.25 \ f_{ps} - f_{se} \ d_b$	(3)
Abrishami and Mitchell (1993)	$L_d = 0.33 f_{pi} d_b \ \overline{\frac{3}{f'_{ci}}} + \ f_{ps} - f_{se} \ d_b \ \overline{\frac{4.5}{f'_c}}$	(4)
Lane (1998)	$L_d = \ \frac{4f_{pt}}{f'_c}d_b - 5 \ + \ \frac{6.4 \ f_{ps}-f_{se}}{f'_c} + 15$	(5)
Kose and Burkett (2005)	$L_d = \ 95\frac{f_{pi} \ 1-d_b \ ^2}{\overline{f'_c}} \ + \ 8 + 400\frac{f_{pu}-f_{pi} \ 1-d_b \ ^2}{\overline{f'_c}}$	(6)
Ramirez and Russell (2006)	$L_d = \frac{120}{\overline{f'_{ci}}}d_b + \frac{225}{\overline{f'_c}}d_b \geq 100d_b$	(7)

where f_{si}, f_{pi}, f_{pt} is initial stress in prestressing steel (ksi); f'_{ci} is compressive strength of concrete at release (ksi); f'_c is compressive strength of concrete at 28-day (ksi).

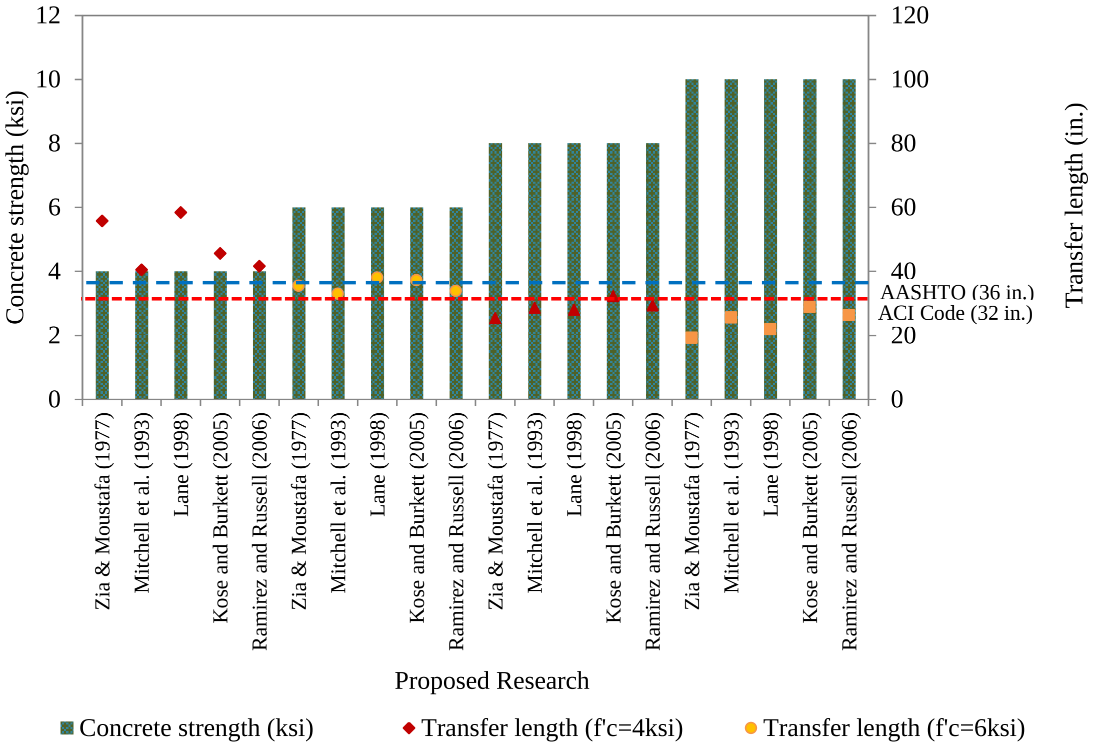

Fig. 1. Transfer length and concrete strength

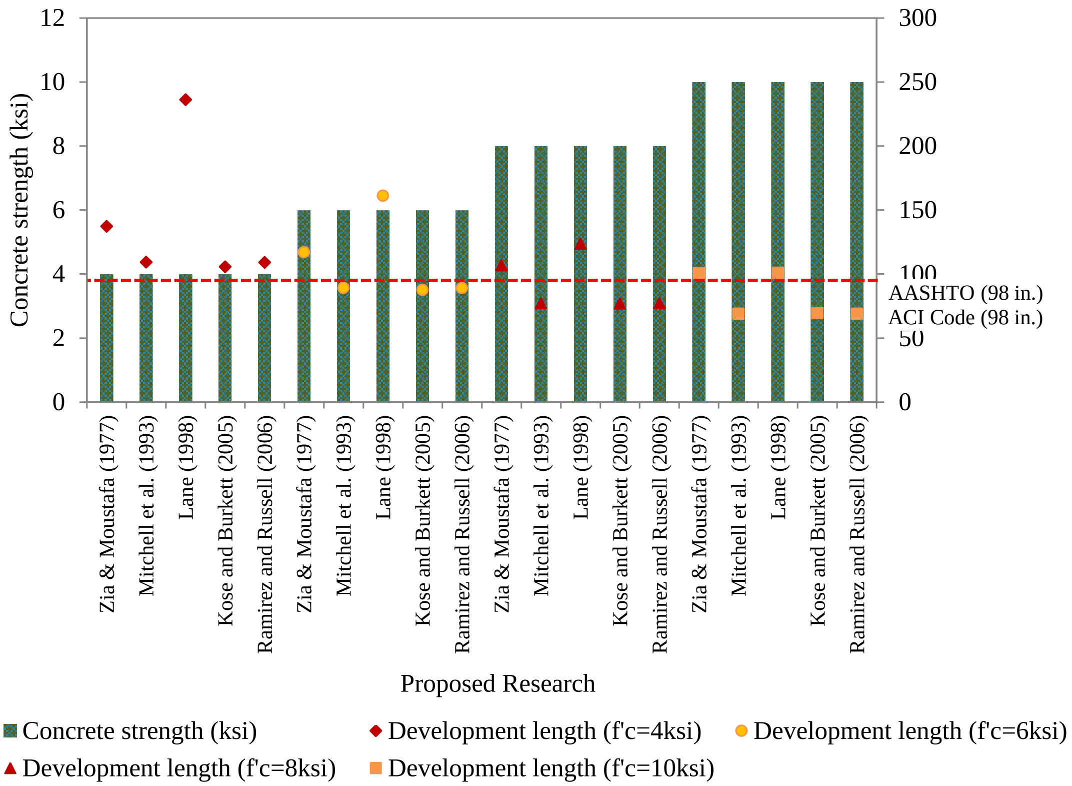

Fig. 2. Development length and concrete strength

Concrete Composition

Cement and water are two of the four major components of a concrete mixture. Aggregate occupies from 60% to 70% of the volume of hardened mass. Fine aggregate (or sand) is also an important ingredient. Cement works as a paste to glue aggregate and sand into a solidified mass and fills the tiny voids that the coarse and fine aggregate cannot fill. Water is necessary for cement hydration. As water content increases, the concrete workability increases, but the compressive strength decreases because of the larger volume of voids created by the water. Thus, the water/cement (*w/c*) ratio is a significant factor that affects concrete strength and therefore the bonding capacity of the strand.

The significance of the *w/c* ratio was investigated by researchers very early. Armstrong[10] concluded that bond strength reduced as the w/c ratio was increased. Fu et al.[11] found out that the bond capacity between steel rebar and concrete was improved by increasing the w/c ratio from 0.45 to 0.60. The research disregarded using a pull-out test to investigate the bond of reinforcement to concrete. The electromechanical testing was used to measure the bond strength.

The most recent research was implemented by Martí-Vargas et al.[12]. The study focused on investigating influences of concrete composition on bond behavior by alternating cement content and *w/c* ratio. The bond performance was indirectly analyzed by measuring the transmission length by the ECADA test method. The specimens had a cross-section of 2.5

in. by 2.5 in. with varying lengths which depended on testing transmission length. Each specimen contained one strand placed in the center. The strands were 0.5 in. diameter, Gr270 and low relaxation. Four cement contents were tested, and the w/c ratio was alternated between 0.3 and 0.5. Totally, 120 specimens were tested and evaluated. The research supposed an equation that showed a relationship between transmission length and w/c ratio. It proved that increasing the w/c ratio negatively affected the bond of strand to surrounding concrete. A smaller *w/c* ratio could shorten the transmission length by enhancing the bond strength.

