

**TIME-DEPENDENT CHARACTERISTICS OF AN SCC MIX FOR KANSAS
PRESTRESSED CONCRETE BRIDGE GIRDERS**

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ABSTRACT

Creep and shrinkage test results of the proposed SCC mix for bridge girders in the state of Kansas are presented. Four bridge girders with an inverted tee profile were used to measure the creep and shrinkage in typical bridge girders. In two of the girder specimens the strands were tensioned to seventy-five percent of ultimate tensile strength. The strands of the other two girder specimens used were left untensioned to evaluate the shrinkage effect of the concrete. In addition, the fully tensioned girder specimens were used to determine the transfer length of the prestressing strand.

Keywords: Creep, Prestressed concrete, Self-consolidating concrete, Shrinkage, Time-dependent losses, Transfer length

INTRODUCTION

Self-Consolidating Concrete (SCC) has rapidly become a widely used material in the construction industry. The primary reasons for the increased use of SCC are the economical advantages that SCC has over normal conventional concrete (NC). The Interim Guidelines for the use of Self-Consolidating Concrete in PCI Member Plants¹ defines SCC as “a highly workable concrete that can flow through densely reinforced or complex structural elements under its own weight and adequately fill voids without segregation or excessive bleeding without need for vibration.”

The Interim Guidelines also state in the commentary that the hardened properties of SCC may be different than those of NC. Where modulus, creep, and shrinkage are important design guidelines, it states that the mix should be properly investigated before using in design. When designing prestressed concrete members, these properties are very important for an accurate estimation of time-dependent losses.

PROBLEM STATEMENT

The Kansas Department of Transportation (KDOT) would like to use SCC in pretensioned bridge members to enhance the aesthetics and improve consolidation in congested areas. However, before allowing the use of SCC in state bridges, KDOT needed to investigate the time-dependent losses of an SCC mix proposed by the local precaster. A previous study (“Bond Characteristics of an SCC Mix for Kansas Prestressed Concrete Bridge Girders,” companion paper at the 2005 National Bridge Conference) using SCC was conducted to investigate the bond between the strand and the concrete. At the time of this study the American Concrete Institute (ACI) and American Association of State Highway Transportation Officials (AASHTO) did not address the issue of members cast with SCC. KDOT wanted a thorough investigation of long term creep and shrinkage properties of a proposed SCC mix before allowing it to be used in state projects.

BACKGROUND

American Concrete Institute Building Code Requirements, AASHTO LRFD Bridge Design Specifications, KDOT, and The PCI Design Handbook, Sixth Edition all have slight differences in determining the losses of prestressed members. They are listed in the appendix section.

EXPERIMENTAL PROGRAM

PRESTRESS LOSS DETERMINATION

To determine the time-dependent losses, KDOT funded an experimental program to evaluate the long-term performance of inverted T-shape (IT) members cast with SCC. Four IT's, twelve foot in length, were cast in order to determine the time-dependent losses of actual bridge girders. A twelve foot length was considered to be an adequate length for this SCC mix because previous tests concluded that a six-foot development length was all that was needed to achieve full bond. The girder type used was the IT600. The cross-section of this shape can be seen in Figure 1. Table 1 presents the geometric properties of the IT600. Dimensions of the cast specimens were measured and then used for all calculations. Of the four girders, two of them had the prestressing strand jacked to seventy-five percent of the ultimate guaranteed tensile stress (f_{pu}) and were designated as FT #1 and FT #2, where FT stands for fully-tensioned. These two girders were used to determine the combined effects of creep, shrinkage, and relaxation. In addition, the two fully tensioned specimens were used to evaluate the transfer lengths, as discussed in the following section. The remaining two specimens, used to determine the effect of shrinkage alone, had the prestressing strand pulled to a "hand-tight" condition. The designations of these specimens were UT #1 and UT #2, where UT stands for untensioned. The strand was placed in these shrinkage specimens to match the transformed section properties of the two specimens that had the strand jacked to seventy-five percent of f_{pu} .

