I −A190 Fatigue Crack Growth Behavior Under Variable Amplitude Loading

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1. Introduction

Increase in traffic in recent years makes the fatigue design of steel highway bridges more and more necessary. Field measurements of these bridges reveal that most of the stress cycles are extremely low, which makes the fatigue lives of the joints normally fall into the long life region. In this region, the applicability of linear cumulative damage rule known as Miner's rule, which is well accepted in various fatigue design specifications such as BS5400, ECCS, AASHTO and JSSC, remains to be fully discussed. An important shortcoming of it is that it does not take into account the load sequence effect, which may exist in the service loading of highway bridges. The present study is among a series of experimental studies, aiming at establishing a new fatigue crack growth model. In the study, fatigue crack growth measurements were carried out under two variable amplitude (VA) loading spectra, β 1 and β 3, on center-cracked tension (CCT) specimens made of structural steel SM520B. The minimum stress or the maximum stress were kept constant, respectively, corresponding to the cases where low or high welding residual stress exists in a welded joint.

2. Outline of the tests

Fig. 1 shows the probability density functions versus the normalized stress range relations for β 1 and β 3. Corresponding to the probability density distribution, 1000 loading cycles, called a loading block, were generated by Monte Carlo simulation. Fig. 2 shows the loading block for the four tests. In β 1L and β 3L, the minimum stress 20MPa was held constant and the maximum stress obeyed the probability density function. Identically, in β 1H and β 3H, the maximum stress was held at 153MPa. In each test, the loading block was repeatedly applied until the end of the measurement.

During the test, the crack size a and the corresponding number of elapsed loading cycles N were recorded, based on which the crack growth rate da/dN can be calculated out by taking the average value between two successive measurements. The measurement interval was selected as 3000 cycles.

Altogether two specimens were used in the tests and each specimen was used for two loading spectra in order the shorten the testing time. For

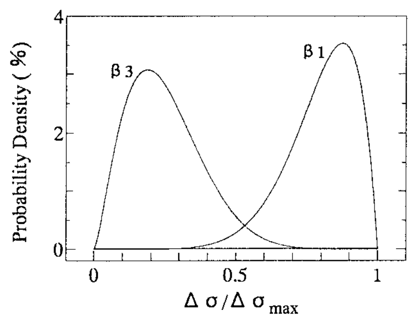

Fig. 1 Probability density function with respect to normalized stress range

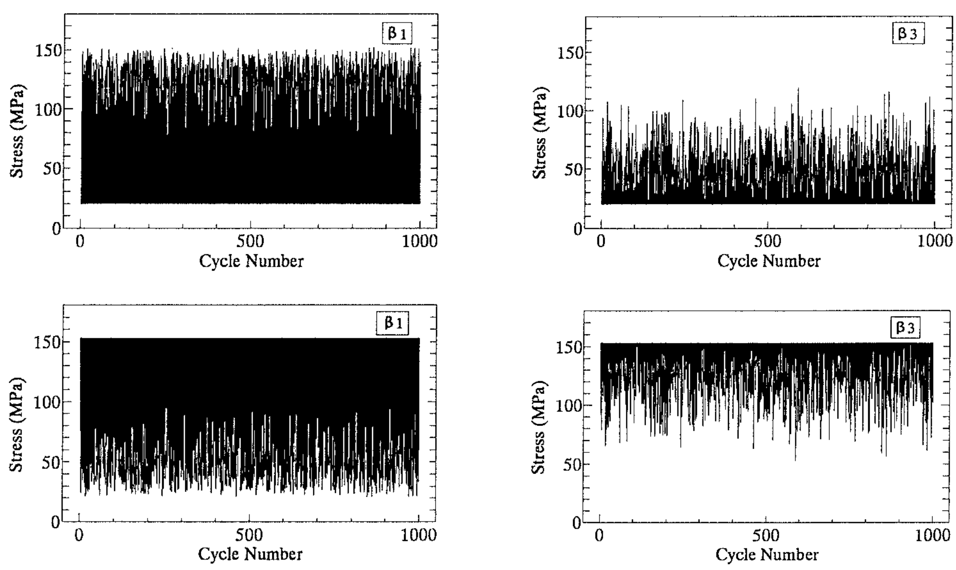

Fig. 2 1000-cycle loading block in each test

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specimen 1, the applied loading spectra were chronologically β 1L, β 3L, β 1L and β 3L. For specimen 2, the loading spectra were β 1H, β 3H, β 1H and β 3H.

