PRESTRESSING FORCE TRANSFER IN HIGH STRENGTH PRETENSIONED CONCRETE ELEMENTS

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Summary: *The analytical expressions for transfer length of prestressing strand in prestressed beam specified in codes and recommendations are not sufficiently able to accurately predict values for wide range values of concrete strength class. Production of pretensioned elements requires the shortest possible time for the preparation of elements. In this sense, achieving rapid growth of compressive strength of concrete is a basic requirement for shortening the time of production of elements.*

Keywords: *Transfer length of prestressing force, pretensioned elements.*

1. INTRODUCTION

Transfer length of prestressing force in concrete is the length of cable as measured from the end of the prestressed element along which the effective stress due to prestressing is transferred to the concrete. The force of pretensioning in the concrete linearly increases along the transmission line from the value 0 at the end of the element to the effective value of prestressing stress on the length l_t (Figure 1).

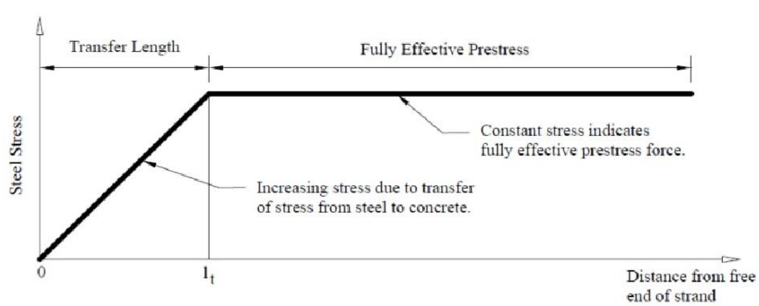

Figure 1. Idealized diagram that refers to the stress in the cable within the prestressed element[11]

The manufacturing process of pretensioned concrete members consists of three stages: first the restressing reinforcement is tensioned; next, the concrete member is cast around

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the prestressing reinforcement; and finally, the prestressing reinforcement is released, and the prestressing force is transferred to the concrete by bond.
In the case of pretensioning - adhesive prestressing, force from the cable is being transferred to the concrete only through adhesion between steel and concrete after the strands have been cut. In order to introduce force into the concrete, it takes a certain length - the length of the transfer of prestressing force. This value is usually defined by the regulations. At this length, tensile stress in the strand grows from zero at the end of the strand to the value of design stress σ_{k0}.
Prestressing force is being transferred to the concrete through several different mechanisms. It primarily refers to: the adhesion between concrete and cables of prestressed concrete, wedging effect and mechanical joining.
A frequent problem of the precast industry is to evaluate the real transmission length in precast prestressed concrete structural elements. The semi-empirical formulae proposed by codes are usually thought for conventional concrete and usual cast conditions, but high performance concrete (high-strength, self- compacting, etc.) and non-usual cast conditions (*v.gr.* accelerated curing processes) are becoming more and more frequent.
Prestressing strand and concrete in a pretensioned, prestressed member interact through *bond*. Bond is the mechanism through which tension in a strand is transferred to compression in the concrete. The entire concept of prestressed, pretensioned concrete as a structural material is thus based on this bond between the strand and concrete. Without bond, no transfer of forces would occur and the member would not act integrally. As modern high strength materials are adopted for use in prestressed concrete, higher forces must be transmitted between the strand and the concrete. As a result, the demand on bond is magnified. For the implementation of these modern materials to be effective at the structural-member level, their interaction at the level of bond must first be understood.