Elastic shortening losses occur at the time the prestress force is transferred to the concrete and thus can be eliminated from long term calculations. The increase in relaxation losses from transfer to final loss calculations are very small compared to the creep and shrinkage losses and are not included in calculations. Elastic shortening and relaxation were determined from the change in strain just after detensioning and subtracted from the measurements that were recorded from the two fully-tensioned specimens. Then the values of shrinkage, obtained from the two un-tensioned specimens, was subtracted from the above mentioned fully-tensioned specimens along with the elastic shortening and relaxation to determine the effects of creep alone. To record the long term strains that all the specimens had undergone, Vibrating Wire Strain Gages (VWSG) were used. Gages with a six-inch gage length were chosen for this project. All the gages were connected to a data-logger that could take data readings at any desired time interval. Readings were taken every five minutes for the first day and then the collection interval was changed to two hours. Gages were placed at the height of the top strand (4 inches from the top), the neutral axis of the section (8.21 inches from the bottom and in one case this value changed slightly and thus the recorded value was used), and the last gage placed at the bottom strand height (two inches from the bottom). The setup of the gages is shown in Figure 2. The gage at the bottom was primarily used to gather the long term strains. To determine the stress at the strand height, Hooke's Law was used.

$$\sigma = E_{ps} \varepsilon \quad (1)$$

where

E_{ps} = modulus of elasticity (ksi)

ε = recorded strain value (in/in)

Strains were zeroed just prior to detensioning. Therefore, the subsequent strain changes were due to prestress losses. A load cell was placed at the “dead” end of the prestressing bed in order to get an exact prestress force at detension. The nominal value of the jacking stress, f_{pj} , was calculated to be 202.5 ksi. However experimentally it was found to be 197.7 ksi and this value will be used for all calculations using code and experimental data. For the methods that were compared to the experimental data, no intermediate days are calculated, just final values. In order to estimate creep and shrinkage values for periods less than two years, the expression by Corley and Sozen² was used. The following equation made it possible to compare creep and shrinkage values for periods less than two years.

$$R = 0.13 \ln(t+1) \quad (2)$$

where

R = the total time-dependent proportion

t = time (days)

