A Synthesis Report on Concrete Bridge Shear Load Rating

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Of the 615,000 bridges in the National Bridge Inventory, approximately 42% are reinforced concrete and 25% are prestressed concrete structures, based on the material of the main span superstructure. Load rating concrete bridges for shear allows the owner to determine how to manage and operate them; however, doing this appropriately is challenging. One of the significant challenges is how to apply modern design standards to bridges that were designed to past design specifications.

History of Specifications

The history of bridge design standards includes both gradual evolution and periodic significant changes. In 1931, the American Association of State Highway Officials published the first edition of the *Standard Specifications for Highway Bridges* (ASD). In 1973, the organization, renamed the American Association of State Highway and Transportation Officials (AASHTO), incorporated load factor design (LFD) into the 11th edition of the specifications. In 1994, AASHTO published its first reliability-based load and resistance factor design (LRFD) bridge design specifications. In 2017, the 8th edition of the *AASHTO LRFD Bridge Design Specifications* was released.

Over this period, the design live loading, primarily truck loadings, has changed from the earliest notional truck loading, identified as H20 and H15 for most roadways or H10 for low-volume roadways, to the current HL-93 notional truck loading used in the AASHTO LRFD specifications. In addition, the design processes for application and distribution of live loads to supporting members have evolved from the simplified girder spacing–to–partial lane dimension ratio (S/D) to the current sophisticated distribution formulas in the AASHTO LRFD specifications.

Shear design provisions have also undergone significant changes through the years. **Table 1** summarizes those changes and the applicable

Table 1. Evolution of concrete shear design requirements in American Association of State Highway Officials (AASHO) and American Association of State Highway and Transportation Officials (AASHTO) bridge design specifications

Year	Notable Concrete Shear Design Change	Specifications
1931	Upper shear unit stress limits implemented.	*AASHO Standard Specifications*, 1st ed.
1935	Reinforcing steel and bond unit stress limits added.	*AASHO Standard Specifications*, 2nd ed.
1941	Shearing unit stress formula and required shear reinforcement formula introduced.	*AASHO Standard Specifications*, 3rd ed.
1944	Allowable concrete and bond unit stresses modified to be a function of the concrete ultimate strength.	*AASHO Standard Specifications*, 4th ed.
1961	Prestressed concrete design provisions using LFD methods introduced.	*AASHO Standard Specifications*, 8th ed.
1965	The required shear reinforcement formula adjusted to optimize reinforcement capacity at an angle of inclination of 45 degrees.	*AASHO Standard Specifications*, 9th ed.
1971	Minimum shear reinforcement area modified to accommodate high-strength (60 ksi) reinforcement.	Interim revisions to *AASHTO Standard Specifications*, 10th ed.
1979	Refined equations introduced to more accurately calculate shear stress in concrete members.	Interim revisions to *AASHTO Standard Specifications*, 12th ed.
1980	LFD shear design equation for prestressed concrete introduced.	Interim revisions to *AASHTO Standard Specifications*, 12th ed.
1989	Shear provisions for concrete segmental bridges introduced.	*AASHTO Guide Specifications for Design and Construction of Segmental Bridges*, 1st ed.
1994	Strut-and-tie method included in concrete bridge design specification.	*AASHTO LRFD Bridge Design Specifications*, 1st ed.
1998	Updated concrete shear strength equation provided.	Interim revisions to *AASHTO Manual for Condition Evaluation of Bridges, 2nd ed.*
2005	Segmental concrete bridge shear provisions adopted.	Interim revisions to *AASHTO LRFD Bridge Design Specifications*, 3rd ed.
2007	Simplified shear calculation procedure for prestressed and non-prestressed concrete sections provided.	*AASHTO LRFD Bridge Design Specifications*, 4th ed.
2008	Sectional design model revised to provide a noniterative method for the determination of β and θ factors.	Interim revisions to *AASHTO LRFD Bridge Design Specifications*, 4th ed.
2016	Strut-and-tie procedure modified.	Interim revisions to *AASHTO LRFD Bridge Design Specifications*, 7th ed.

specifications for changes in shear design of concrete bridges.