Concrete Consolidation and Consistency

Researchers have shown that concrete proper concrete placement and consolidation have an important effect on the transfer and development length. Anderson (1976) indicated that the poor consolidation of concrete adjacent strands caused excessive free and slip and impulsive flexural bond failure in prestressed components. One phenomenon related to concrete placement is “top bar effect.” Base (1958) stated that transfer length of wires at the top of members during casting had extensively longer transfer length than wires at the bottom. A study of Stocker and Sozen (1970) recommended that for strands with 12 in. or more concrete cast beneath them, the anchored length should be increased 40%. The ACI Code and AASHTO-LRFD Specification for development length increase as much as 30% for deformed reinforcement bars but not for prestressing strand.

Concrete Cover around Steel

Generally, three parameters govern the thickness of concrete around steel. These include concrete bottom cover, concrete side cover and one-half of the clear spacing between bars. Splitting occurs at the surface that has the smallest concrete cover thickness. If the side cover and one-half of the clear spacing is greater than the bottom cover, splitting occurs at the bottom surface of the beam. If the bottom cover is larger than the side cover or one-half of the clear spacing, splitting occurs at either side surface or between strands.

Table 3. Concrete cover around steel

Diameter Strand	One-half Clear spacing	Bottom cover	Side cover
0.5 in.	0.5x(2 in. – 0.6 in.) = 0.7 in.	2.0	2.0
0.6 in.	0.5x(1.75 in. – 0.5 in.) = 0.625 in.	2.0	2.0

Confining Reinforcement around Steel

The effect of confining reinforcement was examined by Russell and Burns[13]. In each specimen, strands was enclosed by transverse reinforcement that consisted of mild stirrups. The study showed that transverse reinforcement had no significant influence on the transfer and development length. From the standpoint of splitting cracks, research of Orangun et al.[14] specified that transverse reinforcement confined the concrete around anchored bars and reduced the propagation of splitting cracks that might lead prestressing strands to pull-out failure instead of splitting failure. They recommended that transverse reinforcement be positioned to intersect potential splitting planes between adjacent strands. Research conducted by Maeda et al.[15], Azizinamini et al.[16] indicated that the transverse reinforcement rarely yielded in splitting failure. Maximum efficiency of the transverse reinforcement would results from placing the reinforcement immediately adjacent to the strand, where tensile stresses are largest. However, the large number of strands as well as small strand spacing is the most detrimental issue that prevents using the transverse reinforcement to reduce transfer length.

STRAND CHARACTERISTICS

Surface Condition of Strand

Strand surface condition plays an important role in strand bonding capacity. The presence of lubricants and residual films has been directly linked to the bond performance. The pretreatment of rods, postdrawing process, and the lubricants used during strand production were the major agents that alter the amount and properties of lubrication. Residual film, such as contaminates and insoluble substances, always exist after wiredrawing, and it is very tough and costly to remove them. Additionally, the volume of lubrication and residual film on the strand surface varies extensively between manufactures because it is dependent on the manufacturing process. The surface condition of strands throughout the United States is very diverse, and it is difficult to develop a manufacturing standard for the entire industry. However, strand surface characteristics directly affect the strand bond which constitutes the transfer length; an important factor in pretensioned concrete design.

Good bond performance will produce a transfer length that is shorter than predicted by the ACI Code equation leading to uneconomical designs. Conversely, it is not conservative to use the design length estimated by the ACI Code when the bond strength is poor, because these strands require a longer transfer length to develop the design prestress and nominal service load. Consequently, concerns about the relationship between the strand surface condition and the transfer length has arisen. The relationship between the Standard Test for Strand Bon (STSB) values and transfer lengths is a linear function with a negative slope as shown in Fig. 3. Based on this correlation, five regions have been suggested; each one with a proposed multiplier “k” for the transfer length as shown in Table 4. Strands which do not meet the minimum pull-out force criterion (12,600 lbs), need a longer transfer length or a “k” value that was larger than 1.0 in and vice versa. These results give guidance for designers to adjust the transfer length of 0.6 in. (15.2 mm) diameter strand in their designs flexibly. Obviously, additional research is needed to investigate the relationship of STSB values and the development length.

