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Modeling of transfer length of prestressing strands using genetic programming and neuro-fuzzy

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A B S T R A C T

In this study, the efficiency of neuro-fuzzy inference system (ANFIS) and genetic expression programming (GEP) in predicting the transfer length of prestressing strands in prestressed concrete beams was investigated. Many models suggested for the transfer length of prestressing strands usually consider one or two parameters and do not provide consistent accurate prediction. The alternative approaches such as GEP and ANFIS have been recently used to model spatially complex systems. The transfer length data from various researches have been collected to use in training and testing ANFIS and GEP models. Six basic parameters affecting the transfer length of strands were selected as input parameters. These parameters are ratio of strand cross-sectional area to concrete area, surface condition of strands, diameter of strands, percentage of debonded strands, effective prestress and concrete strength at the time of measurement. Results showed that the ANFIS and GEP models are capable of accurately predicting the transfer lengths used in the training and testing phase of the study. The GEP model results better prediction compared to ANFIS model.

1. Introduction

Although there are many variables affecting the transfer length, only the effective prestress, f_{se}, and the strand diameter, d_b, are taken into account in the current code requirements of the transfer length of prestressing strands [1–3]. There are more two parameters affecting the transfer length of prestressing strands. These parameters can be categorized as type, diameter, and surface condition (bright, rusty, epoxy coated) of prestressing strand, stress level at prestressing strand, type of release (gradual, sudden), debonding of prestressing strand, time-dependent effects and concrete strength.

A linear relationship between the transfer length and the diameter of the strand was first shown by Kaar and Magura [4]. In many proposed equations for the transfer length of prestressing strands, this linear relationship has been used. It was shown by Castrodale et al. [5] that for the concrete strength of 64.8 MPa, the transfer length of prestressing strand is 30% shorter compared to that for the concrete strength of 35.2 MPa. It was also shown by Mitchell et al. [6] that increase in the strength of the concrete led to decrease in the transfer length of prestressing strand.

Surface condition of the prestressing strands can be bright (no dust/corrosion), lightly rusted, well rusted, epoxy coated with grit (e.g. aluminum oxide) or oiled. Each of these surface conditions affects the bond between the strand and concrete due to change in the coefficient of friction. The transfer length of the prestressing strand is significantly influenced by the surface condition of prestressing strand. It was shown by Cousins et al. [7] that strands with rusted or epoxy coated with grit surface condition have considerably small transfer length compared to the prestressing strand with oily or bright surface condition.

An increase in the effective prestress force leads to an increase in the transfer length of prestressing strand because longer bond length between the concrete and prestressing strand is required to balance the larger effective prestress force. Also, sudden release of prestressing strands by flame cutting or sawing causes the increase in the transfer length. It was shown by Kaar and Magura [4] that a 20–30% increase in the transfer length of prestressing strand was determined when the prestressing strands were released by flame-cut. It was also shown by Hanson and Kaar [8] that a 102 mm increase in the transfer length of prestressing strand was measured when the prestressing strands were released by flame-cut.

Cross-section size and the number of prestressing strand in the cross-section also affect the transfer length of prestressing strands. In case of sudden release of prestressing strand by flame cutting, prestressing strand in prestressed beams with larger cross-sections have smaller transfer length because smaller damage was occurred in large mass of concrete. Also, the high number of prestressing

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Nomenclature

A_{ps}	total area of prestressing strands
A_c	area of beam cross-section
d_b	nominal diameter of prestressing strand
f'_c	strength of the concrete at 28-days
f_{se}	effective stress in prestressed reinforcement after all prestress losses
f_{si}	effective stress in prestressed reinforcement after short-term losses
f_{pi}	stress in the prestressing strands prior to release
f_{pt}	initial prestress prior to release
L_t	transfer length

strands in a prestressed concrete beams with large cross-section behaves like reinforcement by helping to distribute energy stress from the sudden release of prestressing strand [9].

Long-term transfer length of prestressing strand is usually larger than short-term transfer length of prestressing strand. This is called time-dependent effect. Also, debonding of the prestressing strand leads to an increase in the transfer length of prestressing strand. Moreover, the change in the transfer length over time increases as the percentage of debonded strands increases [10].

