Concrete Bridge Shear Load Rating: Updates to the AASHTO *Manual for Bridge Evaluation* and Further Guidance

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Shear design procedures have evolved since the American Association of State Highway and Transportation Officials (AASHTO) first released its *Standard Specifications* in 1931. This evolution of shear design provisions has led to reinforced and prestressed concrete bridges with different section shapes and types as well as different quantities of transverse shear reinforcement. It has been challenging to load rate these structures consistently and accurately for shear.

Several recent publications have investigated the history of shear load rating and developed recommended procedures for load rating concrete structures for shear.[1–4] The recommended procedure for shear load rating uses the modified compression field theory (MCFT), which was first introduced into the *AASHTO LRFD Bridge Design Specifications* in 1994.[5]

The recent Federal Highway Adminstration (FHWA) report *Modified Compression Field Theory (MCFT) for Shear Load Rating – Pretensioned Example*[6] provides guidance on using MCFT for shear load rating of pretensioned concrete components. The report includes a summary of MCFT theory and application, possible shear failure mechanisms that may occur in pretensioned components, and a shear load rating example based on Example 9.4 from the *PCI Bridge Design Manual*.[7]

Shear Failure Mechanisms

There are three general shear failure mechanisms that may control the calculated resistance for pretensioned concrete components:

- Sectional shear resistance
- Longitudinal tension resistance
- Horizontal shear resistance

Figure 1 illustrates these three failure mechanisms. Sectional shear resistance (Fig. 1 [a]) is typically associated with a diagonal shear crack leading to either crushing of the web concrete or yielding of the transverse reinforcement and sliding along the shear crack.

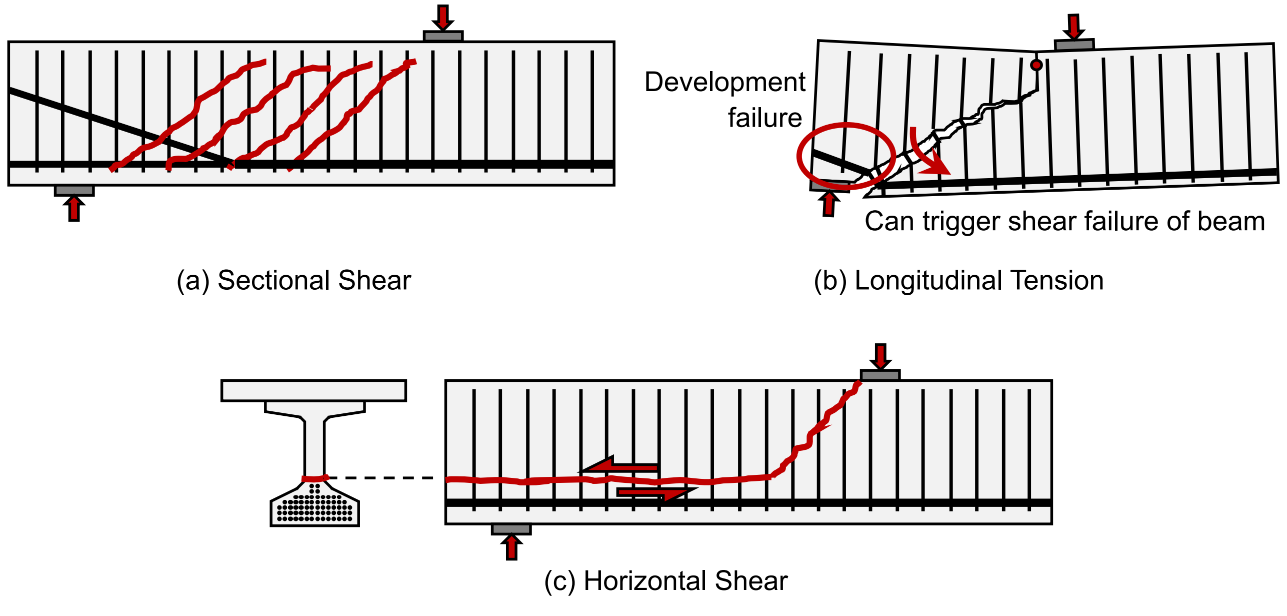
If properly developed or anchored, the longitudinal tension reinforcement will work with the transverse reinforcement to hold a diagonal shear crack closed and allow the concrete shear resistance to engage. If the amount of developed longitudinal tension reinforcement is insufficient, diagonal shear cracks can open and lead to a shear failure (Fig. 1 [b]).

Article 5.7.4.1 of the AASHTO LRFD specifications[8] states that interface shear transfer (that is, shear friction) shall be considered across a given plane at:

- *An existing or potential crack;*
- *An interface between dissimilar materials;*
- *An interface between two concretes cast at different times; or*
- *The interface between different elements of the cross section.*

Interface shear transfer in bridge design is

Figure 1. Three possible shear failure mechanisms related to modified compression field theory. All Figures: Federal Highway Administration.