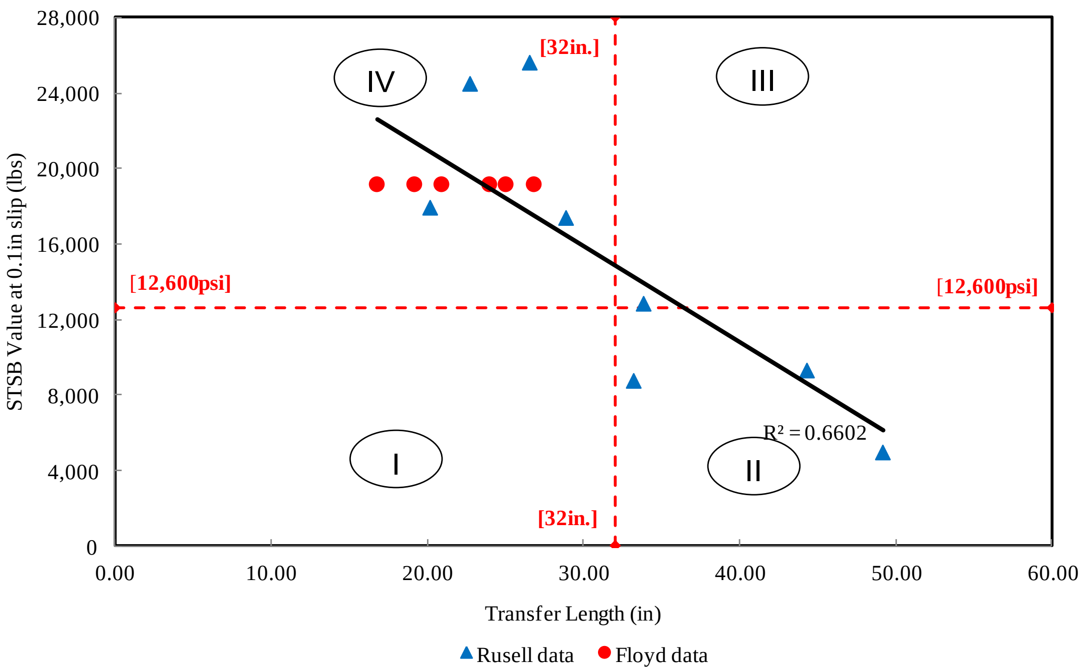

Fig. 3. Relationship between STSB test values and the transfer length

Table 4. "k" factor

Region	STSB Test Value (lb)			$L_{t\,(measured)}$ (in.)	$k = \dfrac{L_{t(measured)}}{L_{t\,(ACI\ Code)}}$
	Minimum	Maximum	Average		
Limit A	4,000	8,000	6,000	49	1.54
Limit B	8,000	12,000	10,000	42	1.30
Limit C	12,000	16,000	14,000	34	1.05
Limit D	16,000	20,000	18,000	26	0.81
Limit E	20,000	24,000	22,000	18	0.56

Diameter of Strand

The ACI Code and ASSHTO-LRFD Specification consider that there is a linear relationship between the lengths and diameters of strand. In particular, the transfer and development lengths of 0.6 in. diameter strand are 1.2 times larger than those of 0.5 in. diameter strand, and the ratio is 1.4 for 0.7 in. diameter strand in comparison to 0.5 in. diameter strand. Many researchers have shown that transfer and development lengths increase as the strand diameter increases by the given ratios. However, there are a few studies that show some discrepancies. Test data of Russell and Burns[13] on 0.5 in. and 0.6 in. diameter strand indicated that the transfer length did not increase with a direct proportion as the strand diameter increased. The testing program measured transfer lengths of 44 specimens which contained of 0.5 in. and 0.6 in. diameter strands. All strands had similar surface conditions. The data showed that the ratio of transfer length of 0.6 in. and 0.5 in. diameter strand was

1.36 instead of 1.2. From the test data at the Texas Tech University and prior research, Kose and Burkett (2005) proposed an equation that demonstrated the ratio of transfer length as well as development length of 0.6 in. and 0.5 in. diameter strand was 1.56. Generally, diameter strand is a critical factor in the transfer and development length equation, and the expression of the current Codes shows a well-agreed approximation with prior testing programs.