There have been many studies to determine the transfer length of prestressing strands in prestressed concrete beams. Since there is no linear relationship between the transfer length and the parameters explained above, the effect of all these parameters on the transfer length can not be included by statistical models. Current code and proposed equations include only two or three main parameters in their models and neglect the effect of other parameters. Also, code specifications and several proposed equations were developed based on the results of some studies. However, these equations can not be generalized and give accurate results for the experimental data used in their development.

The objective of this study is to investigate the usability of neuro-fuzzy inference system (ANFIS) and genetic expression programming (GEP) in predicting the transfer length of prestressing strands in prestressed concrete beams. The ANFIS and GEP approaches were used to predict the mean transfer length of prestressing strands in prestressed concrete beams. Complex relationship between the parameters affecting the transfer length and the transfer length of prestressing strand can be easily modeled by use ANFIS and GEP approach unlike statistical models. Experimental transfer length data were collected from various studies to be included in training and testing phase of ANFIS and GEP approaches.

2. Determination of transfer length

In general, prestressed beams were fabricated with varying concrete strength, number and levels of bonded/debonded prestressing strands. The percentage of debonded prestressing strands can be and up to 75% of the total prestressing strands depending on the design requirements. In case of debonded prestressing strands, bond between the concrete and the prestressing strand is prevented from developing by split sheathing. The number and location of strands, level of initial prestress, and length of debonding differs from test to test in the literature.

In the bottom flange of prestressed concrete beam, small circular metal pieces, demec points, were epoxied to both ends of the beams at the height of the centroid of the prestressing strands prior to the release of the prestress force. Demec points were placed over a distance greater than the predicted transfer length. Distance between demec points was measured by mechanical strain gauge device to determine the distance between the demec points prior to the release of the prestress force.

The compressive strain between demec points occurred immediately after the release of the prestress force was determined by taking demec point measurements. Then, a compression strain profile along each end of each beam was developed. The developed strain profile was used to determine short-term transfer length of the prestressing strand for each beam. In addition to measurement taken immediately after the release of prestress force, demec point measurements were also taken 4–6 weeks after release of prestress

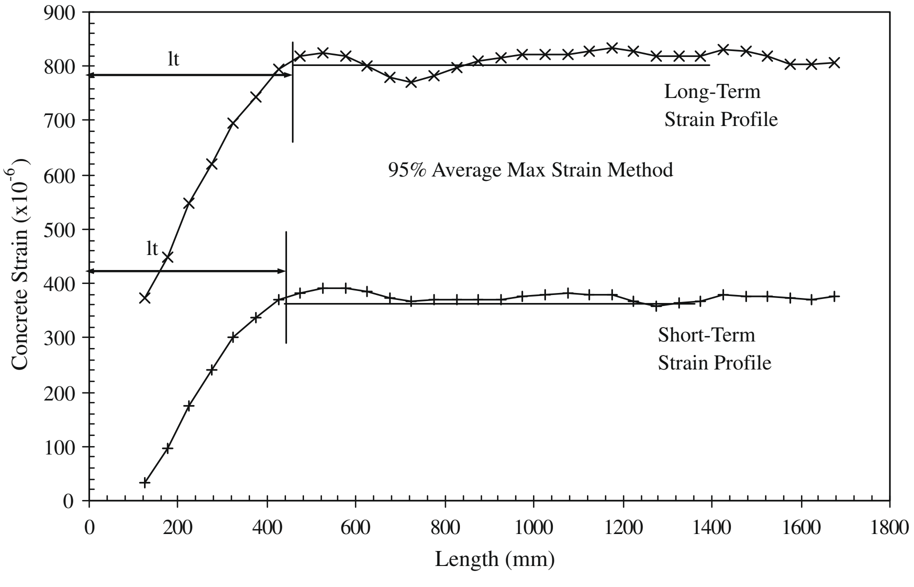

Fig. 1. Typical strain profile for the fully bonded strands.