As a companion to its bridge design specifications, AASHTO has developed a bridge load rating manual, the *Manual for Bridge Evaluation* (MBE), which is now in its third edition. The current MBE includes the following provisions for shear load rating of concrete bridges:

Part 6A.5 addresses load and resistance factor rating for concrete structures:

- Article 6A.5.8—Evaluation for shear
- Article 6A.5.11—Rating of segmental concrete bridges
- Article 6A.5.11.4—Design-load rating
- Articles 6A.5.11.5.1—Service limit state legal load rating
- Article 6A.5.11.5.2—Service limit state permit load rating
- Article 6A.5.11.7—Evaluation for shear and torsion

Part 6B.5 addresses nominal capacity for allowable stress rating and load factor rating:

- Article 6B.5.2.4.3—Allowable stress method for concrete shear (diagonal tension)
- Article 6B.5.3.3—Load factor method for prestressed concrete

Rating a concrete bridge for shear is challenging and complicated because of the many changes to standards that have been made over time, as well as the multiple procedures in the current specifications. When an existing concrete bridge is load rated using a method that is different from the method used to design the bridge, it is difficult to assess the actual margin of safety.

Synthesis Report

In July 2017, the Federal Highway Administration (FHWA) started work to develop a synthesis report that compiles the technical aspects of shear load rating for concrete bridges that are difficult for owners to assess. A critical review of relevant specifications, technical literature, and transportation agency and industry practices and experiences was performed for the synthesis report. The review investigated the specifications and provisions related to shear design and shear load rating for concrete bridges specified in the current and previous editions of AASHTO design specifications and the MBE.

A survey of selected state departments of transportation was conducted to help define challenges that need to be addressed in the review. In the survey, states reported that the current general shear procedure using modified compression field theory (MCFT) in the AASHTO LRFD specifications occasionally gives a lower shear capacity for existing post-tensioned box girders than the procedure described in Section 5, Appendix B5, of the AASHTO LRFD specifications. Some states also found that shear may govern the load rating for some existing concrete bridges with no visible sign of shear distress. Another finding from the survey was that shear load rating for the HL-93 notional live load does not correlate with the shear load ratings for legal and permit loads. States reported that for some existing concrete bridges, shear load rating controls when applying the LFRD MCFT for permit loads, which may require more stringent restrictions. They also found that for certain legal loads, the shear load rating controls and a bridge may require load posting.

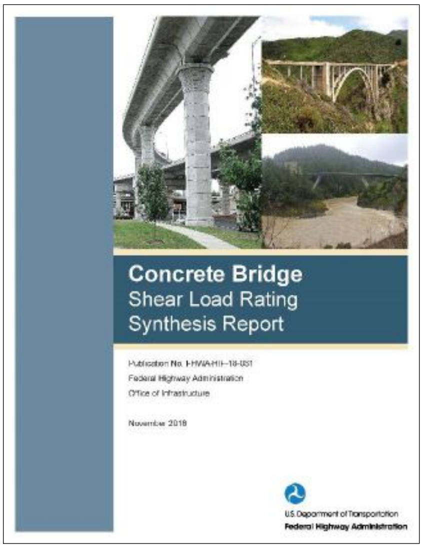
The final FHWA report,[1] which was published in November 2018, includes a history of changes in shear design provisions in AASHTO design specifications and the MBE. The report also summarizes states' practices and identifies the issues that states are facing in rating existing concrete bridges using the MBE shear provisions.

Further Work

Fifteen findings are identified and documented in the *Concrete Bridge Shear Load Rating Synthesis Report*.[1] Some could be addressed through modifications to the MBE or the AASHTO LRFD specifications. Other findings, such as the following, warrant further investigation or additional guidance:

- Finding 7: Correct estimation of the strain is critical for use in MCFT-based calculations.
- Finding 8: Using MCFT and the strain equations in LRFD when prestressing is on the compressive flexural side can provide incorrect and overly conservative shear strengths.
- Finding 9: MCFT-based shear strength calculations are load dependent.
- Finding 10: An existing girder not meeting minimum shear reinforcement requirements with MCFT may have its shear strength unduly penalized.
- Finding 12: Reinforcement detailing should be verified for adequacy when load rating concrete bridges in shear.

FHWA recently awarded a task order to develop improved concrete bridge shear load rating guidance and examples using the MCFT. The objectives of the work are to address the findings and pertinent recommendations in the report and provide training for bridge design and analysis engineers.



For example, based on the available shear test data set that is in the published literature,[2,3] the task-order contractor will develop methods for determining shear resistance for sections that do not meet minimum reinforcement requirements (either minimum longitudinal tension reinforcement or minimum shear reinforcement). The procedure will include how to accurately compute strain, resistance, concurrent force effects, and rating factors, including shear-moment interaction and consistency in shear resistance determination for strain and force effects. A minimum of three shear analysis examples will be developed to demonstrate the best approaches for shear assessment of concrete bridge members.

References

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