2. BOND MECHANISMS

There are three mechanisms by which the concrete and steel strand bond to one another in pretensioned, prestressed concrete members: adhesion, Hoyer's effect (wedge effect), and mechanical interlock. Each mechanism is discussed briefly below:
Adhesion—There is a small adhesive effect between the prestressing strand and surrounding concrete that contributes to bond in pretensioned members. This adhesion is present only prior to any relative slip that may occur between the strand and the concrete. Therefore, this component of bond is often neglected.
Hoyer's effect (wedge action)—As a strand is tensioned, its diameter and cross-sectional area reduce an amount determined by Poisson's ratio of the strand. Upon transfer, the strand near the end of a pretensioned beam tries to return to its original unstressed state. However, the surrounding concrete prevents the lateral expansion of the strand back to its original diameter and area. This restraint, in the form of a normal (radial) force on the strand, induces a frictional force along the longitudinal axis of the strand. This frictional force opposes any relative movement between the strand and surrounding concrete. Since Hoyer's effect may be visualized as the strand wedging itself against the surrounding concrete to prevent slip, it is often referred to as *wedge action*.

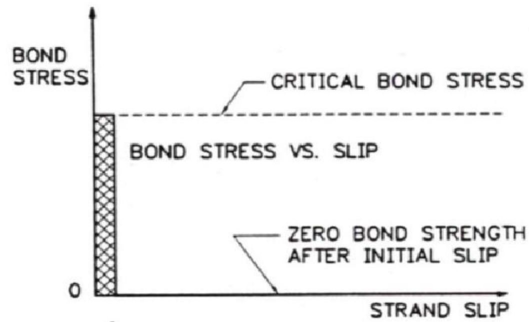

Figure 2. Adhesion between cables for prestressing and the concrete [11]

Mechanical interlock—Seven-wire strands consist of six small wires wound around one center wire to form a helical shape. Because of this helical shape, a component of the normal force between the outer wires of the strand and the surrounding concrete acts along the axis of the strand. This component acts to resist slip between the strand and concrete. This mechanism is extremely similar to the pullout resistance provided by patterned deformations on reinforcing bars in reinforced concrete. Mechanical interlock will develop in pretensioned members only if twisting of the strand is prevented. When strand twist is not restrained, the strand will simply slide through the member, as normal forces will not be developed.

3. FACTORS FOR BOND BEHAVIOR

The bond behavior of prestressing strands in precast pretensioned concrete members, and its transmission length, depends on several factors. The industry of precast prestressed concrete members aims to obtain products in the shortest possible time. For this reason, an early age usually fixed by the concrete compressive strength is required at prestress transfer.

It is undeniable that the mutual interaction of a larger number of parameters influences the value of transfer length of prestressing force. Among others, these are: the ratio of cross-sectional area prestressing cables and cross-sectional area of concrete, boundary conditions regarding the connection between cables and concrete, cross-section of cables, the percentage of cables without adhesion, the effective stresses during prestressing, compressive strength of concrete at the moment of measurement, cement content, water-cement factor, the value of the prestressing force, strand diameter, strand surface condition, method of release of prestressing forces on the trail and others.

However, nowadays there are no general expressions being used in order to obtain the most significant parameters that determine the transfer length of prestressing force. Some authors propose expressions for transfer length of prestressing force in which properties of concrete are not being influential parameter, in other words they take into consideration only concrete compressive strength. On the other hand, there are a lot of expressions that show a relation between transfer length of prestressing force and the concrete parameters (quantity of cement, w/c, water content, etc.).

3.1.1. Strand Diameter

Many studies [5,6, 9, 10] have investigated the variation of transfer and/or development length with strand diameter. All of these studies, with one exception [5], have shown that transfer and development lengths increase for larger strand diameters. Kaar et al. [9] determined that the variation in transfer length is nearly linear with respect to strand diameter. Also, the value of transfer length of prestressing force increases if the percentage of cables without adhesion increases. The reason for the increase of the percentage of cables without adhesion is the need to achieve the best possible stress state near the end of the element, where the prestressing force is being introduced. Cables are being put through tubes which are afterwards being closed in order to prevent the contact between steel and concrete during the application of concrete.

3.1.2. Concrete Strength

Properties of adhesively prestressed concrete elements, in other words transfer length of prestressing force depends on several factors. Usually, when discussing the properties of concrete, the primary parameter for the analysis is compressive strength. Regarding the strength of concrete, there are various opinions on its impact on transfer length of prestressing force. According to one group of authors, the strength of concrete significantly affects the value of transfer length of prestressing force, and it is possible to establish a clear correlation between these values. According to other authors, the relation between these two quantities is not systematically determined by aid of performed tests.

