Post-Weld Treatments for the Service Life Extension of Existing Steel Bridges

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Summary

The problem of fatigue cracking in existing steel bridges is becoming an increasingly important one due to the natural aging of these structures, as well as the increasing traffic loads and volumes to which they are being subjected. One possible method of rehabilitating structures such as these that has received recent attention is the use of residual stress-based post-weld treatments, such as needle, hammer, or ultrasonic peening. Herein, a strain-based fracture mechanics model for predicting the effects of these treatments is presented and validated using the results of a test-based study. This model is thought to be particularly well suited for predicting the effectiveness of these treatments under realistic service loading conditions. The validated model is used to study the effects of the constant amplitude loading parameters, compressive overload magnitude, and treatment timing (i.e. before or after dead load introduction) on the treatment benefit.

Keywords: Steel bridges; Rehabilitation; Fatigue; Post-weld treatments; Residual stresses.

1. Introduction

Residual stress-based post-weld treatments such as needle, hammer, and ultrasonic peening offer a novel and promising means for extending the service lives of existing steel bridges. Although their effectiveness has been demonstrated in a number of studies, several issues related to these treatments remain unaddressed, and have thus slowed their adoption by authorities responsible for bridge maintenance. Among the most important of these are: 1) a lack of quantitative means for controlling the quality of the treatment work once it is completed, and 2) a lack of certainty in the treatment benefit, in particular under actual service loading conditions.

Only a few studies have been performed to date to examine the effectiveness of peening treatments under variable amplitude loading. According to these studies, the treatment benefit may be reduced under certain variable amplitude load histories.

Herein, a short test-based study of needle peened welds under various loading conditions is presented. The results of this study are then used to validate a strain-based fracture mechanics model. Unlike the more conventional linear elastic (LEFM) models, this approach implicitly considers nonlinear material effects. The use of such a model is thought to be necessary to predict the effectiveness of peening treatments under realistic service loading conditions that include (for example) periodic compressive overloads. The validated model is used to study the effects of a number of loading parameters on the treatment benefit.

2. Summary of Main Results

Using the validated strain-based fracture mechanics model, the following studies were performed: a constant amplitude (CA) loading study, wherein the applied stress range, ΔS, and ratio, R, were varied, a variable amplitude (VA) loading study wherein the overload magnitude, S_{ol}, was varied, and a CA loading study to examine the effects of treatment timing.

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The results from these studies are presented in Figs. 1 and 2. Looking at the S-N plot on the left in Fig. 1, it can be seen that as the stress ratio is increased from -1 to 0.5, the effect on the predicted S-N curves for the untreated welds is relatively minor. However, increasing the stress ratio results in a significant reduction in the fatigue life increase for the treated welds.

In the second study, a VA stress history containing 10 compressive overloads every 1000 cycles was examined. For this study, the CA stress ratio was held constant, and the overload magnitude was varied, as a fraction of the material flow stress, $\sigma_0 = (F_y + F_u) / 2$. Looking at the resulting S-N plot on the right in Fig. 1, it is seen that compressive overloads equal to 25% of σ_0 have little effect on the treatment benefit. For larger overloads, the treatment benefit is seen to diminish.

In the third study, rather than adding the applied stress distribution to existing the residual stresses, effectively modelling treatment of the weld prior to erecting the structure, the residual stress due to the treatment was superimposed after the introduction of the mean applied stress level, thereby simulating a case of "field treatment". In this case it is expected that better results may be obtained, since the compressive treatment stresses will effectively negate any tensile dead load stresses near the surface of the treated weld (see Fig. 2). Comparing Fig. 1 (left) and Fig. 2 (right), it can be seen that the "treatment timing" has no effect at R = -1.0 in this analysis. This is expected, since the mean stress is zero in this case. For the higher stress ratios, on the other hand, the treatment benefit is seen to improve for the field treatment case. Essentially, the stress ratio ceases to have an effect, and the treatment benefit for all stress ratios is the same as for R = -1.0.

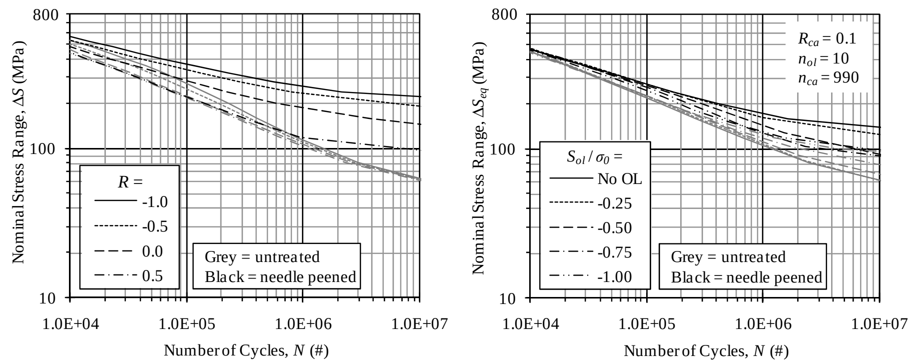

Fig. 1: Results of CA (effect of R) and VA (effect of S_{ol}) loading studies

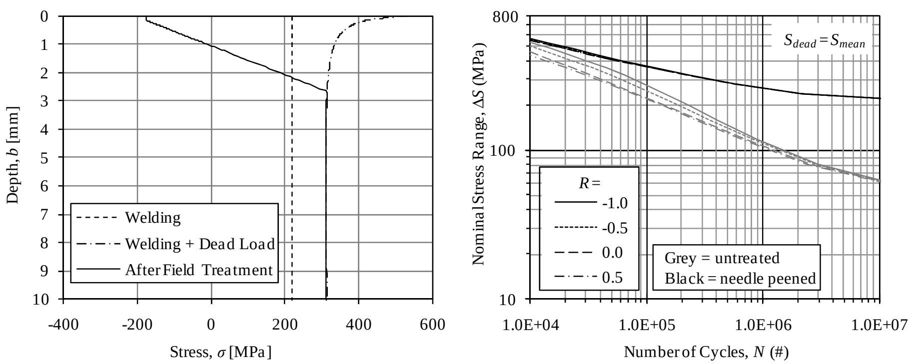

Fig. 2: Assumed initial elastic stress distributions and S-N curves for field treatment study