Strand Stress Level

The transfer length increases as the effective stress increases because a longer bond length is necessary to balance the larger effective prestress force. However, the flexural bond length decreases as the effective stress increases, because the additional stress to increase from effective stress level to ultimate stress level decreases. Generally, the decrease of flexural bond length is smaller than the increase of transfer length, which consequently shows that the development length is reduced as the effective stress increases as shown in Fig. 4.

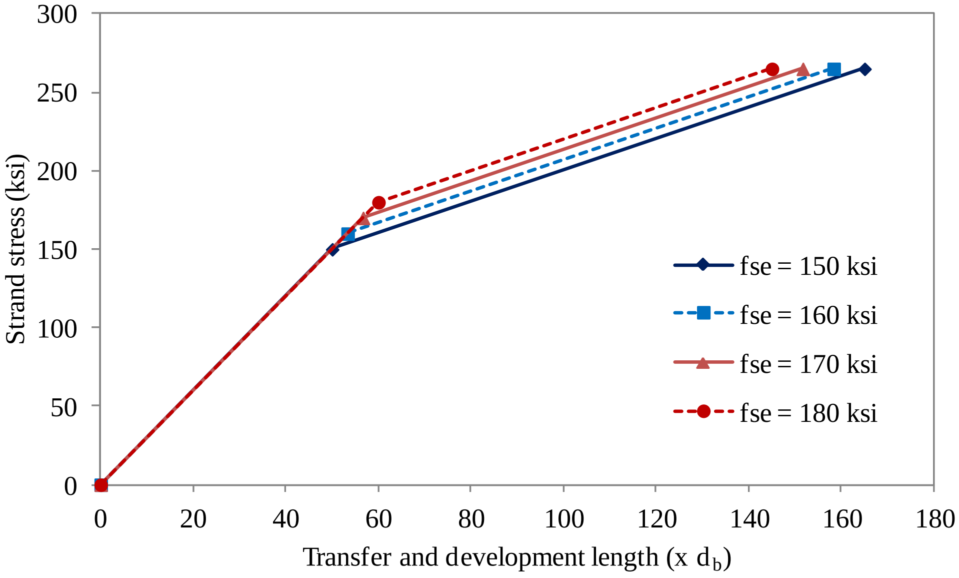

Fig. 4. Comparison various transfer and development length by different strand stress

TESTING CONDITION

Method of Prestress Release

There are two ways to release prestressing strand. In the first method, the strands are released immediately by flame cut or sawed at full tension. In the second method, the strands are detensioned gradually. There are few studies that have been conducted to investigate effects of detensioning on the transfer and development length. Research performed by Kaar proved that the transfer length increased 20% - 30% when strand are released using a flame cut. A study accomplished by Hanson showed similar results. Transfer length increased 4 in. when strands were released by flame cut. Research of Russell and Burns[13] proved that influence of prestress release method was more common in transfer length tests of small specimens rather than full-scaled components. In order to consider influence of prestress release method, CEB-FIP Model Code 1990 increased transfer length up to 25% when strands in prestressed components were released suddenly.

Time Dependent Effect

Many studies proved that transfer and development length increased with time. Research conducted by Kaar et al. (1964) found that transfer length increased an average of 6% over one year. Based on tests performed on high strength concrete, Russell et al. concluded that transfer length increased approximately 10% during the first 28-days for full-scaled prestressed specimens. Lane (1998) concluded that transfer length increased up to 30% in the first 28-day. However, Floyd (2011) performed testing program on six kinds of concrete, Normal Strength Clay Concrete, Normal Strength Shale Concrete, Normal Strength Limestone Concrete, High Strength Clay Concrete, High Strength Shale Concrete, High Strength Limestone Concrete. Transfer length was measured at release (normally at 1-day), 3-day, 7-day, 14-day, and 28-day. His testing data did not show a significant change in transfer length during the first 28 days.

