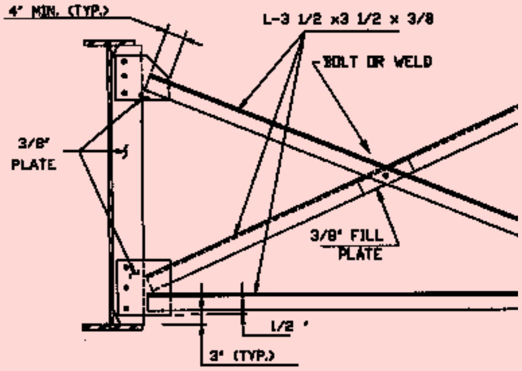

BRIDGE CROSSINGS

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Practical Information For The Bridge Industry

Bridge Fatigue Myths

By Dennis R. Mertz, P.E., Ph.D.

Categorizing Details: What if a detail experiences no applied tension?

Many times, engineers look at welded steel bridge details, either on contract drawings or on actual bridge members, and categorize the details into one of the AASHTO-specified detail categories, A through E', based merely on the detail's geometry. However, such categorization is premature. The detail must be expected to experience applied tensile stresses due to the specified design loads before they should ever be considered as a fatigue-sensitive detail and labeled as one of the ASSHTO detail categories.

This fact is inherent to all AASHTO specifications, yet even learned steel experts can become confused by information beyond that contained in the specifications. For example, knowing that residual stresses play an important role in the performance and design of fatigue-sensitive details, even experts have suggested restricting the use of what they deem to be fatigue-sensitive details, even if the detail does not experience tensile stresses due to the design loads. This misinterpretation of the specifications results because they know that residual stress due to welding are tensile near the detail.

Residual stresses are very localized. These locked-in stresses may cause cracking in a very localized region near a weld, but these cracks will not grow if the applied stresses do not include a tensile component.

With the 1974 *Interim AASHTO Specifications*, the *AASHTO Standard Specifications for Highway Bridges* no longer considered details that experienced only fluctuating comprehensive stresses for fatigue design. In *National Cooperative Highway Research Program* (NCHRP*) Report 147*, which reported on one of the research efforts that formed the basis of the interim specifications, Professor John W. Fisher of Lehigh University observed:

"Failures occurred due to destruction of the primary tension flange of all beams with details subjected to tension-tension and partial reversal of stress. Crack growth also was observed in the compression flange. However, the growth arrested after the cracks grew out of the tensile residual stress region unless there was a reversal of stress. There were no failures when the flange was subjected to compression-compression stress cycle."

In the current edition of the *Standard Specification for Highway Bridges*, 16th Edition, details to be considered for fatigue are tabularized in Table 10.3.1B. In this table, one column is defined as "Kind of Stress." Examination of this column reveals that no entry for details subjected to compressive stresses alone, only those experiencing a range of tensile stresses or reversal of stresses involving both tension and compression during the stress cycle, are considered for fatigue.

The *LRFD Bridge Design Specification*, 1st Edition, is more explicit in their description of the application of the fatigue provisions. In Article 6.6.1.2.1, the provision states: "These provisions shall be applied only to details subjected to net applied tensile stress." In other words, only if during the passage of a truck the detail is anticipated to cycle into tension due to the net applied stresses-both due to dead load and live load-is the detail considered for fatigue.

Design for Fatigue: How many cycles are enough, or is a bridge's fatigue life gone after 2 million cycles?

A typical fatigue-resistance curve, in log-log space, is shown in Figure 1. The sloping portion of the curve represents the finite-life fatigue resistance. Along this part of the curve, for a given stress range, a corresponding finite life defined by the curve is anticipated. The dashed horizontal portion of the curve represents the infinite-life fatigue resistance. If all of the stress ranges experienced by a detail are less than the stress range defined by the horizontal line, it is anticipated that the detail will not crack. The dashed horizontal portion of the curve is called the constant-amplitude fatigue threshold.

