Application of Multiaxial Sequential Law to Estimate Secondary Stress Based-Fatigue Life of Riveted Connections

P.B.R. Dissanayake[1*] and S.A.S.C. Siriwardane[2]

[1]Department of Civil Engineering, Faculty of Engineering, University of Peradeniya
[2]Department of Civil & Environmental Engineering, Ehime University, Japan

Introduction

The secondary stress effect in riveted connections between the primary members of bridges was found to be one of the main reasons for fatigue damage. Present approaches, which are generally used to predict such fatigue damage, are based on a combination of secondary stress histories, effective stress with Miner's rule and code provided fatigue curve. But under many variable amplitude loading conditions, Miner's predictions have been found to be unreliable since it does not properly take the loading sequence effect into account. Therefore, a new damage indicator-based sequential law was recently developed to capture the loading sequence effect of variable amplitude loads (Mesmaque *et al.*, 2005). The main objective of this study is to estimate the fatigue life of a riveted connection using this multi-axial sequential law.

A new damage indicator based-sequential law

Suppose a structural component is subjected to a stress σ_i for n_i number of cycles at load level i and N_i is the corresponding fatigue life (see Figure 1). The residual life at load level i can be obtained as $(N_i - n_i)$. The stress $\sigma_{(i)eq}$ is the i^{th} level damage stress. Hence, the new damage indicator is given by;

$$D_i = \frac{\sigma_{(i)eq} - \sigma_i}{\sigma_u - \sigma_i} \quad (1)$$

Where, σ_u is the intercept of the Wöhler curve with the ordinate at one-quarter of first fatigue cycle. The same damage is then transformed to load level $i+1$.

$$D_i = \frac{\sigma_{(i)eq} - \sigma_i}{\sigma_u - \sigma_i} = \frac{\sigma'_{(i+1)eq} - \sigma_{i+1}}{\sigma_u - \sigma_{i+1}} \quad (2)$$

Where, $\sigma'_{(i+1)eq}$ is the damage equivalent stress at the level $i+1$. Thus, $N'_{(i+1)R}$ can be obtained from Figure 1. σ_{i+1} is the applied stress at the level $i+1$ and suppose that it is subjected to $n_{(i+1)}$ number of cycles. Then the corresponding residual life at load level $i+1$ is $N_{(i+1)R} = N'_{(i+1)R} - n_{(i+1)}$. The cumulative damage at load level $i+1$ is defined as,

$$D_{(i+1)} = \frac{\sigma_{(i+1)eq} - \sigma_{i+1}}{\sigma_u - \sigma_{i+1}} \quad (3)$$

The damage indicator is normalized to one (Di=1) at fatigue failure. The effective stress, which characterizes the deformation of the material, is then used to enter a uni-axial S-N curve to determine the damage indicator Di of the sequential law for multiaxial stress state.

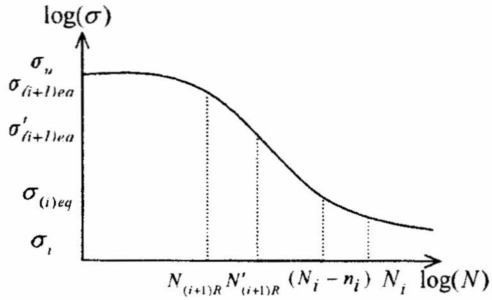

Figure 1. Schematic representation of parameters in Wöhler curve

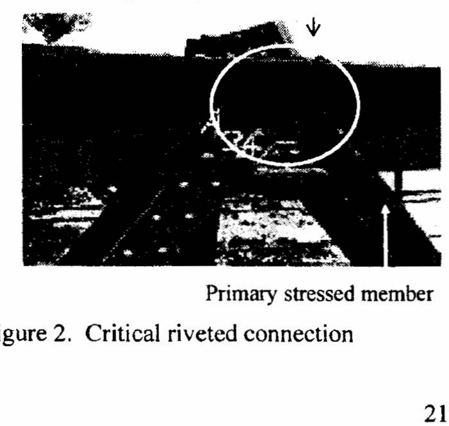

Figure 2. Critical riveted connection

Considered connection

A riveted connection was selected in a highly stressed member, which was found from the detailed investigation of one of the longest railway bridges in Sri Lanka. The selected connection is shown in Figure 2.

Secondary stress evaluation

The critical member without rivets was considered for analysis (Figure 3). The actual air gap restraint conditions were applied to represent the unilateral contact between rivet and plate. The measured uniform tensile stress history of the member was used as the external load. The obtained von Mises stress histories (Figure 4) obtained are converted to stress ranges using the reservoir counting method (Network Rail, 2001).

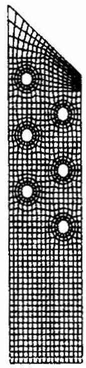

Figure 3. FE mesh

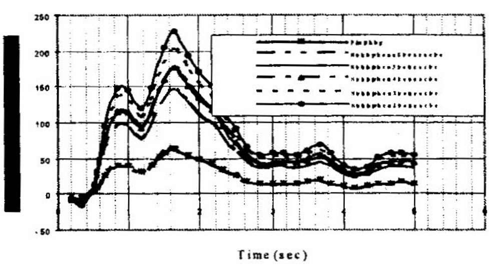

Figure 4. The von Mises stress histories at critical locations due to heaviest rail traffic

Determination of fatigue curve

The obtained mean *S-N* curve obtained from the assessment code (Network Rail, 2001) was transformed into a fully known Wöhler curve by using Kohout and Vechet Wöhler curve modeling technique as in Figure 5.

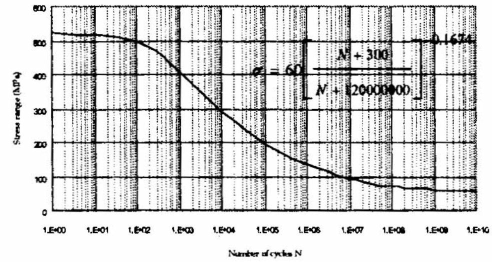

Figure 5. The Wöhler curve for wrought iron

Fatigue life estimation

The new damage indicator based sequential law in multiaxial fatigue was utilized to obtain a more realistic service life for the riveted connection..

Comparisons and discussions

The proposed method-based estimated fatigue lives were compared with two other previous approaches. Previous approach 1 (Imam *et al.*, 2007) is based on combination of secondary stress histories, effective stress with Miner's rule and railway code provided mean fatigue curve. Previous approach 2 (Alampalli and Lund, 2006) is based on combination of primary stress histories, Miner's rule and code given modified fatigue curve (using the stress concentration factors). The comparisons reveal that results based on the proposed method deviate from previous approaches and it show less residual fatigue lives than other predictions. Finally, the study indicates that the sequential law-based proposed approach gives more realistic residual fatigue life of riveted bridge connections where the detailed stress histories are known.

References

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