Engineering Structures 97 (2015) 105–117

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Predicting bond formulations for prestressed concrete elements

Carlo Pellegrino [a,*], Mariano Angelo Zanini [a], Flora Faleschini [a], Livio Corain [b]

[a] University of Padova, Department of Civil, Environmental and Architectural Engineering, Via Marzolo 9, 35131 Padova, Italy
[b] University of Padova, Department of Management and Engineering, Stradella San Nicola, 36100 Vicenza, Italy

ARTICLE INFO

Article history:
Received 10 September 2014
Revised 2 April 2015
Accepted 7 April 2015
Available online 22 April 2015

Keywords:
Prestressed concrete
Bond
Strands
Transmission (transfer) length

ABSTRACT

One of the most important features in design of pretensioned concrete elements is the determination of correct transmission (transfer) length. A number of formulations have been proposed by some authors, codes and guidelines but, although a huge experimental literature is available, the problem does not seem completely solved. In this work an experimental database of measured values of transmission length in prestressed concrete specimens is gathered and an assessment of some current formulations is developed. A statistical analysis is also performed in order to identify the effect of the main variables influencing transmission length. Some useful information is obtained and can be eventually used for a possible validation/improvement of actual relations; a new formulation for transmission length evaluation is also proposed.

1. Introduction

Pretensioning technique is commonly diffused in precast elements production, used in industrial and bridge applications. An important application of pretensioning is in hollow core slabs, which are mainly used in office and residential buildings. The peculiarity of this productive process lies in three successive phases: the first in which strands are tensioned by means of end anchorages; secondly concrete is cast into formworks; finally strands are allowed to release tension. The last step occurs only once concrete achieves enough strength, in order to transfer prestress force to the concrete element, along a certain length, which is known as *transmission* (*EU*) or *transfer* (*US*) *length* L_t. At the ends of the element, the strain in the strands is equal to zero, and this value gradually increases through L_t up to the effective prestressing tendon strain ε_{pe}, and it remains almost constant once exceeded that distance (Fig. 1).

Another important feature concerning this technique refers to the distance at which the prestress reaches a linear distribution over the concrete cross-section, which is called *development length* (*EU*). In the *US* this term is related to the embedment length required to transfer the ultimate tendon force to the concrete. In case of a pretensioned tendon this *development length* (*US*) is the sum of *transfer length* (*US*) and *flexural bond length* (*US*). The latter is that part of the embedment length where bond is only activated after a bending crack has originated. In *EU* no such distinction is made, thus the equivalent of *development length* (*US*) is *anchorage length* (*EU*).

Transmission (or transfer) length has to be calculated to check the adequacy of the prestressing force in the cable over its length, providing an adequate distance outside the transmission length for sections with high bending moment values, preventing failure due to bond slip. Moreover, shear resistance of sections included in the transmission length has also to be calculated considering reductive factors. According to these reasons a correct evaluation of the transmission length is crucial for a proper design of prestressed reinforced concrete elements.

A number of formulations have been proposed by guidelines and codes. The approach of *fib* Model Code 1990 [1] subsequently improved by *fib* Model Code 2010 [2] is worth to be cited. Furthermore, Eurocode 2 formulation [3], inspired by *fib* Model Code 1990 [1], has a wide diffusion in Europe whereas ACI Committee 318 formula [4] is typically adopted in United States of America.

In scientific literature this topic has been studied by several authors, providing other formulations, as in the work of Cousins [5], but sometimes showing contrasting transmission length estimations. A review of some proposed formulations can be found in the work of Buckner [6]. In the chapter 6 of fib Bulletin No. 10 [7] a useful state-of-the-art report about bond of prestressing tendons can be found.

In particular, other than well recognised relevant parameters such as diameter of prestressing steel, initial prestressing force, concrete strength [8], a number of other parameters have been

* Corresponding author. Tel./fax: +39 049 8275618.
E-mail address: carlo.pellegrino@unipd.it (C. Pellegrino).