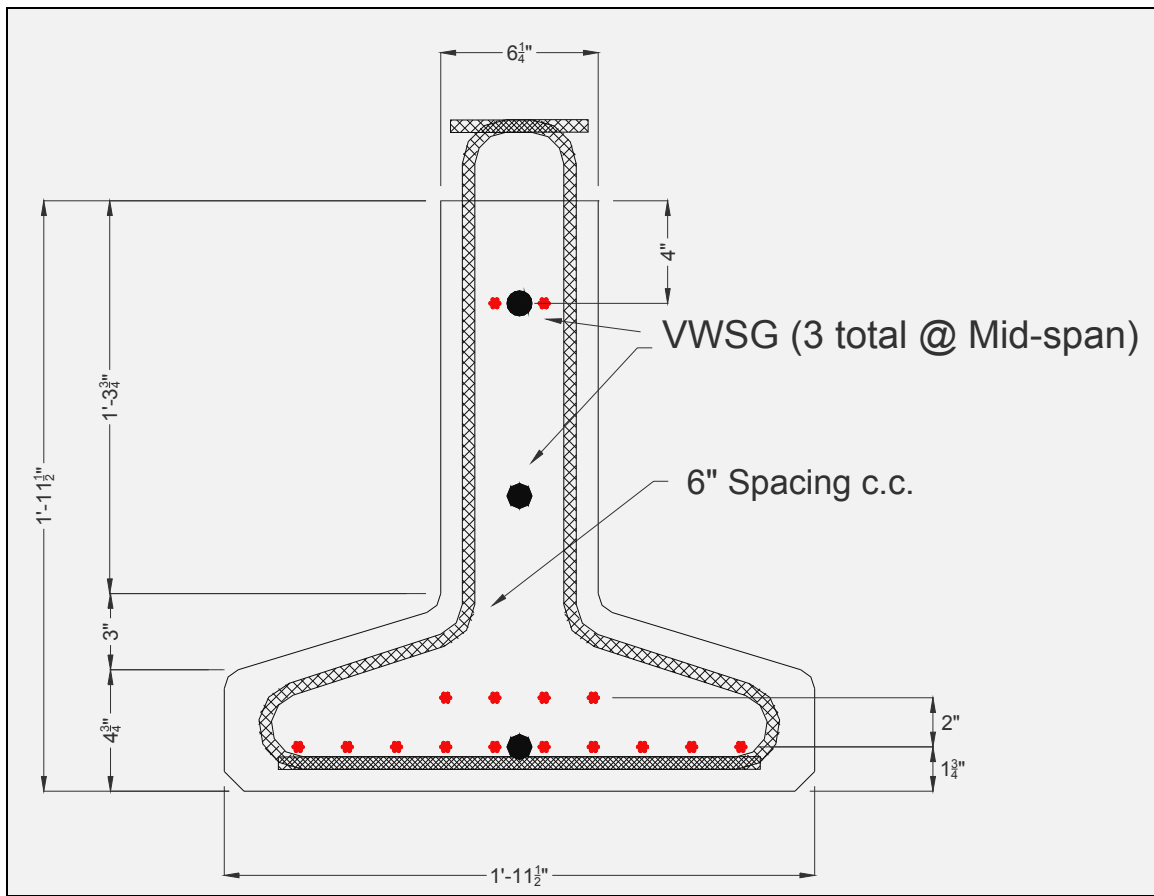


Fig. 1 Cross Section of IT600

Table 1. List of Measured Geometric Properties of IT600

$A = 255.9 \text{ in}^2$	$I = 12,822 \text{ in}^4$	$E_{ps} = 28,500 \text{ ksi}$
$E_{ci} = 3600 \text{ ksi}$	$Y_{bot} = 8.45 \text{ in}$	$e = 3.86 \text{ in}$
$M_{sw} = 4.41 \text{ k-ft}$	$RH = 65\%$	$A_{ps} = 2.448 \text{ in}^2$
$f_{pj} = 197.7 \text{ ksi}$		$V/S = 2.87 \text{ in}$

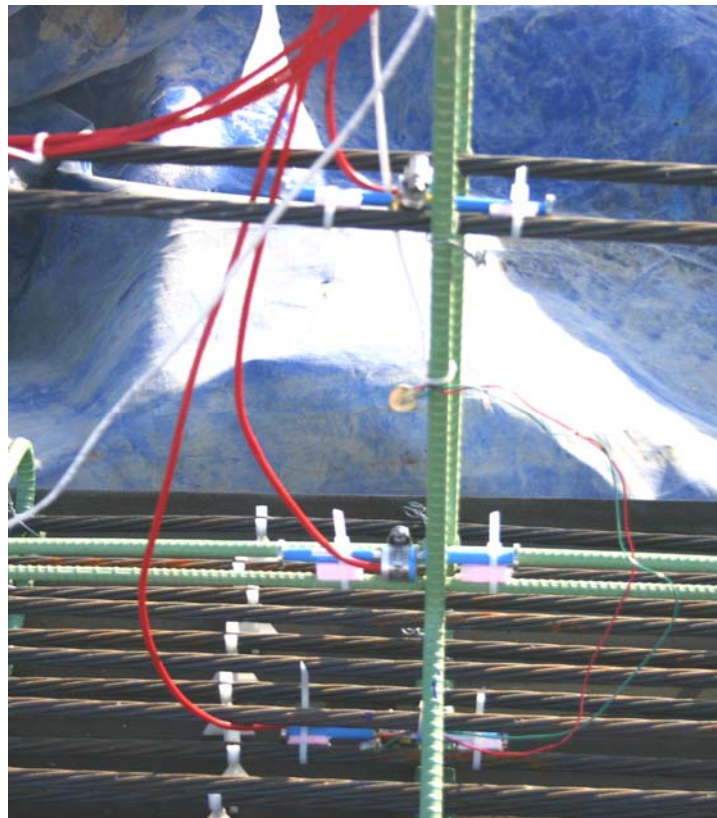


Fig. 2 Location of VWSG's

TRANSFER LENGTH SETUP

Measurements of the transfer length were accomplished by measuring concrete surface strains with a mechanical strain gage. Whittemore points, stainless steel discs with a machined hole in the center, were adhered along the bottom flange of the specimen of both

