ANALYSIS ON CRACK GROWTH AND FATIGUE LIFE OF WELDED BRIDGE COMPONENTS WITH INITIAL CRACK

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Summary This work aims to investigate the behavior of crack growth and fatigue life of welded bridge components with initial crack under traffic loadings. Considering the damage evolution on the region of crack's tip and its influence on crack propagation, the equation of crack propagation is deduced based on the theory of continuum damage mechanics and fracture mechanics for welded bridge components, then the proposed model is adopted to analyze crack growth and fatigue life of welded specimens.

Initial cracks widely exist in the welded steel structures due to welding. They have a significant influence on the fatigue life of the corresponding welded components. The investigation on bridge fatigue failures done by Fisher [1] has shown that the initial crack of the welded bridge components is one of the main causes of the fatigue failures of bridges. Thus it is important to study the fatigue behavior of welded steel structures with initial crack. However little efforts have been made on the study of the fatigue crack propagation of welded steel structures with initial crack. In this paper, the experimental studies on the fatigue crack propagation are briefly described and the theoretical analysis on the fatigue crack propagation is performed to provide equations of crack growth and fatigue evaluation. The corresponding method to evaluate fatigue life of welded components with initial crack is proposed. As a case of the study, the fatigue crack growth and the fatigue life of two experimental components are analyzed with the proposed model and calculated method.

EXPERIMENTAL STUDY

To study the fatigue behavior of the welded components with initial crack, experimental studies have been done for two types of welded components to investigate the hot-spot stress distribution, crack growth on the vicinity of toe of welded components and fatigue life of tested specimens. The process of crack generating, crack developing and rupturing on the fatigue life of the tested specimens are carefully observed and measured. Observation results suggest that fatigue cracks develop in the shape of semi-ellipse and remain the shape during the propagation.

THEORETICAL STUDY

Fatigue crack propagation is related to the distribution of stress intensity factor on the crack tip where local stress shows its singularity to speedup evolution of material damage, then the damage evolution plays important role to the growth of fatigue cracks. For the welded steel structures under cyclic loading, fatigue damage behavior in the region of crack tip and its influence on the crack growth should be considered in the analysis on fatigue crack propagation, in which fatigue damage in the front of crack tip follows the theory of Continuum Damage Mechanics (CDM) [2] while the growth of cracks is governed by Fracture Mechanics (FM).

With consideration to the characteristic of the stress cycle for welded bridge components, the fatigue damage evolution law for high cycle fatigue damage of the bridge component under traffic loading was proposed by Z.X. Li and T.H.T. Chan [3~5] on the basis of the theory of CDM and used to evaluate the accumulation of fatigue damage for the welded bridge components.

$$\frac{\delta D}{\delta N_{bl}} = \sum_{i=1}^{m_{rb}} \frac{\left[(\Delta\sigma_i + 2\sigma_{mi})\Delta\sigma_i\right]^{\frac{\beta+3}{2}}}{B(1-D)^{\alpha}(\beta+3)} \qquad (\sigma_{Mi} \geq \sigma_f) \tag{1}$$

where m_{rb} is the number of stress cycle with the stress value of the representative stress cycle block greater than the fatigue stress threshold value, N_{bl} is the number of the representative stress cycle block, $\sigma_{M_{ri}}$ is the maximum value of the *i*th stress cycle. And B、α 、β are the material constants.

According to the experimental study of the welded components under repeated stress cycle mentioned above, the semi-elliptical shape of the crack is assumed to remain during the process of fatigue crack propagation. The half-depth (the half short axes of the ellipse) and half-length (the half long axes) of the considered surface crack under the action of N_{bl} times of representative block of stress cycle is denoted as $a(N)$ and $c(N)$ respectively. The stress near the crack tip front could approximately be written as: $\sigma = \frac{K_I^B}{\sqrt{2\pi r}}$; Then the stress intensity factor on the tip (the deepest point) of the semi-elliptical crack could be written as:

$$K_I^B = \frac{F\sigma\sqrt{\pi a}}{\varphi} \tag{2}$$

where F is a correction factor for the ratio of *a/c* and φ is the second type of elliptical integration.

