AASHTO LRFD Bridge Design Specifications: Stress Calculations and Prestress Loss Estimates

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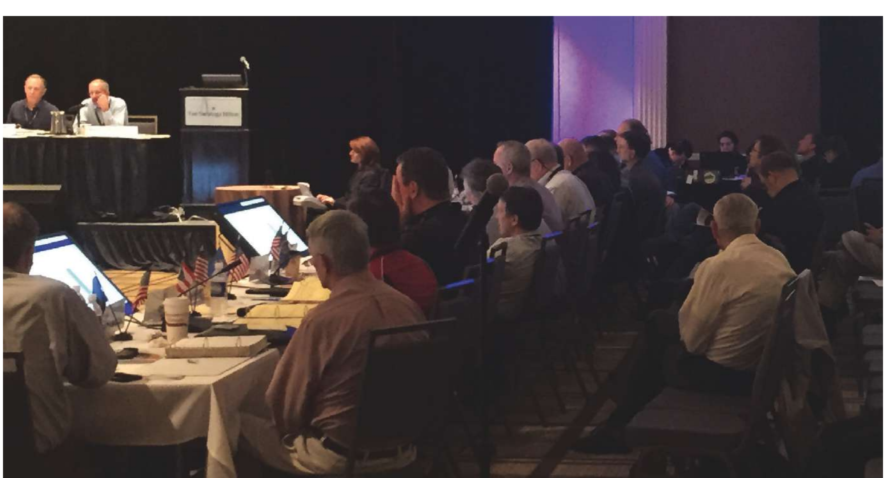
Since the last issue of *ASPIRE*®, a number of questions were raised about stress calculations under service loads for prestressed concrete bridges. This article reviews this topic and shares my thoughts.

The results from a survey of 38 state departments of transportation and from a sensitivity analysis by Brice et al.[1] were published in the Winter 2013 issue of *ASPIRE*. One of the primary conclusions of that article was that "*reducing the allowable tension stress at the service III limit state has the greatest overall influence and has the greatest impact on girder spacing requirements*."

In the same article, the authors noted that different states have different design policies and those policies that promote zero tension design result in more robust bridge designs than designs following the minimum requirements set forth by American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[2] It is always possible, if not recommended, to go beyond the minimum required by the AASHTO LRFD specifications; prestress loss estimations or stress calculations are not exempt from this reasoning.

Another aspect of the questions recently fielded by the *ASPIRE* team relates to what type of section properties (gross or transformed) are more appropriate for computing stresses for the Service III limit state when using the eighth edition of AASHTO LRFD specifications. To the best of my knowledge, there are no restrictions imposed by the specifications in this regard, and further lack of such limitations is consistent with the calibration efforts (that is, code calibration for service level stresses) that took place under Strategic Highway Research Program. In other words, one can choose to use any level of precision in calculating stresses, and the important aspect of this exercise relates to ensuring compliance with a particular state's design policy. Some states may choose a more conservative approach in this regard, while ensuring compliance with AASHTO LRFD specifications.

In an effort to shed additional light on the ongoing discussion on stress calculations, loss estimations, and the use of net, gross, or transformed section properties, let us consider the results of an example problem that I routinely use in my prestressed concrete design class at the University of Texas. As can be seen in the figure below, from left to right, there are increasing levels of analysis complexity.



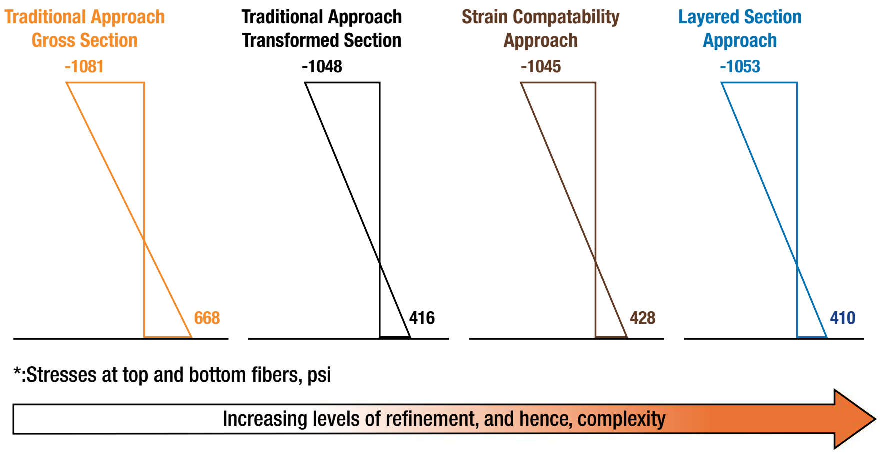
Voting on an agenda item during the 2015 SCOBS meeting. Photo: Dr. Oguzhan Bayrak.

