I −8 Fatigue Life Prediction of Existing Railway Bridges

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1. Introduction

Many of the engineering structures in the today's world are getting old and a very large existing stock of civil infrastructures is in need of maintenance, rehabilitation or replacement, (Jung et al. 2004). Since the present condition of an existing structure is deviated from its original state, it is required to identify the proper technique so as to estimate the service lives of old bridges considering the localized changes. This paper presents, a phenomenological approach for the fatigue life estimation of existing steel or iron railway bridges.

2. Proposed Fatigue Model

The basic concept behind the proposed model is the determination of the internal state variable of material at the place where the stresses are most severe, when it is subjected to multiaxial variable amplitude loading.

In plasticity theory, (Lubliner 1990), for a material exhibiting the kinemetic hardening behavior as shown in Figure 1, the von Misses yield criteria is defined as,

$$\phi = \left(\sigma'_{ij} - \alpha'_{ij}\right)\left(\sigma'_{ij} - \alpha'_{ij}\right) - \frac{2}{3}\sigma_0^2 = 0 \tag{1}$$

where ϕ = the yield function; σ'_{ij} = the deviatoric stress tensor ; α'_{ij} = the deviatoric component of back stress tensor ; and σ_0 = the initial yield stress in uniaxial tension.

For continued yielding beyond the initial yielding, the consistency condition in plasticity defines,

$$d\phi = 2\left(\sigma'_{ij} - \alpha'_{ij}\right)d\sigma'_{ij} - 2\left(\sigma'_{ij} - \alpha'_{ij}\right)d\alpha'_{ij} = 0 \tag{2}$$

When the plastic flow is assumed to be associated, the incremental plastic strain is found for an increase of load in the plastic region from the Drucker's normality condition and it is mathematically described as,

$$d\varepsilon_{ij}^{p} = d\lambda\left(\frac{\partial\phi}{\partial\sigma'_{ij}}\right) \tag{3}$$

where $d\lambda$ = the plastic multiplier; and $d\varepsilon_{ij}^{p}$ = the incremental plastic strain.

In two surface plasticity theory, (Lubliner et al. 1993), the hardening of the loading surface depends upon the distance vector as shown in Figure 1. Hence the hardening rule for a non-linear kinematic hardening material is proposed as,

$$d\alpha'_{ij} = A\,d\lambda\,\mu'_{ij} \tag{4}$$

$$\mu'_{ij} = \left(\sigma^{*'}_{ij} - \sigma'_{ij}\right) \tag{5}$$

where μ'_{ij} = the distance vector; A = the hardening parameter; and $\sigma^{*'}_{ij}$ = the ultimate deviatoric stress tensor.

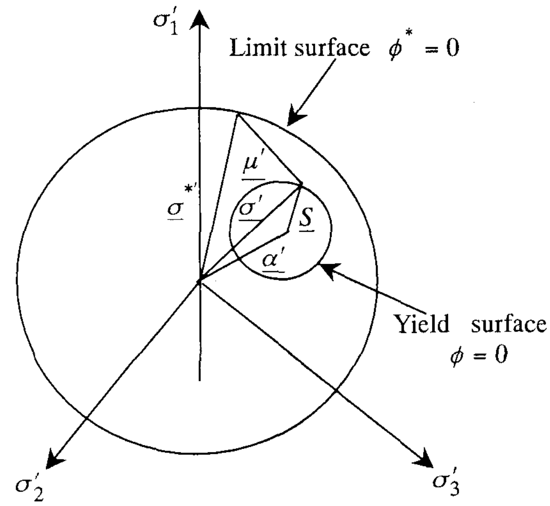

Figure 1. Schematic representation of limit and loading surfaces in π-plane

For loading increment in the plastic region the effective plastic strain is defined as,

$$d\bar{\varepsilon}^{p} = \sqrt{\tfrac{2}{3}\,d\varepsilon_{ij}^{p}\,d\varepsilon_{ij}^{p}} \tag{6}$$

where $d\bar{\varepsilon}^{p}$ = the incremental effective plastic strain; and $d\varepsilon_{ij}^{p}$ = the incremental plastic strain tensor.

Further manipulation of Equation 3,6 the effective plastic strain is eliminated as,

$$d\bar{\varepsilon}^{p} = \tfrac{4}{3}\,d\lambda\,\sigma_0 \tag{7}$$

During the plastic loading process the accumulated effective plastic strain is updated to obtain the current state of effective plastic strain.

$$\left(\bar{\varepsilon}^{p}\right)_{new} = \left(\bar{\varepsilon}^{p}\right)_{old} + d\bar{\varepsilon}^{p} \tag{8}$$

where $\left(\bar{\varepsilon}^{p}\right)_{new}$ = the current effective plastic strain; and $\left(\bar{\varepsilon}^{p}\right)_{old}$ = the previous effective plastic strain. When the updated effective plastic strain reaches to the failure strain of the material, the fatigue life of the component is assumed to be over.

