PRESTRESS LOSSES IN PRETENSIONED HIGH-STRENGTH CONCRETE GIRDERS

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INTRODUCTION

Accurate estimate of prestress losses becomes more important as concrete strength and prestress level increase in order to properly assess concrete stresses and member deformations. Recent research has indicated that the current methods of prestress loss calculation in normal-strength concrete do not provide adequate estimates when high-strength concrete is used. Two sources of errors are associated with the current methods. The first is the inherent inflexibility of the formulas to varying long-term material properties such as creep and shrinkage. The second is that current methods do not account for the effects of composite action. The research reported in this presentation was conducted as National Cooperative Highway Research Program (NCHRP) project 18-07. It consisted of experimental and theoretical components. The experimental component consisted of material testing and prestress loss measurements of seven full-scale bridge girders. The bridge girders are located in four states; Nebraska, New Hampshire, Texas and Washington, representing different material and environmental conditions. Previously reported measurements of thirty-one pretensioned girders in seven different states were also examined. New formulas for estimating modulus of elasticity, shrinkage and creep of concrete were developed. A detailed method for estimating prestress losses based on pseudo-elastic analysis theory using an age-adjusted modulus of elasticity of concrete was proposed. This detailed method takes into account the long-term material properties and the effect of composite action. An approximate method was also introduced and produced reasonable upper bound estimates for commonly encountered conditions. Both methods are shown to be an improvement over currently available methods even for the lower strength concrete range.

MATERIAL PROPERTIES

PROPOSED MODULUS OF ELASTICITY FORMULA

A formula was developed for estimation of modulus of elasticity of concrete whose strength is up to 15 ksi. The formula includes parameters for the type of aggregates prevalent in a local area and the increase in unit weight of concrete with increasing compressive strength. The formula also gives average, upper bound and lower bound values of the modulus of elasticity. It defaults to about the same values as in the current values in AASHTO LRFD Specifications for conventional concrete strengths.

PROPOSED SHRINKAGE FORMULA

The proposed formula is similar to that in the ACI-209 Committee report (which is essentially the same as that in AASHTO-LRFD) but with the new correction factors that account for the effects of the high-strength concrete. The formula was further simplified for effects of member size, represented by the volume/surface ratio. It defaults to the approximately same values as the LRFD formula for a concrete strength of 5 ksi.

PROPOSED CREEP FORMULA

Similar to shrinkage, the proposed formula for estimating creep coefficient was developed to be an extension of the formula in the LRFD Specifications for concrete strengths higher than 5 ksi. It includes a simplification of some of the contributing effects, including volume-to-surface ratio and concrete strength.

PRESTRESS LOSS

PROPOSED DETAILED PRESTRESS LOSS METHOD

The time-dependent stress analysis in this paper is based theoretically on the age-adjusted effective modulus concept. This theory is expanded here to cover composite action. The total prestress loss is computed in four major steps, each of which relates to a significant construction stage: elastic shortening at transfer; long-term prestress losses between the time of transfer and just before deck placement, identified with the subscript "id"; elastic gain due to placement of the deck and superimposed dead loads; and long-term prestress losses between the time of deck placement and the final service life of the structure identified with the subscript "df". When transformed section properties are used for stress calculation, the first and third items above are automatically accounted for and do not need to be calculated separately. Total prestress loss, Δf_{pT} relative to the stress immediately before transfer is the sum of several components:

$$\Delta f_{pT} = \Delta f_{pES} + (\Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR2})_{id} - \Delta f_{pED1} - \Delta f_{pED2} + (\Delta f_{pSD} + \Delta f_{pCD1} + \Delta f_{pCD2} + \Delta f_{pR3} - \Delta f_{pSS})_{df} \tag{1}$$

The instantaneous prestress loss due to elastic shortening at transfer is calculated here only to show that the value of this loss can be determined using transformed section properties. This step is not needed when directly calculating the concrete stresses at transfer using transformed section properties.

The long-term prestress losses between transfer and deck placement due to shrinkage and creep of girder concrete and relaxation of prestressing strands are calculated as three separate components that take into account the interaction between the various components and the time dependent material properties for the loading and environmental conditions to which the bridge is subjected, as well as the estimated time lapse between prestress transfer and deck placement.

The instantaneous elastic prestress gain at placement of the deck and superimposed dead loads is proposed to be calculated separately by the proposed method, or accounted for automatically through use of transformed precast section properties.

The long-term prestress losses between deck placement and final time (composite section) occur due to shrinkage of girder, creep of girder, shrinkage of deck, and relaxation of prestressing steel. Creep of deck was found to be insignificant. For this time period the girder/deck composite section properties and the relevant material properties are used.

The detailed method has been shown to give excellent correlation with test results and generally lower prestress losses than the AASHTO LRFD detailed method.

PROPOSED APPROXIMATE PREDICTION OF PRESTRESS LOSSES

This method of predicting long-term prestress losses is a simplified version of the proposed detailed method and reflects the values and trends commonly encountered in practice for precast pretensioned concrete girders. It yields slightly higher loss values than the detailed method.

COMPARISON OF ESTIMATED AND EXPERIMENTAL PRESTRESS LOSSES

The full-scale testing program included instrumentation of two girders per bridge in the states of Nebraska, New Hampshire, and Washington, and one U-beam in the state of Texas. The average predicted total loss was very close to the average experimental value when the proposed detailed method was applied using measured, rather than specified or estimated, material properties. The ratios of estimated-to-experimental loss had an average of 100% and a standard deviation of 15%. The average experimental total prestress losses from transfer to time infinity were 37.3 ksi. This represented 18.4% of average jacking stress of 202.5 ksi.

The average ratios of estimated-to-experimental total losses using the proposed detailed, the proposed approximate, the AASHTO-LRFD Refined, the AASHTO-LRFD Lump-sum, and the PCI-BDM methods were 1.01, 1.07, 1.57, 1.41 and 1.05, respectively. Experimental prestress losses measurements reported in the literature from previous research were also compared with predictions methods. Similar observations were made. The corresponding average ratios for those previous tests were: 1.01, 1.08, 1.60, 1.37 and 1.06, respectively.

For more information on this research or for a copy of the final report, please directly contact the National Cooperative Highway Research Program, Dr. Amir Hanna, Senior Program Officer, Telephone: 202 334 1892, Internet: ahanna@nas.edu, or Mr. Crawford Jencks, NCHRP Manager, Telephone: 202-334-2379, Fax: 202-334-2006, Internet: cjencks@nas.edu.