http://dx.doi.org/10.1016/j.engstruct.2015.04.013
0141-0296/

Nomenclature

A_s	cross sectional area of the strand
B	bond modulus (slope of bond stress curve in the plastic zone)
h	total depth of the concrete section
c	concrete cover
d	strand diameter
$\varepsilon_c(x)$	concrete compression strain along the x-direction
ε_{ce}	strain in concrete at level of strands (after prestress losses)
ε_{pi}	prestressing tendon strain just after release
ε_{pe}	prestressing tendon strain just after prestress losses
$\varepsilon_{ps}(x)$	prestressing tendon strain along the x-direction
f_c	concrete compressive strength
f_{ci}	concrete compressive strength immediately before transfer
f_{ctd}	design value of concrete tensile strength after release
f_{pt}	tensile strength of prestressing steel
σ_{pe}	effective stress in prestressing steel after prestress losses
σ_{pi}	steel stress just after release
L_t	transmission length
U_t'	plastic transfer bond stress (to be found by means of experiments)

showed to influence transmission length [9,10], but their influence is not fully understood [11]. The estimation of the transmission length in prestressed elements is currently one of the topics of discussion in the *fib* (The International Federation for Structural Concrete) Task Group 4.5 "Bond Models" of which the first author is a member from a lot of years and in the recently created *fib* Task Group 2.5 "Bond and Material Models" in which the first author was again involved.

The correct definition of the transmission length in prestressed concrete elements is nowadays an open issue in the scientific community. Preliminary comparisons between experimental results and analytical formulations developed in literature have demonstrated that predictions are sometimes contrasting and disagreeing with experimental results. For these reasons it becomes important to individuate the effect of the main variables influencing transmission length. This work aims to fulfill this gap by means of a statistical analysis of literature dataset, providing some information about the effect of the various parameters and developing a proposal for transmission length estimation.

2. Existing formulations for transmission length

A number of formulations have been proposed in literature but, if compared with experimental data, they sometimes show disagreeing results.

Cousins et al. [5] proposed one of the first analytical models for the design of the transmission length according to Guyon's hypothesis [12]. It considers both a longer plastic and a smaller elastic zone located at the end of the transmission zone allowing elastic behaviour along the transmission length:

$$L_t = 0.5\frac{U_t'\sqrt{f_{ci}}}{B} + \frac{\sigma_{se}A_s}{\pi d U_t'\sqrt{f_{ci}}} \quad (1)$$

The meaning of the symbols is indicated in the Notation section.

Guyon's hypothesis was not frequently observed in experimental investigations as shown in [9,13–15]; hence main codes formulations, such as those of Eurocode 2 [3], ACI 318 [4] and *fib* Model Code 2010 [2], assumed uniform bond stress distribution

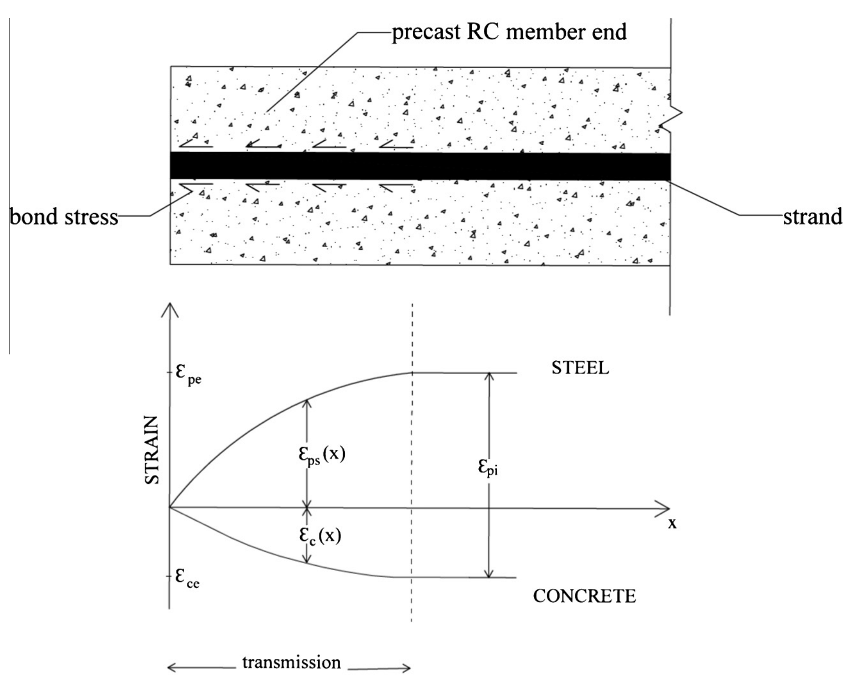

Fig. 1. Definition of transmission length.