DAMAGE MECHANICS BASED FATIGUE ANALYSIS OF THE COPED STEEL BEAMS

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INTRODUCTION

Decision concerning the maintenance of an existing bridge gives serious impact on the traffic patterns and economy of the surrounding community. Thus, it is important to extend the lifetime of a bridge structure and evaluate the fatigue damage evolution accurately. In case of a steel bridge, the structure is composed of longitudinal and transverse members by connections, and there are many copes at the end of these members. In these joints, beam flanges must often be coped to provide enough clearance for the supports. The geometric discontinuities at cope corner produce not only the reduction of cross sectional bending resistance, but also the high stress concentration in the web, and it induces fatigue damage around the cope[1), 2)]. Therefore, high cycle fatigue failure simulation of the coped steel beam was carried out by using damage mechanics.

ANALYTICAL METHOD

In this study, the analytical method of high cycle fatigue failure by using damage mechanics is proposed[3)]. Basic concept of damage mechanics consider the damage variable as the degree of degradation of material in the homogeneous field. Thus, the basic image of damage variable D is defined as the loss of effective area in the meso-scale that is defined by so-called representative volume element (RVE) as shown in Fig. 1.

$$D = \frac{A_D}{A_0} \qquad (1)$$

where A_0 : the total area of considered plane, A_D: the area of all micro-defects

In general, damage is caused by the accumulated plastic strain due to stress concentration in the neighborhood of micro defects, and it is defined as

$$dp = \sqrt{\frac{2}{3} d\varepsilon_{ij}^{p} d\varepsilon_{ij}^{p}} \qquad (2)$$

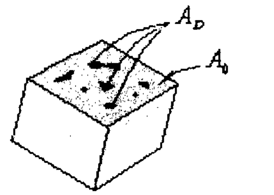

Fig. 1 Basic definition of damage variable

where dp : the accumulated plastic strain increment

It is assumed that damage occur when the accumulated plastic strain exceeds a certain value p_D, and rupture occurs at the meso-scale when damage variable exceeds the certain critical value Dc (Fig. 2).

For high cycle fatigue, there is no plasticity occurs on the macro scale, but there is micro cracking due to irreversible plastic strain on the micro-scale. Therefore, the damage evolution is derived from the associated flow rule with the strain energy density release rate Y and the existence of potential of dissipation F_D at micro scale.

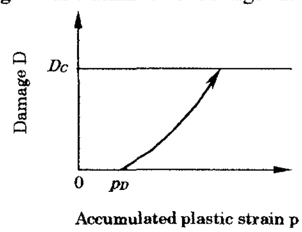

Fig. 2 Damage evolution

$$dD = \frac{\partial F_D^{\mu}}{\partial Y^{\mu}} d\lambda^{\mu} = \left(\frac{Y^{\mu}}{S}\right)^{s} dp^{\mu} \qquad (3)$$

where S: determined from the gradient of the stress-strain curve in unloading path.

In order to calculate the high cycle fatigue damage evolution in the RVE, the stresses at micro scale σ_{ij}^{μ} are evaluated from the macro scale stresses σ_{ij} by introducing two scales model based on the localization of self-consistent scheme[4)].

$$\sigma_{ij}^{\mu} = \sigma_{ij} - aE\varepsilon_{ij}^{\mu p} \qquad (4)$$

where a is given by the Eshellby analysis of a spherical inclusion

$$a = \frac{1-\beta}{1+\nu} \quad , \quad \beta = \frac{2(4-5\nu)}{15(1-\nu)} \qquad (5)$$

From the yield condition at the micro scale taken kinematics hardening X^{μ} into account.

$$f^{\mu} = \left(\frac{\sigma^{\mu}}{1-D} - X^{\mu D}\right)_{eq} - \sigma_f = 0 \qquad (6)$$

Table 1 Material properties

σ_f : fatigue limit stress (MPa)	160.0
σ_Y : yield stress (MPa)	240.0
σ_u : ultimate stress (MPa)	600.0
S: the energy strength of damage (MPa)	2.4
ε_{pD} : the damage threshold strain	0.44
s : the exponent of damage evolution	2.0
Dc : the critical damage	0.2

Coupled with the law of localization, it is possible to compute the damage evolution up to failure as a function of the macro-scopic stresses.

$$dD = \left[\frac{\left(\sigma_{eq} + k\sigma_f\right)^2 R_\nu^{\mu}}{2ES(1+k)^2(1-D)^2}\right]^{s} \frac{d\sigma_{eq}}{C(1+k)} \quad if \quad \sigma_{eq} \geq \sigma_f \qquad (7)$$

where the triaxiality function $R_\nu^{\mu} = \frac{2}{3}(1+\nu) + 3(1-2\nu)\left[\frac{\sigma_H(1+k)}{\sigma_{eq} + k\sigma_f}\right]^2 \qquad (8)$

