I－A248 ANALYSIS INVESTIGATION OF CRACK CLOSURE FOR BIIDGE STEEL

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1. BACKGROUND

In fatigue life estimation of structural members subjected to variable amplitude loading, the so-called Miner's rule has gained wide acceptance. In the fatigue design of bridge, this rule is believed to be a very efficient way for fatigue life evaluation. However, what should be noted is that this approach does not contain the load sequence effect that does exist, especially in the long-life region. Unfortunately, the fatigue life of most highway bridge details fall into this region because of the relatively smaller ratio of lively load to dead load when compared to that in railway bridge details. Therefore, it is obvious that a better approach that is able to explain the load sequence effect must be established in order to achieve a more accurate prediction of crack propagation behavior and fatigue life.

Elber's crack closure concept provides a good explanation of load sequence effect. Since Elber's original study, numerous researchers try to established the computation model under the crack closure concept, among which Newman's and de Koning's models are most promising. Both of them are called strip model because they employ the Dugdale strip yield model for calculating the crack tip plastic zone. Much work have been done in order to check the applicability and possible restrictions of predictions by these models. However, until now much of them is largely restricted to some aircraft aluminum alloys. Apparently there is still much work to do for bridge steel.

The present study aims at developing a computation model based on strip model in order to achieve a more realistic prediction for variable amplitude loading, especially when the crack-tip plastic zone is relatively larger.

2. DESCRIPTION OF THE COMPUTATION MODEL

(1) Outline of the Strip Model

In strip model, Dugdale model is used to calculate the plastic zone size ahead of the crack tip and modified to leave plastically deformed material in the wake of the advancing crack. These material will lead to the crack closure, i.e., contact between crack surfaces at loads that are low but greater than zero. Furthermore, crack closure will decrease the effective stress intensity factor range and finally decrease the crack propagation rate through the introduction of a great-than-zero opening stress below which the crack does not open at all.

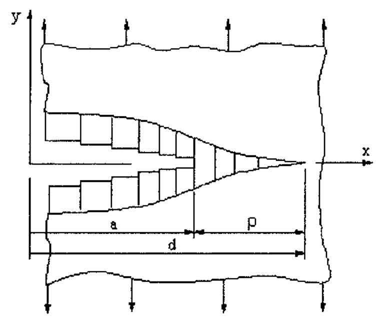

Fig. 1 Schematic of the model

Fig.1 shows a schematic of the model in which a is the half crack size and ρ is the plastic zone size. Here the concept of fictitious crack with a length of 2d (d=a+ρ) is introduced. It is the boundary between elastic-plastic zone and purely elastic zone. That is to say, the region outside the fictitious crack can be treated as an elastic continuum. As a result, the crack surface displacement and stress intensity factor range of it can be solved through those equations acquired in ideally elastic problem. The plastically deformed region between the physical crack and the fictitious crack is formed in the crack propagation procedure during which the physical crack has to pass through the existing plastic zone ahead of the crack tip. Note also that this region is divided into many bar elements. This approach was first proposed by Newman in order to facilitate the numerical procedure.

(2) Improvement in the Present Model

The computation model stated above has been successfully used to analyze the crack behavior under constant amplitude loading and some variable amplitude loading patterns such as single-overloading. However, the bar elements division approach (mesh division approach) and crack propagation increment adopted in the previous studies are too rough to achieve an even more accurate prediction. Moreover, the approach for determining the plastic zone size in the overload affected zone comes into question. Therefore, two improvements, from the mathematical and physical points of view respectively, are made here as stated in the following.

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a) The width of the two bar elements around the crack tip (One is in the crack wake and the other is in the plastic zone.) are set to be the same as the crack propagation increment in the current computation step. The width of the other bar elements are arranged in a geometric progression.

In the region where the opening stress changes sharply, for example when the crack just starts to propagate or when an overload just passes, the number of cycles in each computation step ΔN is set to one. This rule is used in order to prevent too much load sequence effects from getting lost. After the opening stress stabilizes, ΔN increases gradually to a relatively larger value such as 100.

b) In the previous version of strip model, if one ithe present plastic zs smaller than the former one, then the final plastic zone size is selected as the larger value between these two. That is to say, the material ahead of the crack tip deforms independently of the existing plastic deformation, which seems to contradict with one of the assumptions for applying Dugdale model, that is, the crack tip area must be purely elastic before the plastic zone appears.

In the present model, an iterative method instead of the above procedure is used if the present plastic zone is smaller than the former one. As a result, the historical plastic deformation is account for when the new plastic zone is formed, and a more reasonable crack tip behavior is expected.

3. COMPARISON OF PREDICTIONS WITH TEST DATA

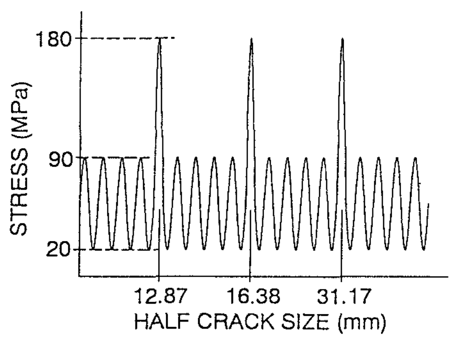

Fig. 2 Loading Spectrum in Single Overloading Test

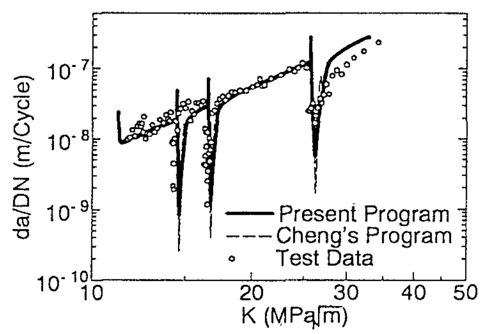

Fig. 3 Computation Result for Single Overloading Test

Since 1994, a lot of crack propagation tests, including constant amplitude loading, single overloading, periodical overloading, block loading and variable loading test, were carried out in Nagoya University of Japan. In the present study, the prediction results of the computation model are compared with some of these test data.

The specimen used for the present comparison is center-prenotched plate specimen that is made of SM520B, a typical bridge steel with the yield stress of 402MPa and the ultimate stress of 539MPa.

Fig.2 show the single-overload loading spectrum in which three overloads are applied into an otherwise constant-amplitude loading spectrum. The computation results of crack propagation rate da/dN versus stress intensity factor range K and crack size a versus the number of loading cycles N are shown in Fig.3 and Fig.4 respectively. Obviously, in the constant amplitude region, both models can give a satisfactory prediction. While in overload-affected region, the performance of the present model seems to be better. The unreasonable large retardation effect is though to be due to some crack-tip complexities that are not taken into account in the strip model. Much work will be done in the future study.

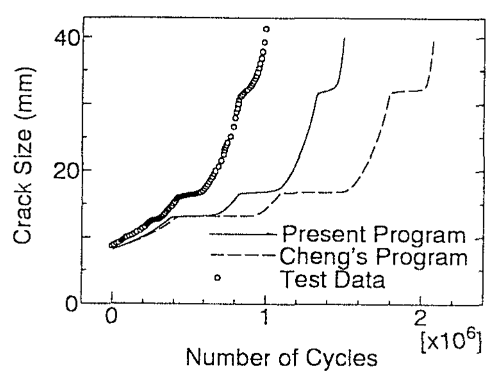

Fig. 4 Calculated Crack Size as a function of the Number of Cycles