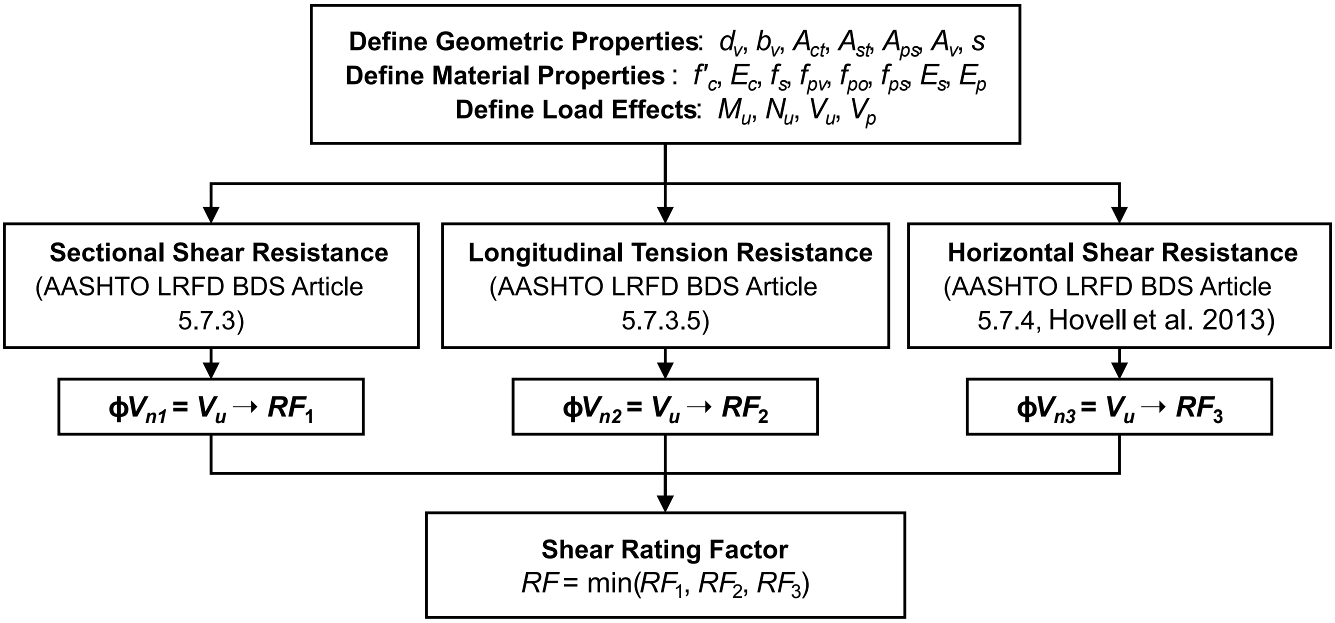


Figure 2. Flowchart for shear load rating using modified compression field theory and the procedure proposed in *Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory*.[3]

most frequently checked in relation to the interface between a cast-in-place composite concrete deck and the top flange of a precast concrete beam, but it also needs to be considered at any other sections where it may be critical. For a prestressed concrete beam, one interface that should be considered is the interface between its thin web and the heavily prestressed bottom flange (Fig. 1 [c]). This type of shear failure, called a horizontal shear failure, has been shown to control the Strength I limit state design for some U-beams and bulb-tee beams.[9,10]

While lack of sectional shear resistance may be the most common cause of shear distress observed in in-service bridges, there have also been cases of distress due to inadequate anchorage or bond of longitudinal tension reinforcement.[11,12] All three possible failure mechanisms should be considered when load rating for shear.

Shear Resistance Corresponding to Each Failure Mechanism

The overall shear resistance and associated shear rating factor *RF* are calculated considering each of the three aforementioned failure mechanisms (**Fig. 2**). The procedures for calculating the sectional shear resistance and longitudinal tension resistance are iterative as the resistance in each case is a function of the demand. A higher shear and moment demand will result in a smaller shear resistance. The shear and moment demand consist of those caused by dead loads, which will remain constant, and those caused by live loads, which can be increased. For the iterative procedures, the shear and associated moment caused by live load are increased or decreased until the calculated shear resistance is equal to the assumed shear demand. The horizontal shear resistance can be calculated directly using Article 5.7.4 of the AASHTO LRFD specifications with the modifications recommended by Hovell et al. (2013).[9] The rating factor associated with each of these failure mechanisms can be determined using the calculated shear resistance, dead-load shear, and live-load shear caused by either operating- or inventory-level loading. The minimum rating factor for the three failure mechanisms is the shear rating factor at the section of interest. This process must be repeated at multiple sections along the length of a component. More details on the procedure and a pretensioned concrete example are provided in *Modified Compression Field Theory (MCFT) for Shear Load Rating – Pretensioned Example*.[6]

Approved Revisions to the *Manual for Bridge Evaluation*

This new procedure will be reflected in the next release of AASHTO's *Manual for Bridge Evaluation* (MBE).[13] The evaluation for shear in load rating is specified in Article 6A.5.8 of the MBE and references Article 5.7.3.6.3 of the AASHTO LRFD specifications. Revisions to the MBE based on the FHWA report *Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory*[3] were approved in June 2022. The following are the primary updates to the MBE shear load rating:

- Article C6A.4.2.1 describes the iterative procedure needed for shear load rating using MCFT.
- Articles 6A.5.8 and C6A.5.8 provide additional details on how to determine the shear load rating considering the longitudinal reinforcement requirement of Article 5.7.3.5 of the AASHTO LRFD specifications. An equation is provided in the MBE commentary to calculate the rating factor based on this check.
- MBE allows two modifications to Article 5.7.3.4.2 of the AASHTO LRFD specifications, as follows:
  - ε_s may be taken as zero if $M_u \le M_{cr}$.
  - The β factor for prestressed concrete components (where $f_{pc} / f'_c \ge 0.02$) may be calculated using Eq. 5.7.3.4.2-1 of the AASHTO LRFD specifications, regardless of whether there is minimum transverse reinforcement provided.
- MBE adds a provision specifying that concurrent load effects should be used in shear load rating analyses. This means that the moment and shear used in the shear load rating should be from the same placement of the live load.

Conclusion

By considering the primary failure and resistance mechanisms, the procedure developed in *Concrete Bridge Shear Load Rating Guide and Examples: Using the Modified Compression Field Theory* improves the consistency and accuracy of shear load rating of concrete structures. Additional guidance and a pretensioned concrete example problem are provided in *Modified Com-*

pression Field Theory (MCFT) for Shear Load Rating – Pretensioned Example.

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