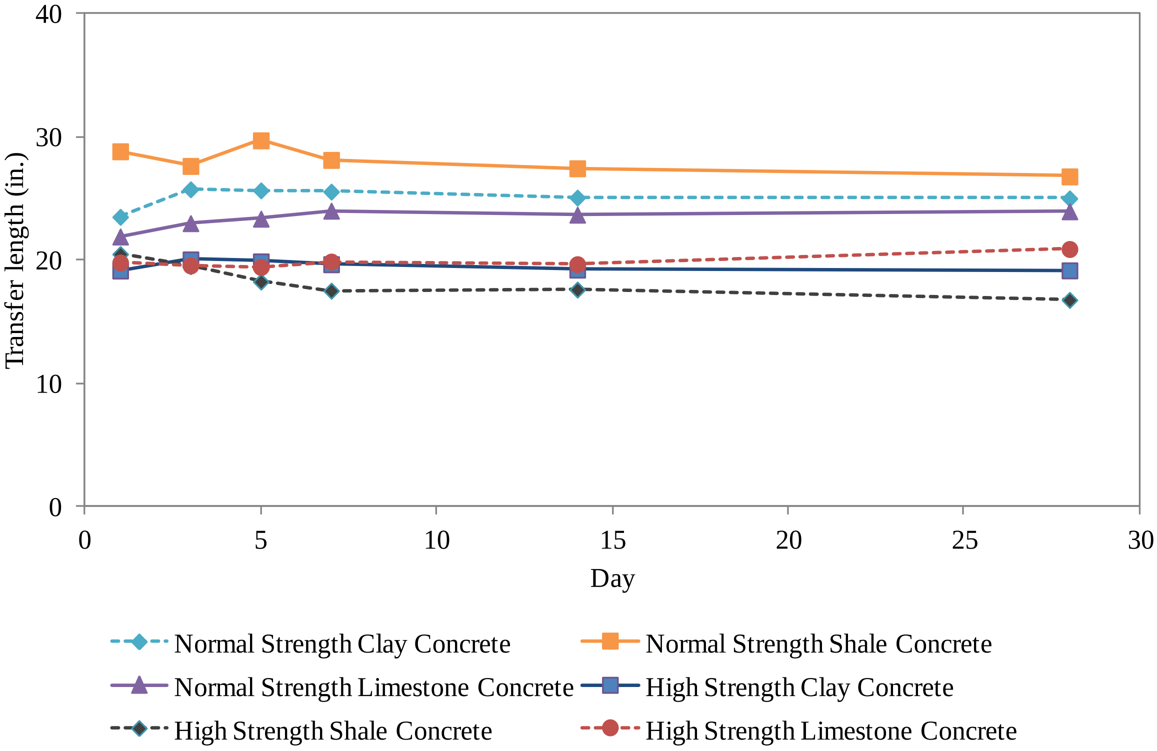

Fig. 5. Transfer length vs. time

CONCLUSIONS/RECOMMENDATIONS

Many factors influence transfer and development length at different levels. Some factors that have a significant effect are included in the current Codes, such as diameter of strand and strand stress level. However, the current Code was established more than 50 years ago, and only a few factors that influenced the transfer and development length at that time were investigated. Currently, there are two contemporary factors, concrete strength and strand surface condition, which affect transfer and development length and should be included in Code equations in the future. Others factor that need further considerations or included in the Commentary of the current Codes as shown in Table 5.

Table 5. Considering factors

Factor	Recommendation
Concrete properties	
Concrete strength	Suggest including in the ACI Code and AASHTO-LRFD Specification
Composition of concrete mixture	Need further consideration
Consolidation and consistency of concrete around steel	Need to consider “top bar effect” for prestressing strand. Currently, only deformed rebar is considered by the Codes.
Concrete cover around steel	Already included
Confining reinforcement around steel	Should be disregarded
Strand Characteristics	
Diameter of strand	Already included
Strand stress level	Already included
Surface condition of strand	Suggest including in the ACI Code and AASHTO-LRFD Specification
Strand spacing	Already included
Testing condition	
Type in the release	Suggest to include in the ACI Code and AASHTO-LRFD Specification
Time dependent effect	Should be disregarded

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