Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory

by Dr. Lubin Gao, Federal Highway Administration, and John Holt, Modjeski and Masters

Bridge engineers have faced technical challenges when applying the shear provisions in the American Association of State and Highway Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] to conduct shear load rating for existing concrete bridges designed to older standards. The *Concrete Bridge Shear Load Rating Synthesis Report* published in 2018 by the Federal Highway Administration (FHWA), documented the challenges.[2] The report found that bridge load-rating engineers needed more information on how the shear resistance is determined when the amount of either longitudinal tension or shear reinforcement is less than that specified in the current modified compression field theory (MCFT) design provisions for new design. In particular, example calculations were needed to demonstrate procedures to apply the MCFT. (For further information on the synthesis report, see the FHWA column in the Fall 2019 issue of *ASPIRE*®.)

Consequently, in April 2022, FHWA published FHWA-HIF-22-025, *Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory*.[3] The focus of this guide is the MCFT, which is not included in any editions of AASHTO's *Standard Specifications for Highway Bridges*. The guide comprises six chapters that can be grouped into three major sections:

- Technical procedures and validation against test data
- Application of the MCFT with the load and resistance factor rating (LRFR) method
- Examples that illustrate the application of the MCFT in shear load ratings of common bridge types

Technical Procedures and Validation

A comprehensive literature search and review was conducted to supplement the 2018 synthesis report. This review identified a 2019 paper by Caprani and Melhem,[4] which confirms that an iterative procedure is necessary to establish consistency between the load effects and capacities when estimating the shear capacity of existing girders with the MCFT. This paper also demonstrates the difference between design and load rating. For design, applied loads including design live load (HL-93) are known and unchanged. For load rating, the live load varies, and the peak resistance is to be determined through the load-rating analysis. Therefore, because the shear resistance is related to the applied loads, iteration will converge to the actual capacity for a particular type of live-load configuration (that is, axle weight [as a percentage of the gross vehicle weight] and spacings).

Choi et al.[5] further demonstrates the iterative procedure for assessment of shear capacity of concrete members. Because many old concrete bridges do not have the threshold amount

Table 1. History of the American Association of Highway and Transportation Officials' (AASHTO's) adoption of the modified compression field theory for shear

Year	Notable Change to Concrete Shear Design	Specifications
1994	• Modified compression field theory is introduced. • Tables and iterations are needed for θ and β. • Strain ε_s is calculated at middepth or at maximum strain location in the web. • Minimum shear reinforcement increased about 50% over the AASHTO *Standard Specifications for Highway Bridges* (2002).	*AASHTO LRFD Bridge Design Specifications*, 1st ed.
2007	• An alternate method called the simplified method is introduced. It requires the evaluation of two nominal concrete shear resistances: the shear resistance when inclined cracking results from combined shear and moment V_{ci}, and the shear resistance when inclined cracking results from excessive principal tensions in the web V_{cw}. • Load and resistance factor design (LRFD) is required for all federally funded bridge designs.	*AASHTO LRFD Bridge Design Specifications*, 4th ed.
2008	• Closed-form solution is provided (iteration is no longer needed). • Strain ε_s is calculated at tension reinforcement.	*AASHTO LRFD Bridge Design Specifications*, 4th ed. Interim Revisions
2010	• LRFD is required for all bridge designs.	
2017	• Alternate method (the simplified method) is removed.	*AASHTO LRFD Bridge Design Specifications*, 8th ed.

Source: Federal Highway Administration.

of reinforcement to use the MCFT procedure without reduction to compute the shear resistance, test data from University of Texas Prestressed Concrete Shear Database were used in the study to investigate size effect (the shear strength of reinforced and prestressed concrete members with insufficient web reinforcement typically decreases as the member depth increases) and the effect of shear reinforcement. The study showed the following:

- In areas of low strain where the section remains uncracked at the strength limit state (that is, where $M_u < M_{cr}$), the strain ε_s may be assumed to be zero; therefore, the angle of inclination of diagonal compressive stresses θ can be taken as 29 degrees.
- For reinforced concrete members with web reinforcement less than the minimum value, such that $A_v < A_{v,min}$, the β factor, which indicates the ability of diagonally cracked concrete to transmit tension and shear, should be adjusted for the size effect. For prestressed concrete beams, if f_{pc} / f'_c is greater than or equal to 0.02, regardless of the amount of shear reinforcement, the size effect may be neglected.

In load-rating analysis, it is important to use concurrent load effects to avoid being overly conservative, which may lead to undue load restriction. In addition, all possible combinations of load effects are to be addressed at a section under consideration. For example, maximum shear with concurrent moment, maximum moment with concurrent shear, minimum (or maximum negative) shear with concurrent moment, and minimum (or maximum negative) moment with concurrent shear should be considered.

