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Remaining Fatigue Life Assessment of a Riveted Bridge Connection

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1. Introduction

The secondary stress effect in riveted connections between the primary members of bridges was found to be one of main reasons for fatigue damage. Therefore it is important to investigate accurately the fatigue damage due to secondary stresses at the riveted connections of existing railway bridges. The most of approaches were based on combination of secondary stress histories, equivalent effective stress with Miner's rule and railway code provided mean fatigue curve. The Miner's rule has always been acknowledged as a simplification that is easy to use in design where detailed loading history is unknown. But under many variable amplitude-loading conditions, life predictions have been found to be unreliable since it did not properly take into account the loading sequence effect (Mesmaque et al., 2005). Therefore, it is uncertain to use the Miner's rule for remaining fatigue life estimation of railway bridges because most of the railway bridges are subjected to variable amplitude loadings. Recently, a new damage indicator-based sequential law (Mesmaque et al., 2005) was developed to capture the loading sequence effect of variable amplitude loads more precisely. Therefore main objective of this paper is to estimate remaining fatigue life of a riveted railway bridge connection due to the effect of secondary stresses using sequential law.

2. A New Damage Indicator based -Sequential Law

A new damage indicator based sequential law is used to obtain a more realistic fatigue life for bridges.

Suppose a part is subjected to a certain stress amplitude or stress range σ_i for n_i number of cycles at load level i and N_i is the fatigue life corresponding to σ_i. The residual life at load level i can be obtained as (N_i-n_i). The stress $\sigma_{(i)eq}$ which corresponds to the failure life (N_i-n_i) is named as i^{th} level damage stress amplitude or stress range. Hence, the new damage indicator, D_i is stated as,

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

where σ_u is the intercept of the Wöhler curve with the ordinate at one-quarter of first fatigue cycle (see Fig 1).

The same damage is then transformed to level $i+1$,

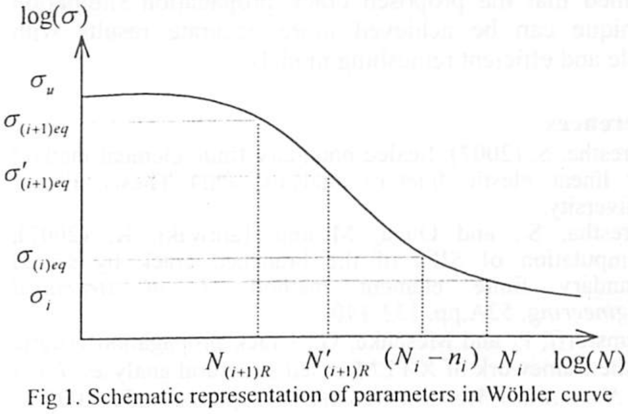

Fig 1. Schematic representation of parameters in Wöhler curve

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

Further simplification of Eq. (2), gives

$$\sigma'_{(i+1)eq} = D_i(\sigma_u - \sigma_{i+1}) + \sigma_{i+1} \quad (3)$$

where $\sigma'_{(i+1)eq}$ is damage equivalent stress amplitude or stress range at the level $i+1$. Thus the corresponding equivalent number of cycles to failure $N'_{(i+1)R}$ can be obtained from the Wöhler curve (Fig 1) σ_{i+1} is the amplitude or range of 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 the load level $i+1$, $N_{(i+1)R}$ is calculated as,

$$N_{(i+1)R} = N'_{(i+1)R} - n_{(i+1)} \quad (4)$$

Hence damage stress amplitude or stress range $\sigma_{(i+1)eq}$, which corresponds to $N_{(i+1)R}$ at load level $i+1$, can be obtained from the Wöhler curve. Then cumulative damage at load level $i+1$ is defined as,

$$D_{(i+1)} = \frac{\sigma_{(i+1)eq} - \sigma_{i+1}}{\sigma_u - \sigma_{i+1}} \quad (5)$$

The damage indicator is normalized to one (D_i=1) at the fatigue failure of material and the same procedure is followed until D_i=1.

3. Extension of Sequential Law for Multiaxial Fatigue

This method basically consists of transforming cyclic multiaxial stresses into equivalent uniaxial stress (generally called as effective stress which characterizes the deformation of the material) amplitude or range, which should generate the same fatigue life as that due to the multiaxial stresses. The equivalent stress amplitude or range is then used to enter a uniaxial S-N curve to determine the damage indicator D_i of the sequential law. The usual methods for making such transformations are extensions of von Mises (octahedral shear stress) or Tresca (maximum shear stress) yield criteria for proportional loading conditions (Suresh, 1998)

4. Considered Riveted Connection of a Railway Bridge

The considered riveted connection (see Fig 2) was selected corresponding to a highly stressed member, which was found from the detailed investigation of one of the longest railway bridges in Sri Lanka. Since this connection shows the lowest remaining fatigue life of the main truss girder, it

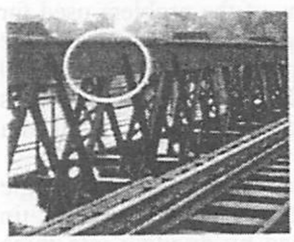
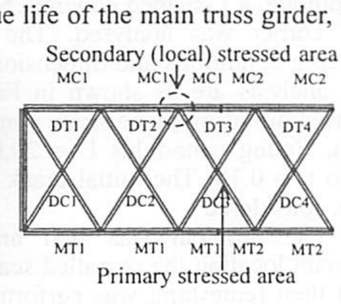

