Washington State Department of Transportation
Bridge and Structures Office

Design Memorandum

TO: All Design Section Staff
FROM: Bijan Khaleghi
DATE: June 4, 2020
SUBJECT: BDM Section 5.2.4A - calculating deflection and camber in concrete members

This design memorandum specifies WSDOT's policy for calculating deflection and camber in concrete members. This memorandum modifies the Bridge Design Manual Section 5.2.4A as specified herein.

Bridge Design Manual Revisions

BDM 5.2.4A is amended with the following:

Deflection and camber calculations shall consider appropriate combinations of dead load, live load, prestress forces, erection loads, concrete creep and shrinkage, and steel relaxation.

1. Instantaneous Deflections

For nonprestressed members, unless obtained by a more comprehensive analysis, instantaneous deflections shall be calculated using the effective moment of inertia, I_e, in accordance with Table 1:

Table 1—Effective Moment of Inertia, Ie

Service Moment	Effective Moment of Inertia, I_e (in.^{4})
$M_a \le \frac{2}{3} M_{cr}$	I_g
$M_a > \frac{2}{3} M_{cr}$	$\dfrac{I_{cr}}{1-\left(\dfrac{\frac{2}{3}M_{cr}}{M_a}\right)^2\left(1-\dfrac{I_{cr}}{I_g}\right)}$

For prismatic members, effective moment of inertia shall be taken as the value obtained from Table 1 at midspan for simple or continuous spans, and at the support for cantilevers.

For continuous nonprismatic members, the effective moment of inertia shall be taken as the average of the values obtained from Table 1 for the critical positive and negative moment sections.

For prestressed members, instantaneous deflections may be calculated based on I_g.

2. Time-Dependent Deflections

For nonprestressed members, unless obtained from a more comprehensive analysis, additional time-dependent deflection resulting from creep and shrinkage of flexural members shall be calculated as the product of the immediate deflection caused by sustained load and the factor λ_Δ:

$$\lambda_\Delta = \frac{\xi}{1+50\rho'} \qquad \text{Eq. 1}$$

where:

$$\rho' = \frac{A_s'}{bd} \qquad \text{Eq. 2}$$

Table 2—Time-dependent Factor for Sustained Loads

Sustained Load Duration (months)	Time-dependent Factor ξ
3	1.0
6	1.2
12	1.4
60 or more	2.0

ρ' is calculated at midspan for simple and continuous spans, and at the support for cantilevers.

Additional time-dependent deflection of prestressed concrete members shall be calculated considering stresses in concrete and reinforcement under sustained load, and the effects of creep and shrinkage of concrete and relaxation of prestressed reinforcement.

All variables are as defined in AASHTO LRFD, except as revised below:

b = width of the compression face of the member (in.); for a flange section in compression, the effective width of the flange as specified in AASHTO LRFD 4.6.2.6 (in.); width of corbel or ledge (in.); least width of component section (in.);

width of a pier (in.); design width (in.)

I_{cr} = moment of inertia of the cracked section, transformed to concrete ($in.^4$)

I_g = moment of inertia of the gross concrete section about the centroidal axis, neglecting the reinforcement ($in.^4$)

M_a = maximum moment in a component due to service loads at the stage for which deformation is computed (kip-in.)

M_{cr} = cracking moment (kip-in.)

y_t = distance from the centroidal axis of the gross section to the extreme fiber in tension (in.)

λ_Δ = multiplier used for calculating additional time-dependent deflection

ρ' = ratio of A's to bd

ξ = time-dependent factor for sustained loads

Background

This design memorandum provides updated methods for calculating deflection and camber in concrete members. The changes are based on an agenda item currently under consideration by AASHTO. The changes primarily effect nonprestressed members.

The effective moment of inertia approximation, developed by Bischoff and Scanlon (2008), has been shown to result in calculated deflections that have sufficient accuracy for a wide range of reinforcement ratios. M_{cr} is multiplied by 2/3 to consider restraint that can reduce the effective cracking moment as well as to account for reduced tensile strength of early-age concrete that can lead to cracking during construction.

Previous editions of AASHTO LRFD used a different equation to calculate I_e. The previous equation did not consider the effects of restraint, and has subsequently been shown to underestimate deflections for members with low reinforcement ratios. For members with greater than 1 percent longitudinal tension reinforcement and a service moment at least twice the cracking moment, there is little difference between deflections calculated using the former and the current provisions.

Shrinkage and creep cause time-dependent deflections in addition to the instantaneous deflections that occur when sustained loads are first placed on the structure. Instantaneous and time – dependent deflections are additive in determining the total deflection. Such deflections are influenced by temperature, humidity, curing conditions, age at time of loading, amount of compression reinforcement, and magnitude of the sustained load. Eq. 1 is considered satisfactory for use with the calculation procedure for instantaneous deflections provided in AASHTO LRFD 5.6.3.5.2a, and with the limits given in AASHTO LRFD 2.5.2.6.2. The deflection calculated is the additional time-dependent deflection due to the dead load and those portions of other loads that will be sustained for a sufficient period to cause significant time-dependent deflections.

Eq. 1 was developed in Branson (1971). In Eq. 1, the term $(1 + 50\rho')$ accounts for the effect of compression reinforcement in reducing time-dependent deflections. $\xi = 2.0$ represents a nominal time-dependent factor for a five-year duration of loading.

Calculation of time-dependent deflections of prestressed concrete flexural members is challenging. The time-dependent deflection is usually based on mix-specific data in combination with creep and shrinkage characteristics, and the calculation procedures are described in AASHTO LRFD 5.4.2.3.

If you have any questions regarding this policy memorandum, please contact Anthony Mizumori at Anthony.Mizumori@wsdot.wa.gov, Rick Brice at Richard.Brice@wsdot.wa.gov or Bijan Khaleghi Bijan.Khaleghi@wsdot.wa.gov at (360) 705-7181.

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