By contrasting the specialized model for uniaxial stress state with material tensile test results, the hardening parameter A is determined as,

$$A = \left[\frac{\tfrac{4}{3}\left|\frac{d\sigma}{d\varepsilon}\right|\sigma_0}{\sigma^{*} - \sigma}\right]\frac{1}{\left[1 - \tfrac{1}{E}\left|\frac{d\sigma}{d\varepsilon}\right|\right]} \tag{9}$$

where σ = the value of uniaxial stress at particular point of the material; and σ^{*} = the ultimate tensile strength of the material; and E = the elastic modulus of the material.

3. Case Study

The selected bridge is one of the longest railway bridge in Sri Lanka spanning 160 m over two banks of a river situated close to the capital city Colombo. It is a six spanned riveted bridge having warren type semi through trusses, supported on cylindrical piers and having double lane rail tracks. The bridge deck constructed material is wrought iron and piers are made up of cast iron casings with infilled concrete. The Bridge was constructed in 1885.

3.1 Testing of bridge materials

The bridge material was subjected to uniaxial proportional, reverse and cyclic loading operations following the ASTM E8. With the probabilistic evaluation on the results, three finalized stress- strain diagrams for each type of test of particular material were obtained.

3.2 Verification of the proposed model

In favor of the verification, the model predicted behaviors were compared with the real uniaxial stress/strain diagrams of proportional, reverse and cyclic loading operations. The sample result of the comparison is shown in Figure 2.

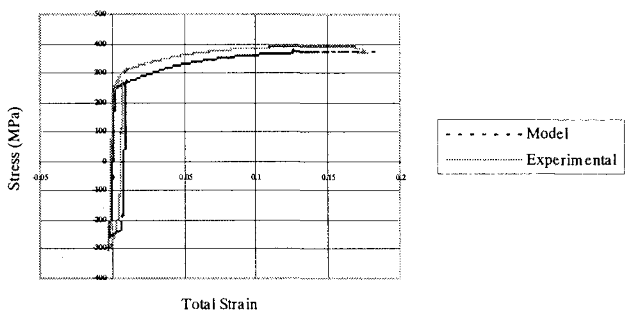

Figure 2. Model and experimental stress/strain behaviors in cyclic loading

The comparison revealed that the model prediction has a reasonable agreement with real behaviour of the material.

3.3 Life estimation

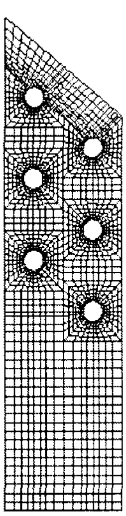

Figure 3: FE model

The bridge was analyzed using the FE method employing the general-purpose program SAP 2000, (Siriwardane et al. 2004). The validated FE model reveals that critical members are subjected to around 60 to 80MPa uniform stress across the mid span section due to actual loading.

To investigate the stress distribution around rivet holes, the most critical member of truss girder was subjected to further analysis. The nine node isoperimetric 2D plane stress elements were used for the FE mesh as shown in Figure 3. To simulate the different unilateral contacts between rivet and plate, three types of restraint conditions were used such that fully bonding, smooth contact and actual air gap behavior.

Since the major objective of this linear elastic analysis is to find out the most critical state of stresses around rivet holes, the different cases associated with different possibilities of the rivets with the plate were considered. Finally it revealed that some locations in the connected members were subjected to multi axial stress state and von Misses stress could exceed even the yield stress of the material in some cases. Therefore in such cases, which can be subjected to low cycle fatigue, were selected for life estimation. Since the major criteria behind the life estimation is the determination of the effective plastic strain at the critical location, the elastoplastic FE analysis, which is combined with proposed model was performed. The sophisticated finite element modeling and analysis program ALGOR 12, (ALGOR.inc.2003), was used.

3.4 Results

Out of varies types of critical cases, it was revealed that the active number of rivets which are able to transfer the load deviates the fatigue life significantly. The sample results are shown in Table 1.

Table 1:Predicted remaining fatigue life of the critical member in the bridge.

Number of active rivets	Remaining fatigue life
One rivet	8 days
Two rivets	4 months
Three rivets	1 year & 6 months

Even though the estimated numerical values related to the remaining life are in safe margin, they are not realistic, since the used FE program has lack of facility to handle the monotonic variable amplitude loading.

4. Conclusions

The results illustrate that the present condition of places where the stresses are severe tends to deviate the fatigue life significantly. Therefore in the frame of extraordinary inspection and maintenance of the bridge, it is great important to investigate accurately the condition of places where the stress concentration effect is severe such as notch, crack or connection area especially in old bridges.

When compared to previous empirical methods published in the literature, finally it can be concluded that this model based remaining life estimation technique of existing bridges is considered as one bounding approach which is not depend on complex experimental works.

5. References

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