A REVIEW OF SHEAR RATING PROCEDURES

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ABSTRACT

A load rating analysis is typically required for new and existing bridges. For prestressed precast concrete bridges, the LFD (load factor design) procedure for stress rating, moment rating and shear rating in positive moment region is the same among different state DOTs and agencies. However, the LFD procedure for shear rating in negative moment regions is not necessarily computed in the same manner by the different state DOT's . This paper reviews the differences in the procedures for shear rating analysis in the negative moment regions. Most states use the 2002 AASHTO rating methodology in which the effect of prestressed strands is included in the shear capacity calculation. One state neglects the effect of prestressed strands in shear capacity calculation and non-prestressed reinforced concrete shear capacity is used. Another state used the modified 1979 AASHTO shear capacity for prestressed concrete members. A case study on a recent Illinois Tollway bridge project is also presented to compare the difference among several shear rating procedures. The case study suggests the selection of the shear rating procedure could impact the scope of work required and the subsequent costs associated with the rehabilitation of the prestressed concrete I-beams.

Keywords: Shear Rating**,** Prestressed Precast Concrete Beams, Girders, Bridges

INTRODUCTION

Bridges built in the 1950s and 1960s are aging, many of these bridges are deteriorating and in need of replacement or rehabilitation. Typically, a bridge inspection is completed and provides a physical evaluation of the existing bridge conditions. Based on the physical conditions and performance of the existing bridges, rational procedures are used for an analytical study of the existing bridge.

For prestressed precast concrete bridges, the LFD (load factor design) procedure for stress rating, moment rating and shear rating in positive moment region is the same among the different DOTs and agencies. However, the LFD procedure for shear rating in the negative moment region is quite different between the various DOTs. This paper reviews the different procedures for shear rating analysis. Our limited research indicates most states use the 2002 AASHTO rating methodology in which the effect of prestressed strands is included in the shear capacity calculation. Other methods used by the different state DOT's are to neglect the effects of prestressed strands in the shear capacity calculation and use a non-prestressed reinforced concrete section for the shear capacity, or, use the modified 1979 AASHTO shear capacity for prestressed concrete members to calculate the shear capacity in the negative moment region.

In this paper shear rating philosophy and procedures are discussed and a case study on a recent Illinois Tollway bridge project is presented to compare the differences among the several shear rating procedures. Our study indicates the selection of the shear rating procedure could change the scope of work for rehabilitation and affect the cost associated with the rehabilitation of a prestressed concrete I-beam bridge.

SHEAR RATING PROCEDURES

Shear in reinforced concrete is still an unresolved problem due to the complexity of the shear resistance mechanism. There still exists a wide range of opinions in explaining the shear behavior and shear resistance at the ultimate strength of a member. Research on shear transfer mechanisms can be traced back to the early 1900s. In 1899, Ritter first proposed the parallel chord truss model. The idealized parallel chord truss is composed of 45 degree diagonal compressive struts, transverse tension ties, top compression chord, and the bottom tension chord. The vertical component of the diagonal compression in this strut is equilibrated by the tension in the transverse ties.

During the last several decades, a considerable amount of research has been carried worldwide with the aim of developing complete shear behavior models. In the sequence of historical development, there are four principal models: the 45 degree truss model, the variable angle truss model, the compression field theory, and its updated version the modified compression field theory. Some of these have been implemented in codes of practice based on the validation of experimental test data. For example, the AASHTO

Standard Specifications and the ACI 318 Building Code adopt the 45^o truss model while LRFD code is based on the modified compression field theory.

For prestressed precast concrete girders, the LFD procedure for calculating the shear capacity in positive moment region is the same among different DOTs and agencies. However, the LFD procedure for shear capacity in negative moment region is quite different among several DOTs. Some of these shear capacity calculations are reviewed as follows.

SHEAR EQUATIONS FOR PRESTRESSED CONCRETE MEMBERS

AASHTO Standard Specifications 2002[1]

The nominal shear strength V_n in AASHTO Standard Specifications is computed by

$$V_n = V_c + V_s \qquad \text{e.q. (1)}$$

The shear reinforcement contribution V_s is evaluated by the 45^o truss analogy as

$$V_s = \frac{A_v f_y d}{s} \qquad \text{e.q. (2)}$$

where A_v is the area of shear reinforcement within a distance s. f_y is the yield stress of shear reinforcement. d is the distance from the extreme compression fiber to the centroid of the longitudinal tension reinforcement.