fully-tensioned specimens prior to detensioning, Figure 3. The location chosen for the line of points was the center of gravity between the bottom two layers of prestressing strand, 2.67 inches from the bottom. Readings were then taken just prior to detensioning and after detensioning, shown in Figure 4. The procedure outlined by Russell and Burns³ was used to evaluate the data. Measured changes in strain were then plotted against the length of the specimen. The concrete strains were the numerical difference between the initial reading and the final reading (just after detensioning). To eliminate any anomalies, measured strains were smoothed by averaging the data over three gage lengths. The equation used to smooth the data is shown as follows:

$$(\text{strain})_i = \frac{(\text{strain})_{i-1} + (\text{strain})_i + (\text{strain})_{i+1}}{3} \quad (3)$$

where

i = the current strain reading

So at any given strain point, that strain and the values just ahead and behind were averaged to obtain the “smoothed” average.

Transfer lengths were then determined by plotting the strains versus the specimen length. The method known as the “95% Average Maximum Strain,” also detailed in Russell and Burns³, was used to estimate the transfer lengths. The first step is to plot the “smoothed” strain profile. Then the maximum strain that the specimen underwent is determined. Next, 95% of this maximum strain value is computed and a line corresponding to this value is drawn. Lastly the transfer length is determined by taking the intersection of the 95% maximum strain line and the “smoothed” strain profile line.

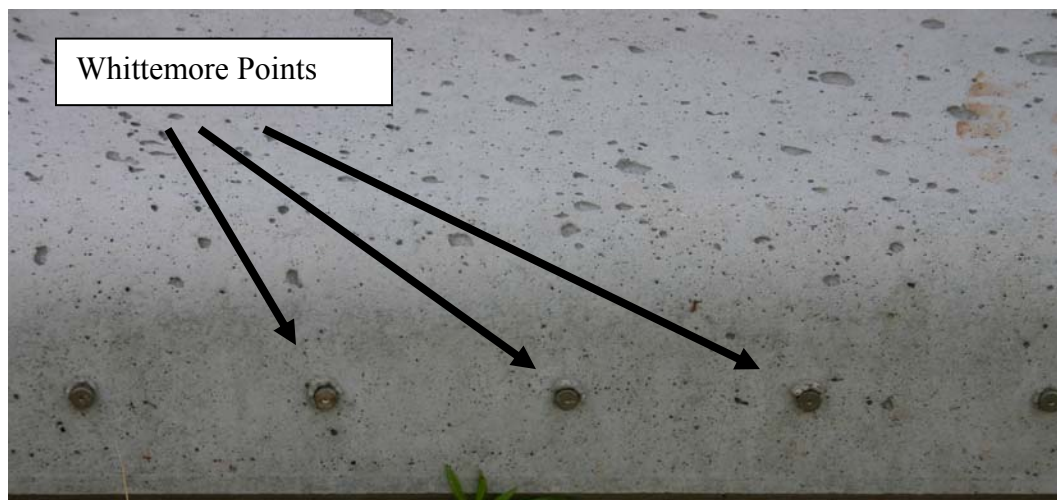


Fig. 3 Whittemore points adhered to the bottom the specimen

Transfer length is implied by both ACI and AASHTO to be expressed as:

$$L_{tr} = \frac{f_{se}}{3} d_b \quad (4)$$

where

d_b = diameter of strand (in)

f_{se} = effective stress in prestressing strand after allowance of prestress losses (ksi)

For the IT specimen geometry and strand configuration used in this study, the transfer length was calculated (using equation 4) to be 24 inches.