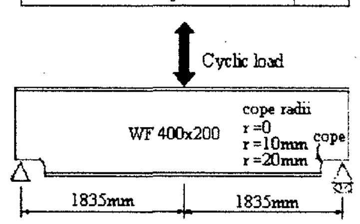

Fig. 3 Cope steel beam model

ANALYTICAL RESULTS AND CONSIDERATIONS

For the purpose of analyzing the fatigue damage, simple support cope beam models are examined (Fig.3). The applied load and cope radius are regarded as the two major analytical parameters. The main difficulty is the identification of the material properties as there is no way to measure directly the parameters characteristic of the behavior at the micro scale. If we assume that the material parameters at the micro scale are of the same as at the macro scale, the material parameters have been identified as Table 1. In this analysis, 30mm crack size at the cope corner is assumed to be the failure condition.

From analytical results, the slope of the fatigue damage growth curves representing the effect of cope radius on the damage growth (Fig. 5). It is recognized that small cope radius cause high stress concentration and it affect the damage growth severely (Fig.4). It is also found that the fatigue life of cope beam increases with increasing cope radius (Fig. 6). Moreover, most engineering components and structures are often subjected to varying loads involve non-zero mean stress. It is, therefore, important to investigate the influence of the mean stress on the fatigue behavior. The fatigue life of cope beam increases with decreasing applied mean stress (Fig. 7), this because the higher mean stress produces the higher tensile stress which cause damage in steel as well. From these results, it is confirmed that the proposed method could give reasonable results for fatigue failure of a typical steel structural member. To improve the evaluation of damage parameter, accurate lifetime estimation can be obtained by using this method.

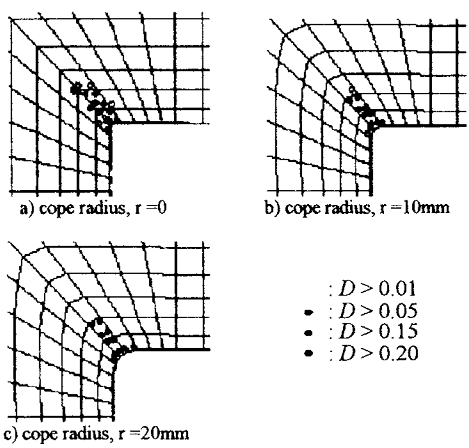

Fig. 4 Damage distribution (10^6cycles)

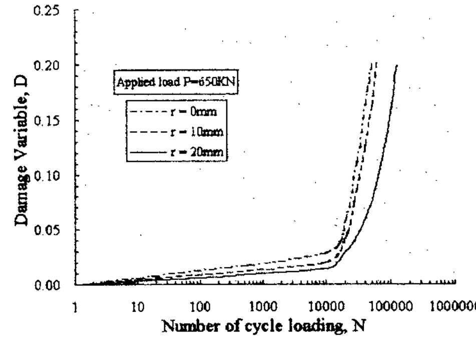

Fig. 5 Effect of cope radius to damage evolution

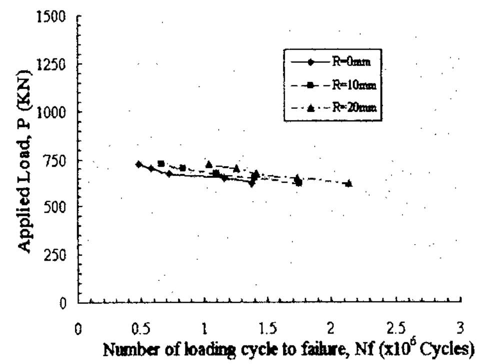

Fig. 6 Effect of cope radius to fatigue life

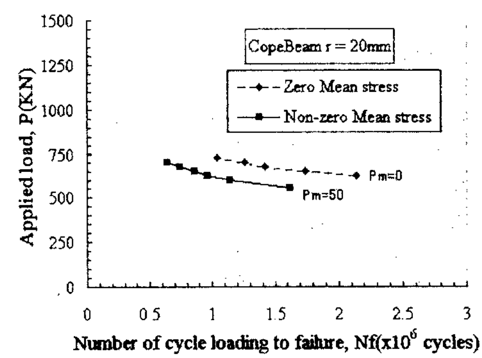

Fig. 7 Effect of mean stress to fatigue life

CONCLUSIONS

High cycle fatigue damage analysis and lifetime prediction of coped steel beams are carried out by using damage mechanics. For high cycle fatigue, the stresses in the micro scale should be evaluated accurately. In this study, it is evaluated from the macro stresses by means of the localization law of self-consistent scheme. The effect of cope geometry was considered to investigate the localization of fatigue damage, and found that cope geometry influenced the high cycle fatigue damage evolution and fatigue life due to the stress concentration. It is also found that the mean stress very influence on the fatigue life. From these considerations, it is confirmed that the presented approach can predict the high cycle fatigue life, and it could be reliable method for lifetime assessment of the steel structure.

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