The concrete contribution to shear resistance at ultimate V_c is taken as the estimated shear force at inclined cracking. For prestressed members, the concrete contribution V_c is to be taken as the smaller of V_{cw}, the resistance to web-shear cracking, and V_{ci}, the resistance to flexure-shear cracking, as given in

$$V_{cw} = (3.5\sqrt{f_c'} + 0.3 f_{pc})b_w d + V_p \qquad \text{e.q. (3)}$$

$$V_{ci} = 0.6\sqrt{f_c'} b_w d + V_d + \frac{V_i M_{cr}}{M_{max}} \qquad \text{e.q. (4)}$$

where f'_c is the concrete strength. b_w is the width of web. f_{pc} is the precompression stress in concrete due to the effects of prestressing, V_p is the vertical component of the prestressing force, V_d is the shear force at a section due to unfactored dead load, V_i is the factored shear force at a section due to externally applied loads occurring simultaneously with $M_{\max}$, and M_{cr} is the moment causing flexural cracking at a section due to externally applied loads.

In Equation (3), V_{cw} was derived from the Mohr's circle of stress with the state of stress evaluated at the centroidal axis of the member and the tensile cracking strength of the concrete taken as approximately $4\sqrt{f_c^{'}}$. In deriving V_{ci} it was assumed that V_{ci} is the sum of the shear required to cause a flexural crack ($V_d + \frac{V_i M_{cr}}{M_{max}}$) plus an additional increment of shear required ($0.6\sqrt{f_c^{'}} b_w d$) to change a flexural crack to become a flexure-shear crack.

AASHTO Standard Specifications 1979[2]

The concrete shear strength is computed by

$$V_c = 0.06 f_c^{'} b^{'} jd \leq 180 b^{'} jd \qquad \text{e.q. (5)}$$

where jd is the distance from the slab reinforcement to the center of gravity of the compression area under ultimate loads. $b^{'}$ is the width of web.

The shear strength provided by web reinforcement is taken as:

$$V_s = \frac{2 A_v f_{sy} jd}{s} \qquad \text{e.q. (6)}$$

SHEAR RATING FOR PRESTRESSED CONCRETE MEMBERS

The prestressed force can enhance the shear capacity of prestressed member in two ways: (1) increasing the shear cracking strength and (2) causing a flatter cracking angle; thus the inclined crack crosses more stirrups. As presented above, the AASHTO Standard Specification 2002 takes higher cracking load V_c value while the 1979 equation utilizes a coefficient of 2.0 in the calculation of V_s to account for the flatter angle and increased number of stirrups crossed.

For the positive moment region, the advantages of prestress on shear capacity are uniformly accepted by all state practices. Most states follow the AASHTO Standard shear provision (V_{ci} & V_{cw} method) to account for the benefits of the prestress strands However, for shear capacity in the negative moment region, discrepancies exist among states in whether to consider the effect of the prestressed force or not. Some states neglect the effect of prestress in the negative region over the supports and treat the prestressed beam as a normally reinforced beam. It is assumed the negative moments over the supports will reduce the effects of the prestress in the beam and thus approximates the condition of a conventionally reinforced concrete beam. Listed as follows are practices in some the states policies that were reviewed:

1) Illinois[3]

Illinois DOT neglects the effects of prestress over the piers and uses the shear strength equations for non-prestressed concrete girders.

2) Missouri[4]

Missouri DOT used the 1979 AASHTO shear equation for positive moment region, but neglects the prestress effect for negative moment region by using 45 degree angle. The concrete shear strength is computed by

$$V_c = 180 b' jd \qquad \text{e.q. (7)}$$

The shear strength provided by web reinforcement is taken as:

$$V_s = \frac{A_v f_{sy} jd}{s} \qquad \text{e.q. (8)}$$

This modified shear strength, V_s, is reduced by a half of the shear strength used in the positive moment region.

3) Iowa[5]

Iowa DOT uses 2002 AASHTO shear strength equations for both positive and negative moment regions.

4) Colorado[6, 7]

Colorado DOT is using 2002 AASHTO shear strength equations for prestressed concrete girders design. When the LFD method is used for rating girders, unless a more rational methodology like the modified compression field theory in the AASHTO LRFD code is adopted for use, prestressed girders shall not be rated for shear.

CASE STUDY

In a recent Illinois Tollway rehabilitation project, a shear rating analysis was performed on two 4-span, prestressed precast concrete I-beam bridges (NB and SB bridges). The original structure or NB bridge was built in 1957 to carry local traffic over the Tri-State Tollway, I-294. The superstructure consists of a four span reinforced concrete deck supported on 48” continuous precast prestressed beams utilizing integral pier caps and expansion bearings at the abutments. In 1987 a companion structure or SB bridge was built adjacent to the original structure. It was constructed using a similar span arrangement and precast prestressed beams with expansion bearings at the abutments, pier 1 and pier 3. The NB bridge has four span lengths of 53’-3”, 86’-11”, 86’-11” and 60’-6” with a total length of 287’-7”. The SB bridge layout is similar to the NB bridge. The elevation view and the typical section of the bridge are shown in Fig. 1 and Fig. 2, respectively.