Fig. 4 Measuring concrete surface displacements with a Whittemore gage

RESULTS

PRESTRESS LOSSES

By using the methods for determining prestress losses as described earlier and presented in the appendix, all the values for elastic shortening, creep, shrinkage, and relaxation were calculated, see Table 1. It was found that the ACI and PCI methods gave the same results; therefore they are presented in the same row. The experimental values for elastic shortening, creep, shrinkage, and relaxation are also given. However, it must be noted that data collection for this paper was stopped at 144 days and collection of strains will continue for a much longer time in order to obtain more complete data.

Table 1 Summary of time-dependent losses

Method	Elastic Shortening	Creep	Shrinkage	Relaxation	Effective Prestress Loss
AASHTO ⁷	17.6	26.6	7.3	1.9	144
ACI ⁶ /PCI ⁵	16	34.7	6.8	2.7	138
KDOT ⁸	17.3	26.6	7.3	1.6	145
Experimental [*]	17.7	18.8	0.5	1.1	159

all values in ksi
^{*} Data recorded at 144 days

Strains have been recorded throughout the life of the specimens. By using equation 1, time-dependent losses were estimated at several days and compared to the experimentally-determined values. It must be noted that the strains from FT #1 and FT #2 were averaged and then converted to stresses. The results are shown in Table 2. Figure 5 presents the long term losses in graphical form.

Table 2 Strand stress at various ages

Time (Days)	AASHTO ⁷	ACI ⁶ /PCI ⁵	KDOT ⁸	Experimental
Transfer	179	176	176	180
25	165	162	165	171
50	162	158	162	168
75	160	156	160	164
96	159	155	159	163
120	158	153	158	162
144	157	152	157	159
Long Term	144	138	145	150*