Ignoring, for the moment, the constant-amplitude fatigue threshold, the curve can be thought to

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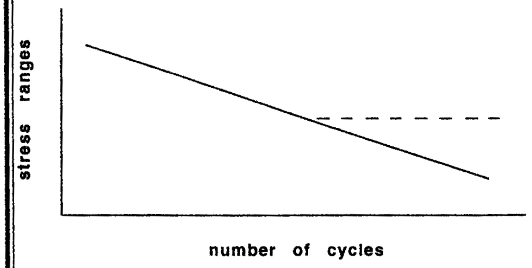

Figure 1:
Typical Fatigue-Resistance Curve

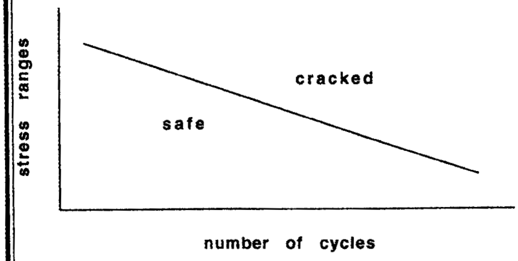

Figure 2:
Graphical Representation of Fatigue Damage

represent the locus of points of equal fatigue damage, as shown in Figure 2. Anywhere in the region to the left of the curve, the steel detail is considered safe (the term “uncracked” would not be appropriate, as all materials contain very small flaws). Anywhere in the region to the right of the curve, the steel detail is considered cracked (the term “unsafe” would not be appropriate as the cracks may be smaller than the critical size). Anywhere along the curve, the details would experience equal fatigue damage (simplistically thought of as having a crack size equal to the size used to define cracking). This equal amount of fatigue damage accumulates faster (in less numbers of cycles) at higher stress ranges, and slower end, however the damage is considered equal anywhere along the curve despite the magnitude of the stress range.

Table 10.3.1A of the *Standard Specifications* represents fatigue-resistance curves for all of the fatigue categories, A through E’. The allowable stress ranges for more than two million cycles are the constant-amplitude fatigue thresholds. The difference in the values for redundant and non-redundant bridges represent the different consequences of cracking in redundant versus non-redundant bridges. The codewriters attempted to arbitrarily increase safety against fatigue in on-redundant bridges. The allowable stresses for redundant bridges are the laboratory-derived values.

The *LRFD Specification* includes and equation to define fatigue resistance of each fatigue category (Equation 6.6.1.2.5-1). When 100,000, 500,000 and two million cycles are plugged into the general equation in the *LRFD Specification*, the allowable stress ranges for redundant bridges in the *Standard Specifications* result. Further, the constant-amplitude fatigue thresholds given in Table 6.6.1.2.5-1 of the *LRFD Specification* are equal to the allowable stress ranges for more than two million cycles in the table for redundant bridges in the *Standard Specifications*.

Thus, the specified resistance of the *Standard Specifications* and *LRFD Specification* are identical, with the exception that the *LRFD Specification* treats redundant versus non-redundant bridges differently.

The true differences between the two specifications lie on the load side of the equation. Since the curve shown in Figure 2 represents equal fatigue damage, the two specifications are comparable in their respective magnitudes of stress range and cycled yield equal fatigue damage on the curves, which are common to each specification.

The codewriters who developed the fatigue provisions of the *Standard Specifications* did not want to require that designers deal with a loading specific to fatigue. They used multiple HS20 truck and lane loads for the fatigue checks, just as these loads are used for strength considerations. Knowing that these are fictitiously high loads for fatigue, the codewriters specified that a fictitiously low number of cycles be considered for fatigue. The higher resultant stress range in conjunction with the lower that actual number of cycles results in fatigue damage comparable to the actual bridge. This fictitiously low number of cycles has led to confusion.

The codewriters who developed the fatigue provisions of the *LRFD Specification* wanted the number of cycles for the fatigue check to be realistic so bridge evaluators could better comprehend the actual remaining like of the bridge in comparison to the number of cycles used for design. Instead of designing for, say, two million cycles, the designer will consider tens of millions of cycles when designing to the *LRFD Specification*. Thus, a new load was required for fatigue: 75% of a single HS20 truck (or an HS15 truck) with a fixed rear-axle spacing of 30’. This load is representative of all the trucks that will cross the bridge during its life. Theoretically, if every truck that crossed the bridge during its life-both those heavier and those lighter than the fatigue truck-was replaced by the fatigue truck, fatigue damage equal to the actual fatigue damage would result. The stress ranges resulting from the new fatigue load, in conjunction with the higher, more realistic number of cycles, yields comparable fatigue damage as the *Standard Specifications*, yet will not lead evaluators to believe that the fatigue life is over after two million trucks have crossed the bridge.

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The mission of The National Steel Bridge Alliance (NSBA), which was formed in 1995, is to enhance the art and science of the design and construction of steel bridges. Its activities include organizing meetings, conferences and national symposia, conducting the Prize Bridge Awards competition, supporting research, developing design aids, and providing assistance to bridge owners and designers. The NSBA membership includes representatives from all aspects of the steel bridge industry.