Fig. 1 Bridge Elevation

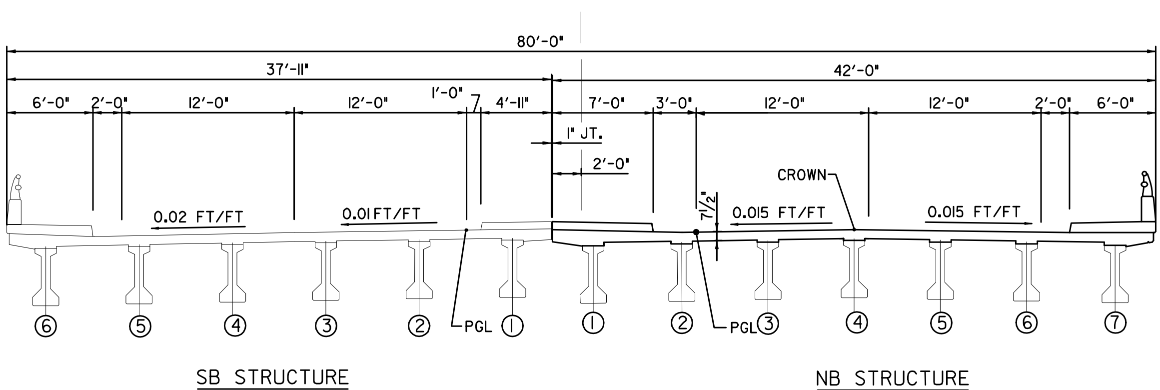

Fig. 2 Typical Bridge Section

Critical assumptions used for the rating calculations are follows:

- Future Wearing Surface (FWS) = 25 psf instead of the present IDOT standard of 50 psf
- Haunch heights were assumed to be 2" for the as-built rating calculation. The haunch was included for dead load weight and for calculating the structural capacity of the beams

- Original concrete strength of the prestressed beams 5000 psi for the northbound structure, and 6000 psi for the southbound structure; concrete strength normally increases as the concrete ages, this was not considered. The concrete strength would need to be verified via concrete cores taken from the prestressed beam webs.
- The design live load for the structures is AASHTO HS20-44

Table 1 presents the shear capacity and rating factors in negative moment region from different shear rating procedures or methods using 2002 AASHTO shear strength equations for prestressed concrete girders, shear strength equations for non-prestressed concrete girders (Illinois DOT) and modified 1979 AASHTO shear strength equations for prestressed concrete girders (Missouri DOT).

The results shown in Table 1 indicate that the 2002 AASHTO procedure yields the highest shear capacity with Illinois DOT and Missouri DOT methods producing a somewhat lower shear capacity.

Table 1 Shear Capacity and Rating Factor Comparison with Different Rating Methods

Methods	Vc (ksi)	Vs (ksi)	Vn (ksi)	IR	OR
2002 AASHTO	159.1	121.4	280.5	1.53	2.56
Illinois DOT	91.4	121.4	212.8	0.87	1.45
Missouri DOT	106.8	111.4	218.2	0.92	1.54

Note: IR and OR denote Inventory Rating and Operate Rating, respectively.

Based on the bridge inspection report that shows the existing prestressed concrete I-beams are still in good condition, four solutions were proposed to the client as follows:

1) If 2002 AASHTO rating methodology is used, shear rating is adequate. No shear strengthening is required.
2) If Illinois shear rating procedure is used, shear strengthening is required. The cost to strengthen the beams using the fiber wrap method to increase shear capacity was approximately $92,000.
3) If concrete coring samples from existing girders show existing concrete has a strength of 6000 psi as opposed to design strength of 5000 psi, no shear strengthening is required.
4) Section 7.4.1 paragraph two of AASHTO "Manual for Condition Evaluation of Bridges"[8] states; "A concrete bridge need not be posted for restricted loading when it has been carrying normal traffic for an appreciable length of time and shows no distress". However in a case like this the manual does call for frequent inspection intervals to look for signs of distress. The areas of concern should receive added attention during future inspections.

After thorough consideration and discussions with the client the AASHTO rating methodology was applied and additional construction cost was saved.

CONCLUSIONS

The LFD procedures for shear rating in the negative moment region can be different between different DOTs. This study finds the selection of the shear rating procedure to be used could change the scope of work for rehabilitation and affect the cost associated with the rehabilitation of prestressed concrete I-beams. Of course, the engineer needs to follow client's shear rating procedures and discuss any proposed variances prior to completing the final rehabilitation plans. Bottom line; if the bridge doesn't rate and the strengthening cost is high, the engineer should follow up with the client and evaluate the shear rating procedures used based on the physical conditions and performance of the existing bridges.

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