all values in ksi

* Estimated by extrapolating curve to 2 years

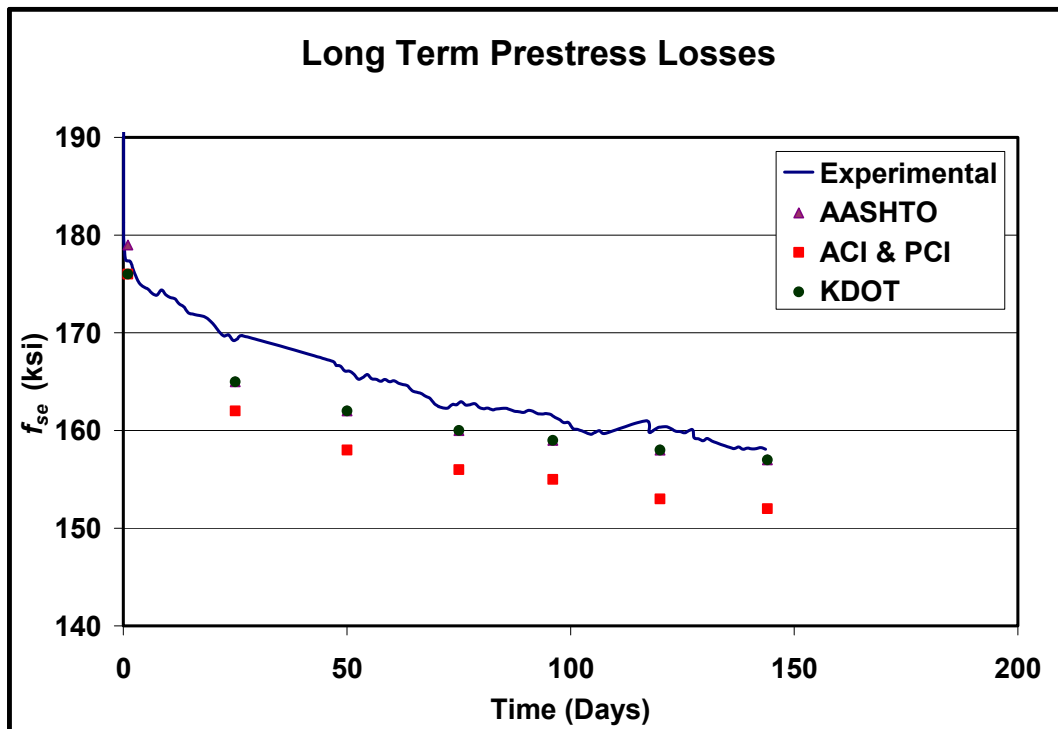


Fig. 5 Long term effective prestress losses

TRANSFER LENGTH RESULTS

The concrete strain profile verses length for both FT #1 and FT #2 are shown below. FT #1, seen in Figure 6, had transfer lengths of 32 inches on one end and 23 on the other. FT #2, seen in Figure 7, had transfer lengths of 24 inches on one end and 28 inches on the other. The ends of the specimens that had the greatest transfer lengths both were flame-cut at detensioning while the ends with the smaller values underwent a gradual release during detensioning.