Fig 2. Critical riveted connection

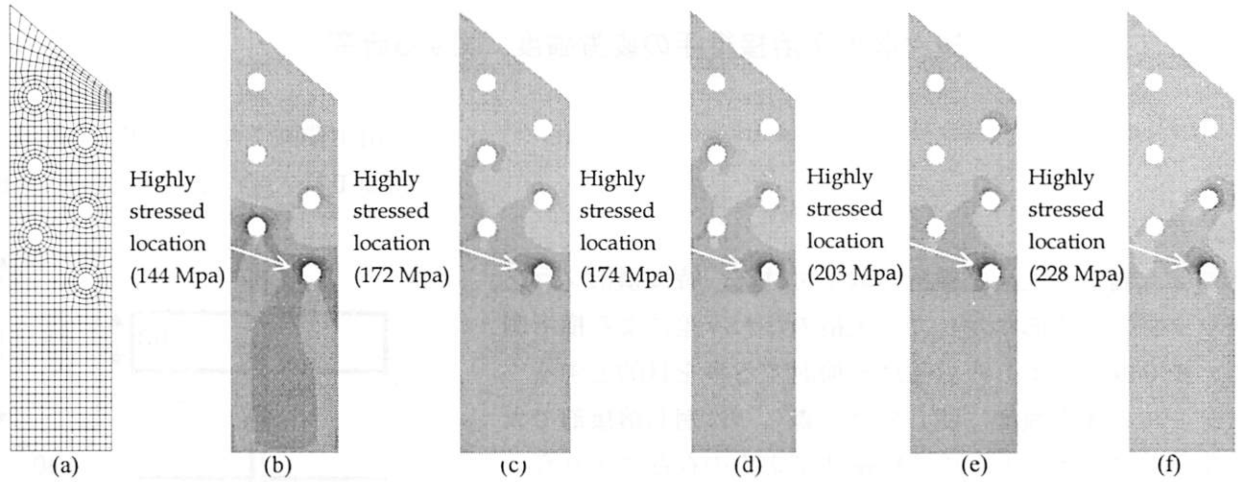

Fig 3. (a) Fine FE mesh (b) Maximum von Mises stress contour when all six rivets are active (c) Maximum von Mises stress contour when five rivets are active (d) Maximum von Mises stress contour when four rivets are active (e) Maximum von Mises stress contour when three rivets are active (f) Maximum von Mises stress contour when two rivets are active

was introduced as critical connection of the truss.

5. Remaining Fatigue Life Evaluation

The life evaluation mainly consists of secondary stress evaluation, determination of fully known Wöhler curve and application of sequential law. The fatigue damage is evaluated based on a criterion called critical state of stress due to release of contactness of rivet while all the rivets have low clamping force. The rivets, which carries the load, are called as active rivets. The fatigue lives were evaluated stepwise by reducing the contribution of active number of rivets in the connection.

To evaluate the so-called secondary stresses, the riveted area of the member has been subjected to further fine mesh FEM analysis using SAP 2000 general-purpose package (Fig 3). To represent the effect of no clamping forces in the rivets, the actual air gap restraint conditions were applied to represent the unilateral contact between rivet and plate. The obtained maximum stress contours are shown in Fig 35 and it shows that maximum stressed locations are subjected to elastic state of stress. Then the von Mises stress histories at critical location due to daily passage of trains were obtained. Finally, von Mises stress histories are converted in to stress ranges using the reservoir counting method.

The suitable fatigue curve for this evaluation, the mean *S-N* curve, which can be assumed to represent the case of having a low or no clamping force in the rivets, was obtained from the UK railway assessment code for

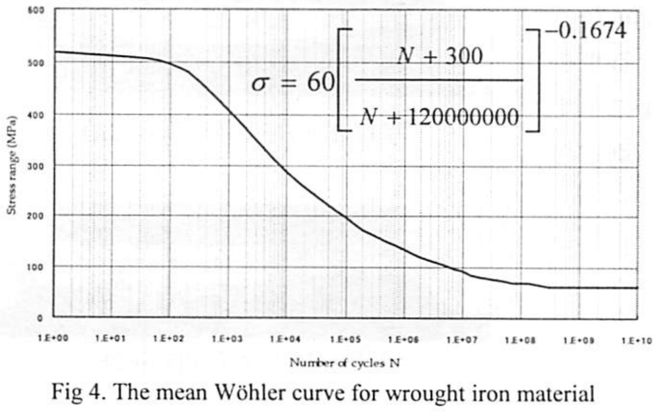

Fig 4. The mean Wöhler curve for wrought iron material

Wrought iron material. The chosen partially known Wöhler curve was transferred to fully known Wöhler curve by using Kohout and Vechet Wöhler curve modeling technique. The obtained function and the geometrical shape of the new fatigue curve are illustrated in Fig 4.

Proposed extension of sequential law for multiaxial fatigue (section 3) was utilized in this section to obtain a more realistic service life for the riveted connection. The calculated lives are shown in Table 1.

Table 1: Comparison of remaining fatigue lives

Considered feature of riveted connection	Remaining fatigue life from today (months)	
	Sequential law	Miner's rule
All six rivets are active	245	272
Five rivets are active	63	70
Four rivets are active	59	65
Three rivets are active	19.7	22.5
Two rivets are active	6.5	7.4

6. Conclusions

The estimated fatigue lives are compared with Miner's rule based-approach. The comparisons (Table 1) reveal that sequential law based-results deviate from Miner's approach and it shows less remaining fatigue life than other prediction.

The observation and the phenomenological validity of the new damage indicator-based sequential law tend to conclude that the application of the sequential law-based proposed approach gives much more realistic remaining fatigue life of riveted bridge connections where the detailed stress histories are known. The obtained function and the geometrical shape of this fully known design *S-N* curve can be employed to assess the fatigue damages of other wrought iron riveted bridges.

References

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Suresh, S., *Fatigue of materials*, 2nd ed., UK, Cambridge University Press, 1998.