Suppose that the crack propagation occurs when fatigue damage accumulates until to a certain extent, so that the damage on the crack tip should be introduced as a continuum damage zone near the crack front. The crack propagation process is actually a gradual movement of the damage zone near the crack tip. When the fatigue damage on the tip is up to a critical value, the crack begins to propagate.

Substituting the local stress in the damage zone near the crack tip, which is relative to the stress intensity factor and can be obtained from Eq. (2), into the Eq. (1), then integrating the equation with respect to the stress cycle N_{bl}, the number of stress cycle block when the value of fatigue damage reaches to the threshold of growth, D_c, for the crack with the half-depth a and $a+\delta L$ can be obtained respectively. By comparing the number of stress cycle block for the damage evolution at the crack with the half-depth a and that for $a+\delta L$, the increment of crack growth with respect to the stress block cycle N_{bl} can be obtained as follows:

$$\frac{\delta L}{\delta N_{bl}}=\frac{(\alpha+1)\Delta K^{(\beta+3)}}{B(\beta+3)\left[(1-D_0)^{\alpha+1}-(1-D_f)^{\alpha+1}\right]}\left(\frac{1}{\sqrt{2\pi r_c}}\right)^{(\beta+3)}\left(\frac{2}{\beta+3}\right)a \tag{3}$$

which could be rewritten as:

$$\frac{\delta L}{\delta N_{bl}}=C_B\left(\Delta K\right)^{(\beta+3)} \tag{4}$$

where:

$$C_B=\frac{(\alpha+1)}{B(\beta+3)\left[(1-D_0)^{\alpha+1}-(1-D_f)^{\alpha+1}\right]}\left(\frac{1}{\sqrt{2\pi r_c}}\right)^{(\beta+3)}\left(\frac{2}{\beta+3}\right)a \tag{5}$$

α , β , B, r_c are constants related to characteristics of material damage. D_0, D_f is the initial and the final values of material damage. It can be seen from Eqs. (4) and (5) that, the propagation rate of fatigue crack given by Eq. (4) is similar to the Paris law of crack propagation. Moreover, the proposed equation gives a clear explanation to the common used Paris law and provides necessary theoretical background, on the basis of CDM and FM, for the process of fatigue crack propagation. As shown as Eq. (5), the parameter C_B is related to the initial and final value of fatigue damage in the continuum damage zone on the front of crack tip and the current value of crack depth.

NUMERICAL ANALYSIS

The proposed model of fatigue crack growth is then adopted to calculate the crack growth and the fatigue life of two types of welded specimens with fatigue experimental results, in which the calculation of the stress intensity factors are modified by the factor of geometric shape from the BS7910 [6] for the welded components in order to reflect the influence of the welding type and geometry on the stress intensity factor. The calculated results [7] show that the proposed model of fatigue crack growth is reasonable. The ratio of the crack depth length to the half surface crack length a/c varies with the crack propagation. The results of crack growth a/t are significantly related to the initial value of crack depth a_0/t_0 and the initial half-length a_0/c_0. The fatigue life increases with the increase of a_0/c_0 under the same value of a_0/t_0.

CONCLUSIONS

Experimental and theoretical studies on fatigue crack growth of the welded bridge components with initial cracks are carried out, and the crack growth model is derived for the welded components under actual loading of the bridge service, in which fatigue damage evolution under traffic loading is considered in the zone of continuum damage on the front of crack tip. The damage evolution and its influence on the crack growth are evaluated based on the CDM fatigue damage theory and the fracture mechanics. The numerical analysis using the proposed model shows that the proposed model for the fatigue crack growth of welded bridge components is reasonable and some of useful results on behavior of fatigue crack growth are obtained.

References

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