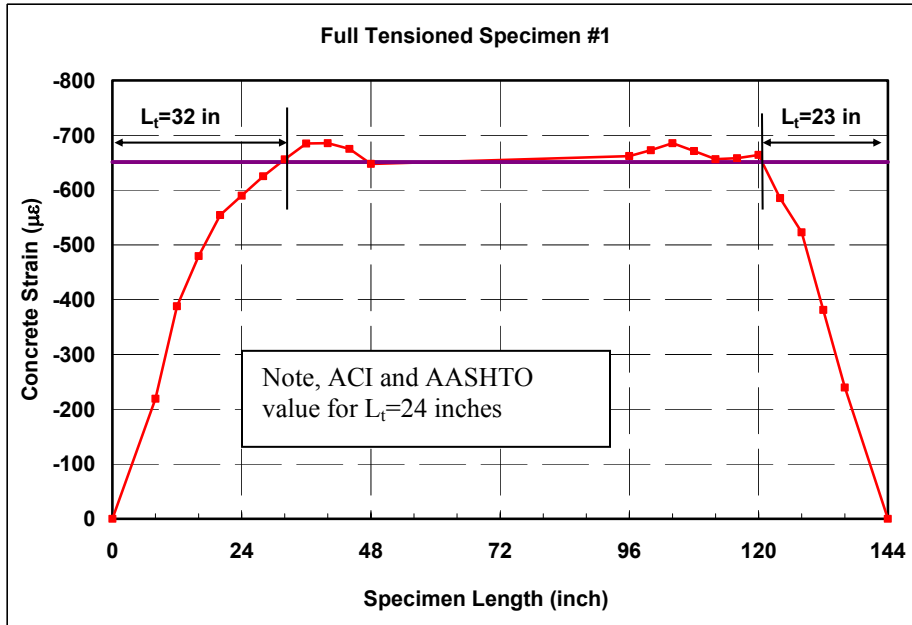


Fig. 6 Transfer length profile for FT #1

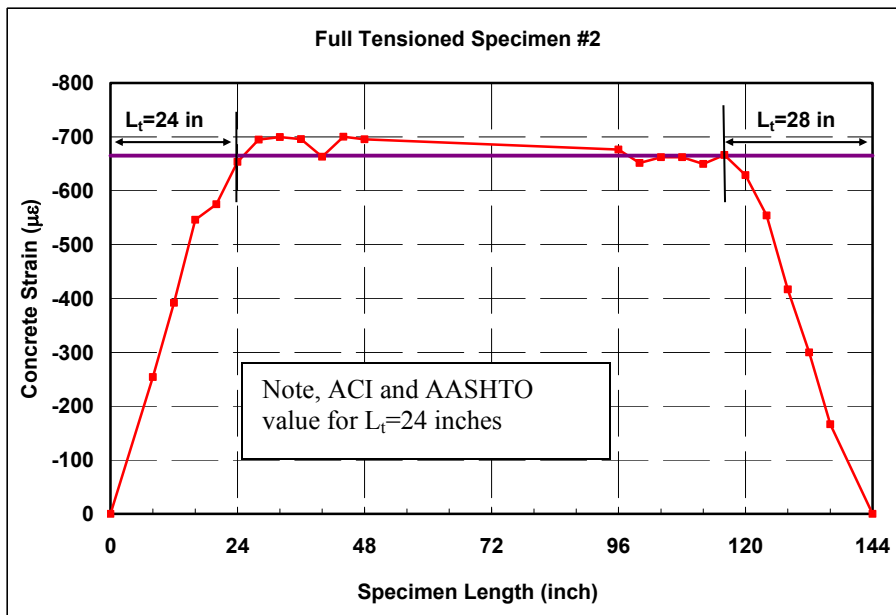


Fig. 7 Transfer length profile for FT #2

CONCLUSIONS

1. Total observed losses for the experimental specimens were slightly less than those predicted by the current AASHTO, ACI/PCI, and KDOT design expressions.
2. Measured transfer lengths for the proposed SCC mix and specimen geometry were in general accordance with the current AASHTO and ACI/PCI design assumptions, with the maximum measured transfer lengths being 33 percent larger than the calculated value.
3. Using the proposed SCC mix, it was found that effective prestress losses were in general accordance with current AASHTO, ACI/PCI, and KDOT code equations and no special design considerations need to be taken.

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APPENDIX

ACI⁴ and PCI⁵ METHOD

Both use the findings of Zia et al⁶ for calculations.

Elastic Shortening of Concrete (ES)

For members with bonded tendons,

$$ES = K_{es} E_s \frac{f_{cir}}{E_{ci}} \quad (5)$$

in which

$K_{es} = 1.0$ for pretensioned members

$K_{es} = 0.5$ for post-tensioned members when tendons are tensioned in sequential order to the same tension. With other post-tensioning procedures, the value for K_{es} may vary from 0 to 0.5.

$$f_{cir} = K_{cir} f_{cpi} - f_g \quad (6)$$

in which

$K_{cir} = 1.0$ for post-tensioned members.

$K_{cir} = 0.9$ for pretensioned members.

Creep of Concrete (CR)

For members with bonded tendons,

$$CR = K_{cr} \frac{E_s}{E_c} (f_{cir} - f_{cds}) \quad (7)$$

in which

$K_{cr} = 2.0$ for pretensioned members

$K_{cr} = 1.6$ for post-tensioned members

Shrinkage of Concrete (SH)

$$SH = 8.2 \times 10^{-6} K_{sh} E_s \left(1 - 0.06 \frac{V}{S} \right) (100 - RH) \quad (8)$$

in which

$K_{sh} = 1.0$ for pretensioned members

or

K_{sh} is taken from Table 1³ for post-tensioned members.

Relaxation of Tendons (RE)

$$RE = [K_{re} - J(SH + CR + ES)]C \quad (9)$$

in which the values of K_{re} , J , and C are taken from Tables 2 and 3.³

AASHTO METHOD

Taken from the Third Edition⁷ for pretensioned members

$$\Delta f_{pT} = \Delta f_{pES} + \Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR2} \quad (10)$$

where:

Δf_{pT} = total loss (ksi)

Δf_{pES} = loss due to elastic shortening (ksi)

Δf_{pSR} = loss due to shrinkage (ksi)

Δf_{pCR} = loss due to creep of concrete (ksi)

Δf_{pR2} = loss due to relaxation of steel after transfer (ksi)

Elastic Shortening (Δf_{pES})

$$\Delta f_{pES} = \frac{E_p}{E_{ci}} f_{cgp} \quad (11)$$

where:

f_{cgp} = sum of concrete stresses at the center of gravity of prestressing tendons due to the prestressing force at transfer and the self-weight of the member at the sections of maximum moment (ksi)

E_p = modulus of elasticity of prestressing steel (ksi)

E_{ci} = modulus of elasticity of concrete at transfer (ksi)

Shrinkage (Δf_{pSR})

$$\Delta f_{pSR} = (17.0 - 0.150H) \quad (12)$$

where:

H = the average annual ambient relative humidity (percent)