Application of the MCFT with LRFR

Chapter 4 of the new FHWA guide concerns how to appropriately apply the MCFT in shear load rating of concrete bridges. It discusses major items that engineers should consider, for example, selection of critical sections, cross-section dimensions for shear, and load-rating expedients. It further illustrates the procedure developed in the first section. A flowchart is included to demonstrate the process to determine shear capacity by the MCFT method and as controlled by the amount of longitudinal reinforcement.

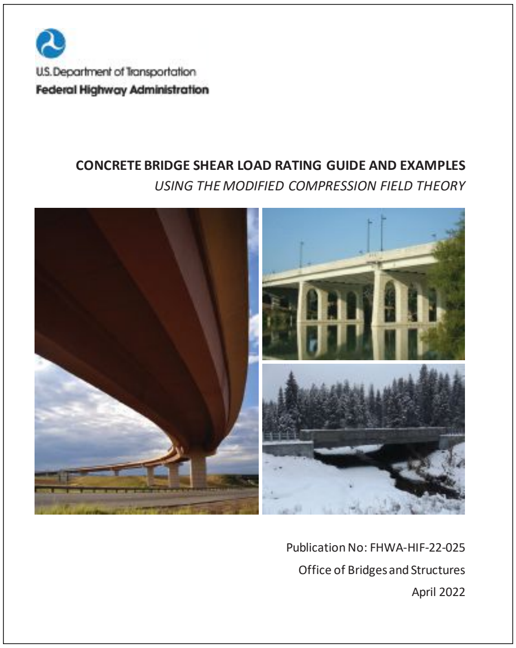
The guide also discusses a horizontal shear failure mode that has been observed at the ends of prestressed girders in laboratory tests.[6] This failure mode occurs at the flange-to-web interface, especially in modern cross sections with thin webs and large flanges that provide optimal cross-section efficiency for flexure but not necessarily for shear. It may also happen if deterioration exists at that interface. The guide also includes a flowchart that demonstrates the process to determine shear strength as controlled by horizontal shear.

Examples

The FHWA guide provides three complete shear load-rating examples:

- Example 1 is for an interior girder of a 47-ft simple-span bridge consisting of five prestressed concrete I-girders that was built in 1972.
- Example 2 is for an interior girder of a three-span (44 ft, 59 ft 6 in., 46 ft) continuous cast-in-place (CIP) reinforced concrete girder bridge. The girders were built integrally with their interior supports and with CIP full-depth diaphragms at end supports. The bridge consists of four T-beams spaced at 7 ft 10 in. and was built in 1969.
- Example 3 is for an interior web of a two-span (128 ft, 128 ft) continuous CIP post-tensioned concrete box-girder bridge. The box consists of four cells, each with a width of 9 ft 9 in. It was built in 1969.

For each example, critical sections are selected and rated for shear at design load-rating levels, both inventory and operating. These examples illustrate the shear load-rating procedure using the MCFT and LRFR developed and detailed in the earlier chapters of the guide.



References

1. American Association of State Highway and Transportation Officials (AASHTO). 2017. *AASHTO LRFD Bridge Design Specifications*, 8th ed. Washington, DC: AASHTO.
2. Holt, J., U. Garcia, S. Waters, C. Monopolis, A. Zhu, O. Bayrak, L. Powell, K. Halbe, P. Kumar, and B. Chavel. 2018. *Concrete Bridge Shear Load Rating Synthesis Report*. FHWA-HIF-18-061. Washington, DC: Federal Highway Administration (FHWA). https://www.fhwa.dot.gov/bridge/loadrating/pubs/hif18061.pdf.
3. Holt, J., O. Bayrak, P. Okumus, A. Stavridis, T. Murphy, D. Panchal, A. Dutta, and A. Randiwe. 2022. *Concrete Bridge Shear Load Rating Guide and Examples Using the Modified Compression Field Theory*. FHWA-HIF-22-025. Washington, DC: FHWA. https://www.fhwa.dot.gov/bridge/loadrating/pubs/hif22025.pdf.
4. Caprani, C. C., and M. M. Melhem. 2019. "On the Use of MCFT per AS 5100.5 for the Assessment of Shear Capacities of Existing Structures." *Australian Journal of Structural Engineering* 21 (1): 53–63. https://doi.org/10.1080/13287982.2019.1664207.
5. Choi, J., J. Zaborac, and O. Bayrak. 2021. "Assessment of Shear Capacity of Prestressed Concrete Members with Insufficient Web Reinforcement Using AASHTO LRFD General Shear Design Procedure." *Engineering Structures* 242: 112530. https://doi.org/10.1016/j.engstruct.2021.112530.
6. Hovell, C., A. Avendano, A. Moore, D. Dunkman, O. Bayrak, and J. Jirsa. 2013. *Structural Performance of Texas U-Beams at Prestress Transfer and Under Shear-Critical Loads*. FHWA/TX 13/0-5831-2. Austin, TX: Center for Transportation Research. https://library.ctr.utexas.edu/ctr-publications/0-5831-2.pdf.