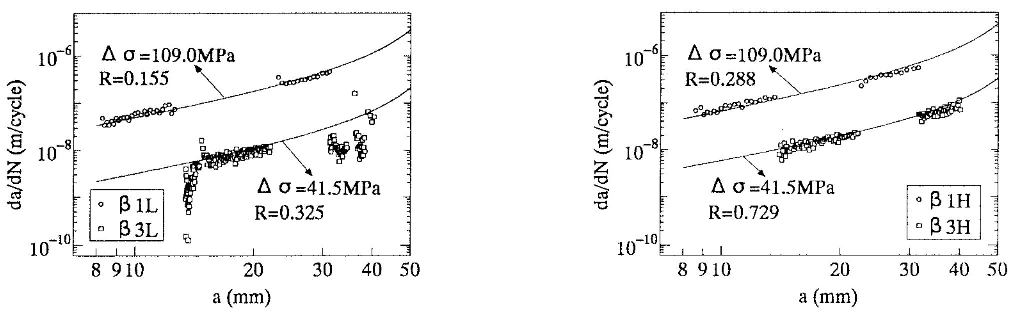
In the end, it should be pointed out that during the test under β 3L loading spectrum, the loading was stopped once at a=36mm (ΔK =16.98 $\mathrm{MPa}\sqrt{\mathrm{m}}$) due to an unexpected trouble of testing machine. Following this, an overload might have been produced.

3. Observation from test results

In the study, stress ratio R is defined as $\sigma_{\min}/(\sigma_{\min}+\Delta\sigma_{RMC})$ and $(\sigma_{\max}-\Delta\sigma_{RMC})/\sigma_{\max}$ for constant-minimum and constant-maximum cases, respectively. Here, $\Delta\sigma_{RMC}$, the root-mean-cube stress range, is 109.0MPa for β 1 and 41.5MPa for β 3. Consequently, the stress ratios for β 1L, β 1H, β 3L and β 3H are 0.155, 0.288, 0.325 and 0.729, respectively. The constant amplitude (CA) fatigue crack growth behavior under each R level is decided based on Newman's model[1].

The *da/dN-a* relationships of the constant-minimum-stress and constant-maximum-stress cases are shown in Fig. 3 (a) and (b), respectively, corresponding to the two specimens in the tests. For the former case, when the specimen is loaded under β 1L, the data points fall onto the CA curve with $\Delta\sigma$ =109.0MPa and R=0.155. When β 3L loading is applied, *da/dN* drops down at first and then increases gradually. Finally *da/dN* stabilizes at a level that is lower than that of the CA loading with $\Delta\sigma$ =41.5*MPa* and R=0.325. When β 1L is applied again, *da/dN* rises up to a level higher than that of the corresponding CA loading and then drops down stabilizing at the CA level. In the end, re-application of β 3L makes *da/dN* decrease. Before it recovers, an overload-like behavior occurs, following which *da/dN* drops down again. Clearly, this is due the machine trouble mentioned earlier.

For the constant-maximum-stress case, test results almost coincide with those of the corresponding CA loading. However, it should be mentioned that the fatigue crack growth rates in large-crack size region seem to be slightly lower than those in small-crack size region. This might be due to the fact that plastic deformation tends to be more in this region, which intensifies the crack closure effect and consequently reduces the crack growth speed.



(a) Constant Minimum Stress (b) Constant Maximum Stress

Fig. 3 Fatigue crack growth rate *da/dN* versus crack size *a* relationship

4. Analysis of test results

Under the present loading conditions, several factors may affect the fatigue crack growth behavior. They are: (1) stress ratio, (2) load interaction effect between β 1 and β 3, (3) threshold level of stress intensity factor range, ΔK_{th}, and (4) load sequence effect inside β 1 or β 3.

In Fig. 3, the first factor has been separated out. Except β 3L, VA fatigue crack growth behaviors coincide with the corresponding CA behaviors, indicating that the other three factors do not work for β 1L, β 1H and β 3H.

For β 3L, the second factor leads to the decrease and increase of da/dN near β 1L-β 3L and β 3L-β 1L transitions, respectively. It should be noted that this effect is generally related to crack closure effect. In specimen 2, due to the large R value of β 3H and therefore the small crack closure effect, this effect becomes negligible.

For β 3L in the small-crack size region, da/dN after stabilization is 15.1% lower than that of CA. The third factor is believed to contribute to this effect. Through calculation, it is known that 49.4% of the stress cycles in β 3L are below ΔK_{th}, i.e., do not contribute to crack growth. After these small cycles are taken out when the equivalent stress range is calculated, the difference between test data and CA curve decreases to be about 4.8%.

Consequently, the fourth factor, i.e, the load sequence effect inside β 1 and β 3 is found to be small in the tests.

Reference

1) Newman, J.C., Jr., A crack-closure model for predicting fatigue crack growth under aircraft spectrum loading, Methods and Models for Predicting Fatigue Crack Growth under Random Loading, ASTM STP 748, pp.53-84, 1981.