Bridge Fatigue

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Fatigue specifications for the design of new, and evaluation of existing, highway bridges are provided by AASHTO in the *LRFD Bridge Design Specifications* (LRFD) and the *Manual for Bridge Evaluation* (MBE), respectively. Recently published NCHRP Report 721 *Fatigue Evaluation of Steel Bridges* contains the latest developments in fatigue evaluation of existing bridges.

Steel fatigue refers to localized damages caused by cyclic stresses of nominal magnitudes well below the static yield strength of the steel. Fatigue damage on steel bridges has been categorized as either load-induced or distortion-induced. Load-induced fatigue is due to the primary in-plane stresses in the steel plates that comprise bridge member cross-sections. The stresses for load induced fatigue can be directly correlated with the bridge live load using conventional design theories, and are typically calculated and checked in the fatigue design or evaluation process. Distortion-induced fatigue is due to secondary stresses in the steel plates that comprise bridge members. These stresses, which are typically caused by out-of-plane forces, can only be calculated with refined methods of analysis or measured by strain gages, far beyond the scope of a conventional bridge design or evaluation.

AASHTO fatigue specifications classify commonly used steel bridge details into fatigue Categories A, B, B', C, C', D, E and E' based on their fatigue characteristics. The "S-N curves", where S is the stress range of a constant amplitude cyclic loading and N is the number of cycles to a fatigue failure, define a lower-bound fatigue resistance for each of the categories. The S-N curves also contain a constant-amplitude fatigue threshold (CAFT) for each fatigue category. No fatigue damage is assumed to occur if the stress range from a constant-amplitude loading is below the CAFT.

For the evaluation of existing riveted bridges, AASHTO provides additional information for fatigue classification. The MBE suggests that the base metal at net sections of riveted connections of existing bridges be evaluated as Category C fatigue detail instead of Category D as specified in the LRFD for the design of new bridges, to account for the internal redundancy of riveted members. NCHRP Report 721 provides further guidelines for the fatigue resistance of tack welds and riveted connections. Tack welds are common in old riveted steel structures, and their fatigue strength has not been well-defined in previous specifications. It was suggested that tack welds of normal conditions be evaluated as a Category C fatigue detail, as opposed to Category E for "base metal for intermittent fillet welds" as defined in previous AASHTO specifications. It was also suggested that for riveted members of poor physical condition, such as with missing rivets or indications of punched holes, Category D should be used.

One of the most important issues in bridge fatigue life assessment is to determine the variable-amplitude stress range spectrum, or histogram, that the fatigue detail is subjected to, and an effective stress range that can properly represent the entire histogram for equivalent fatigue damage. The AASHTO MBE allows alternative methods for estimating load-induced stress ranges for fatigue life assessment. These methods include: simplified analysis and the LRFD fatigue truck loading; simplified analysis and truck weight from weigh-in-motion study; refined analysis and the LRFD fatigue truck loading; refined analysis and truck weight from weigh-in-motion study; and lastly, field-measured strains under actual loads. The MBE provides different load factors for estimating the effective stress range using these methods.

NCHRP Report 721 introduced a Multiple Presence Factor for adjusting the calculated effective stress range based on the AASHTO single-lane fatigue loading to account for the simultaneous presence of trucks in multiple lanes based on weigh-in-motion data.

Evaluation of load-induced fatigue includes the infinite fatigue life check and finite fatigue life estimate. Only bridge details that fail the infinite life check are subject to the more complex finite life assessment. The fatigue life of a fatigue-susceptible detail is infinite if all the stress ranges the detail experiences throughout its service life are less than the constant amplitude fatigue threshold (CAFT). NCHRP Report 721 clarified the infinite life check and recommended that $(\Delta f)_{max}$ (maximum stress range expected at the fatigue-prone detail) be taken as $2.0(\Delta f)_{eff}$ (effective stress range due to variable amplitude bridge loading) for calculated stress range due to a fatigue truck determined by a truck survey or weigh-in-motion study, or the larger value of two times field measured effective stress range or the field measured maximum stress range, unless another suitable value is justified.

NCHRP Report 721 also provided several refinements to finite fatigue life assessment, including: (1) adding an Evaluation 2 fatigue life level; (2) providing a closed form solution for the total finite fatigue life using an estimated traffic growth rate and the present $(ADTT)_{SL}$ (average number of trucks per day in a single lane); (3) introduction of Fatigue Serviceability Index for measuring the performance of a structural detail with respect to its overall fatigue resistance; and (4) providing recommended actions for varying calculated values of the fatigue serviceability index.

The general procedure for evaluating load-induced fatigue should begin with the simplest stress-range estimate allowed by AASHTO. If the detail passes the infinite life check, no further refinement is required. However, if the initial analysis suggests that the detail does not have infinite fatigue life, a refined procedure should be considered. Engineering experience has demonstrated that field strain measurement can most accurately determine live load-induced stress ranges of variable amplitude.▪

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