Creep (Δf_{pCR})

$$\Delta f_{pCR} = 12.0 f_{cgp} - 7.0 \Delta f_{cdp} \geq 0 \quad (13)$$

where:

f_{cgp} = concrete stress at center of gravity of prestressing steel at transfer (ksi)
 Δf_{cdp} = change in concrete stress at center of gravity of prestressing steel due to permanent loads with the exception of the load acting at the time the prestressing force is applied. Values of Δf_{cdp} should be calculated at the same section or at sections for which f_{cgp} is calculated (ksi)

Relaxation (Δf_{pR2})

At transfer

In pretensioned members, the relaxation loss in prestressing steel, initially stressed in excess of $0.50 f_{pu}$, may be taken as:

For stress-relieved strand:

$$\Delta f_{pR1} = \frac{\log(24.0t)}{10.0} \left[\frac{f_{pj}}{f_{py}} - 0.55 \right] f_{pj} \quad (14)$$

For low-relaxation strand:

$$\Delta f_{pR1} = \frac{\log(24.0t)}{40.0} \left[\frac{f_{pj}}{f_{py}} - 0.55 \right] f_{pj} \quad (15)$$

where:

t = time estimated in days from stressing to transfer (days)
 f_{pj} = initial stress in the tendon at the end of the stressing (ksi)
 f_{py} = specified yield strength of prestressing steel (ksi)

After Transfer

Losses due to relaxation of prestressing steel may be taken as:

For pretensioning with stress-relieved strands:

$$\Delta f_{pR2} = 20.0 - 0.4 \Delta f_{pES} - 0.2 (\Delta f_{pSR} + \Delta f_{pCR}) \quad (16)$$

where:

Δf_{pES} = loss due to elastic shortening (ksi)

Δf_{pSR} = loss due to shrinkage (ksi)

Δf_{pCR} = loss due to creep of concrete (ksi)

For prestressing steels with low relaxation properties conforming to AASHTO M 203 (ASTM A 416 or E 328):

Use 30 percent of Δf_{PR2} given by equation 12.

KDOT METHOD

As described in the 2003 release⁸.

The loss of stress in the prestressing steel is as follows:

$$\begin{aligned}\Delta f_s &= SH + ES + CR_C + CR_S \\ \Delta f_s &= \text{Loss of stress, psi} \\ SH &= \text{Loss due to concrete shrinkage, psi} \\ ES &= \text{Loss due to elastic shortening, psi} \\ CR_C &= \text{Loss due to creep of concrete, psi} \\ CR_S &= \text{Loss due to relaxation of steel, psi}\end{aligned}$$

Shrinkage

The shrinkage loss is computed as follows,

$$SH = 17,000 - 150RH \quad (17)$$

Where RH is the average relative humidity in percent. For Kansas, the humidity may be assumed at 65 percent.

Elastic Shortening

Elastic shortening is computed as follows:

$$ES = \left(\frac{E_s}{E_{ci}} \right) f_{cir} \quad (18)$$

$$E_s = 28 \times 10^6 \text{ psi}$$

$$E_{ci} = \text{Modulus of elasticity of concrete at transfer of stress } (33W^{3/2} \sqrt{f'_{ci}} \text{ psi.})$$

$$W = 145 \text{ pcf for normal weight concrete}$$

f_{cir} = Concrete stress at the center of gravity of the prestressing steel due to prestressing force and dead load of the beam immediately after transfer. (At this stage, the initial stress in the tendon has been reduced by elastic shortening of the concrete and tendon relaxation during placing and curing of the concrete.)

Creep of Concrete:

For pretensioned and post-tensioned members

$$CR_C = 12f_{cir} - 7f_{eds} \quad (19)$$

Where f_{eds} is the concrete stress at the center of gravity of prestressing steel due to all dead loads except the dead loads present at the time prestressing force is applied.

Relaxation of Prestressing Steel – (Low Relaxation Strand)

$$CR_S = 5,000 - 0.10ES - 0.05(SH + CR_C) \quad (20)$$

The values of ES , SH , and CR_C are those computed previously,

$$\text{Total losses: } \Delta f = SH + ES + CR_C + CR_S \quad (21)$$

The minimum loss of prestress to be used when computing service load stresses shall be 35,000 psi.