Washington State Department of Transportation
Bridge and Structures Office

Design Memorandum

TO: All Design Section Staff
FROM: Bijan Khaleghi
DATE: July 17, 2020
SUBJECT: Supplement to BDM Section 5.1.1-E – Creep of Concrete

This design memorandum specifies WSDOT's policy for calculating creep of concrete for balanced cantilever segmentally constructed bridges. The creep of concrete calculations for conventional prestressed concrete members and other concrete members shall be determined in accordance with the AASHTO LRFD Bridge Design Specifications Articles 5.4.2.3.2 and 5.4.2.3.3.

AASHTO requires more precise estimate of creep for segmentally constructed bridges including the effect of concrete materials, structural dimensions, site conditions, construction methods, and concrete age at various stages of construction.

For segmentally constructed bridges, estimates of creep may be made using the provisions of any of the following:

- The CEB/FIB Model Code 2010 (MC 2010),
- ACI 209.2.
- AASHTO LRFD, as modified below:

The modified AASHTO creep coefficient for balanced cantilever segmentally constructed bridges may be taken as:

$$\Psi_{(t,ti)} = 2.35\, k_c\, k_{hc}\, k_f\, k_{tdc}\, t^{-0.118} \quad \text{Eq. 1}$$

in which:

$$k_c = 1.45 - 0.13\,(V/S) > 1.0 \quad \text{Eq. 2}$$

$$k_{hc} = 1.56 - 0.008H \quad \text{Eq. 3}$$

$$k_f = 5\,/\,(1 + f'_{ci}) \text{ Eq.}$$

$$k_{tdc} = \frac{3\ln(t^2)}{12\left(\frac{100-4f'_{ci}}{f'_{ci}+20}\right)+2\ln(t)} \quad \text{Eq. 4}$$

where:

H = average annual ambient relative humidity (percent). In the absence of better information, *H* may be taken from LRFD Figure 5.4.2.3.3-1.

k_c = factor for the effect of the volume-to-surface ratio of the component

k_f = factor for the effect of concrete strength

k_{hc} = humidity factor for creep

k_{tdc} = time development factor

t = maturity of concrete (day), defined as age of concrete between time of loading for creep calculations, or end of curing for shrinkage calculations, and time being considered for analysis of creep or shrinkage effects ti = age of concrete at time of load application (day)

V/S = volume-to-surface ratio (in.)

f'_{ci} = design concrete compressive strength at time of prestressing. If concrete age at time of initial loading is unknown at design time, $f'ci$ may be taken as 0.80 f'_c (ksi).

The factor 2.35 shown in Eq. 1 is a notional coefficient that could vary from 1.6 – 3.5 to reflect the ±50% creep of concrete variability on a project-specific basis. The variance in creep shall be considered when determining longitudinal continuity tendon termination points. More accurate creep coefficient variance could be computed by using the B3 or B4 models, or using variance values out of ACI 209.2.

The time development factor, k_{tdc}, (Eq. 4) is an empirical modification to AASHTO LRFD Equation 5.4.2.3.2-5 that add a logarithmic time function designed to parallel the long-term ascent of creep indicated in MC2010.

The factors for the effects of volume-to-surface ratio are an approximation of the following formulas with maximum V/S ratio considered was 6.0 in.

$$k_c = \left[\frac{\dfrac{t}{26\,e^{0.36(V/S)} + t}}{\dfrac{t}{45 + t}}\right]\left[\frac{1.80 + 1.77\,e^{-0.54(V/S)}}{2.587}\right] \qquad \text{Eq. 5}$$

Background:

Creep and shrinkage of concrete are variable properties that depend on a number of factors, some of which may not be known at the time of design. Without specific physical tests or prior experience with the materials, the use of the empirical methods that are not calibrated to testing should be expected to have a variance of ±50 percent.

For precast or cast-in-place balanced cantilever segmentally constructed bridges, creep of the concrete is particularly important. This is partly due to the fact that the construction load distribution, and therefore prestressing, is significantly different that the load distribution of a monolithically constructed structure. Consequently, appropriate provisions shall be made in the design to allow for variations in material properties from those originally envisaged.

These provisions are applicable for design concrete compressive strengths up to 15.0 ksi.

Ultimate creep is less sensitive to surface exposure than intermediate values at an early age of concrete. For accurately estimating intermediate deformations of such specialized structures as segmentally constructed balanced cantilever box girders, it may be necessary to resort to experimental data or use the mix-dependent creep calculations.

It is important to highlight the time development factor was empirically developed to match MC2010. Eq 4 is just the current AASHTO equation derived through an example to achieve the MC2010 late-age slope. Eq 1 follows the form of AASHTO with a higher median notional creep coefficient (2.35 instead of 1.9), consistent with development of Equation 4.

The B3 model is per ACI 209.2R, Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete. The B4 model is from American Society of Civil Engineers (ASCE), 9th International Conference on Creep, Shrinkage, and Durability Mechanics: Pages 429-436 "multi-decade creep and shrinkage prediction by R. Wendner1, M. H. Hubler2, and Z. P. Bažant3

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