3.1.3. Cement content and water cement ratio

The cement content and the water/cement (w/c) ratio are important parameters of the concrete mix design. Nevertheless,few studies [1-4] have been undertaken regarding their influence on the bond properties. [1] conclude that the bond strength decreases when the w/c ratio increases, and also a bond improvement has been found [2] when the w/c ratio increases.
On the other hand, greater bond strength to a larger cement content has been found in [1], whereas the authors in [3,4] concluded that an increased cement content produces a diminution of bond strength.

3.1.4. Strand Surface Condition

The effect of strand surface condition is probably the most important variable affecting transfer length, yet it is the most difficult to determine [10]. Strands may be lightly rusted, well rusted, epoxy coated with grit, oiled, or indented. Each of these conditions will affect the coefficient of friction¾and thus the bonds¾between the strand and the concrete. The variation in transfer and development lengths with strand surface 11 conditions has been noted by many researchers [5, 7, 8, 10]. In general, wellrusted and epoxy-coated strands with grit have significantly shorter transfer and development lengths than clean strands. Likewise, the presence of oils on the surface of a strand will substantially increase transfer and development lengths.

3.1.5. Type of Release

It is generally accepted that a sudden transfer of prestress caused by flame cutting or sawing will result in longer transfer lengths. This trend was reported by Kaar et al. [9], who noted a 20% to 30% increase in transfer length for flame-cut strands. Likewise, Hanson [7] reported an average increase in transfer length of 4 in. for flame-cut strands.

3.1.6. Effective Prestress Force

Transfer length will logically increase with a higher effective prestress force, *fse*, since a higher strand stress must be developed in the transfer zone. Flexural bond length will correspondingly decrease for a higher *fse*, since the additional strand tension to be developed at the critical section will be lower. Most proposed equations assume that the decrease in flexural bond length will be larger than the increase in transfer length for a given increase in *fse*. As a result, the development length decreases with increasing effective prestress forces.

3.1.7. Strand Spacing

Russell and Burns [10] reported no difference in measured transfer lengths for 15.2 mm diameter strands at 51 and 57 mm spacings. Burdette et al. [5] reported similar findings for 12.7 mm diameter strands at 44 and 51 mm spacings. Naturally, there is a minimum spacing for a given strand diameter at which the splitting resistance of the concrete will be exceeded. Further testing is required to determine this minimum spacing for larger diameter strands. However, it is important to note that splitting was not observed in the tests of 15.2 mm diameter strands at 51 mm spacing by Russell and Burns [10].

4. CONCLUSION

This paper presents a review of parameters which influence on transfer length of prestressing force in pretensioned elements. Predicting of the transfer length of prestressing strands as a function of parameters affecting the transfer length is a difficult task to achieve.

The three-dimensional behavior of strand bond in pre-tensioned concrete could be simulated by developing full 3D finite element models. A nonlinear material model could be implemented on the concrete part of the models to assess damage resulting from the pre-tension release process. After modelling it is recommended to perform the testing of experimental beam, in order to compare the results of transfer lengths of prestressing force.

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ТРАНСФЕР СИЛЕ ПРЕДНАПРЕЗАЊА У ЕЛЕМЕНТИМА ОД БЕТОНА ВИСОКИХ ЧВРСТОЋА

Резиме: *Предложени аналитички изрази за дужину трансфера силе преднапрезања у гредним елементима наведени у правилницима и препорукама нису у могућности да довољно тачно дефинишу вредности за шири интервал класа чврстоће бетона. Производња елемената на стази за адхезионо преднапрезање захтева што краће време за израду елемената. У том смислу, постизање брзог прираста притисне чврстоће бетона представља основни услов за скраћење времена производње елемената.*

Кључне речи: *Дужина трансфера силе преднапрезања, преднапрегнути елементи.*