Use of transformed section properties, or other higher-level analyses, such as strain compatibility analysis or layered section analysis, reduce the magnitude of the bottom fiber tensile stress by nearly 40% for this particular example in which a tee-shaped section that is similar to a decked bub-tee was employed. Certainly, higher-order analyses yield more accurate results and their use is recommended in computer-aided calculations.

With that stated, if a particular state's design policy calls for using gross section properties to build additional design conservatism in the calculations or requires zero tension, we must also understand, and respect that line of thinking. Further, some designers may wish to avoid complicated stress calculations in light of many other uncertainties inherent in design. Such uncertainties include the inability to estimate modulus of elasticity of concrete accurately, inaccuracies stemming from live load distribution, just to name a couple.

Because we are discussing accuracy versus conservativeness, it is also appropriate to discuss the prestress loss estimations. Regardless of the analysis technique used (that is, for all techniques shown in the figure below), it is also necessary to estimate the prestress losses. A design must account for losses related to elastic shortening, creep, shrinkage, and relaxation.

In running traditional calculations, with gross section properties as an example, we explicitly calculate all prestress loss components and account for them in our design. In higher-order analyses, the calculation of losses due to elastic shortening becomes implicit, and we therefore do not account for it explicitly. Losses due to creep can be accounted for by use of an effective modulus whereas shrinkage losses are typically calculated using a strain offset (or an explicitly calculated loss component) in design. Relaxation losses



The implications of refinement in analysis for bottom fiber stress calculations. Figure: Nathan Dickerson.

Table 1: Load Factors for Live Load for Service III Analyses (Adapted from Section 3 of *AASHTO LRFD Bridge Design Specifications*[2])

Component	Load Factor, γ_{LL}
Prestressed concrete components designed using the refined estimated of time-dependent losses in conjunction with taking advantage of transient elastic gains	1.0
All other prestressed concrete components	0.8

can also be tackled by using an effective modulus approach; it is typically a very small loss component for modern, low-relaxation strands. As an aside, it is important to note that the AASHTO LRFD specifications allow for the calculation of prestress "gains" due to transient loads; however, if such "gains" are calculated, stress checks in accordance with Section 3 of the AASHTO LRFD specifications is appropriate. In doing so, the stress "gains" experienced by the strands will be coupled with the precompression losses in the concrete that surrounds the strands. In this context, and to be clear about the requirements included in the AASHTO LRFD specifications, we must recall the revisions made to the specifications in the 2016 interim. The commentary provided for article 3.4.1 of the 2016 interim gives a clear explanation on when/where to use load factors of 0.8 and 1.0. For readers' convenience the table adapted from the specifications (Table 3.4.1-4 of the 2016 interim) is included in this article as the table above.

As discussed in this article, a designer can choose from several paths when running stress calculations. While all techniques are in compliance with AASHTO LRFD specifications, they may or may not be permitted by a particular state in new designs. For load-rating purposes, the benefits of a more refined analysis are clear, and, as we move forward, running such a refined analysis may help us better understand the actual bridge behavior.

References

1. Brice, Richard, Bijan Khaleghi, and Stephen J. Seguirant. 2013. "Evaluation of Common Design Policies for Precast, Prestressed Concrete I-Girder Bridges." *ASPIRE* Winter 2013: 10-11.
2. AASHTO (American Association of State Highway and Transportation Officials). 2017. *AASHTO LRFD Bridge Design Specifications*. 8th ed. Washington, DC: AASHTO (and earlier editions as appropriately referenced within the article).
3. Wassef, W.G., J.M. Kulicki, H.H.Nassif, A.S. Nowak and D.R. Mertz 2014. *Calibration of LRFD Concrete Bridge Design Specifications for Serviceability*, report on NCHRP 12-83 (in progress), Transportation Research Board, National Research Council, Washington, DC.