I-45 FURTHER STUDY ON UNIAXIAL CYCLIC PLASTICITY MODEL FOR STEEL WITH YIELD PLATEAU

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1. INTRODUCTION

In order to predict the cyclic behavior of steels with yield plateau accurately, the authors proposed a uniaxial two-surface model[1], following experimental observations. However, when this uniaxial model is extended to the multiaxial stress state, a use of the quantity called *accumulated effective plastic strain*[2](as abbreviated to A.E.P.S.) gives rise to a kind of difficulty because the plastic strain in the multiaxial stress state can not be distinguished, for example, as the tensile and compressive plastic strain in the uniaxial stress state. In the present paper, (1)the equations concerning the A.E.P.S. in Ref. 1) are modified for an easy extension of the uniaxial model to the multiaxial one and (2)the slope of bounding line is assumed to decrease with increase in plastic work.

2. CALCULATION OF THE ELASTIC RANGE AND LENGTH OF YIELD PLATEAU IN THE PRESENT MODEL

In the present paper, A.E.P.S. used in calculating the size of elastic range in Ref. 1)(i.e., Eq.(6) in Ref. 1)) is replaced by the *accumulated plastic strain* (A.P.S.), $\bar{\varepsilon}^p = \int d\varepsilon^p$, which can be written in multiaxial stress state as:

$$\bar{\varepsilon}^p = \int d\varepsilon^p = \int \sqrt{\frac{2}{3} d\varepsilon^p_{ij} d\varepsilon^p_{ij}} \tag{1}$$

On the other hand, the A.E.P.S. used to calculate the end of yield plateau(i.e., Eq.(9) in Ref. 1)) is substituted by the *maximum plastic strain*(M.P.S.), $\bar{\varepsilon}^p_{max} = |\ \varepsilon^p\ |_{max}$, that the material has ever experienced from the beginning to the end of the yield plateau. In this case, the parameter M used in the relationship between M.P.S. and the plastic work W^P is recalibrated from the experimental data. The M.P.S. in the multiaxial stress state is expressed as:

$$\bar{\varepsilon}^p_{max} = \{\sqrt{\frac{2}{3}\varepsilon^p_{ij}\varepsilon^p_{ij}}\ \}_{max} \tag{2}$$

3. THE BOUNDING LINE SLOPE

The slope of the bounding line is usually assumed to be constant throughout the whole loading history in the existing two-surface models. However, it has been found in the cyclic loading experiments that the slope of the bounding line decreases with the increase in loading cycles and approaches a limiting value of zero. As a result, the slope of the bounding line is supposed to decrease with the plastic work in the present paper and expressed as follows.

$$E^P_{0i}(W^P_i) = \frac{E^P_0}{1 + \omega W^P_i} \tag{3}$$

where E^P_{0i} represents the slope of bounding line for the loading path after the i-th reversal loading point(as shown in Fig. 1, for point C, $i = 1$ and $i = 2$ for point D); W^P_i is the plastic work

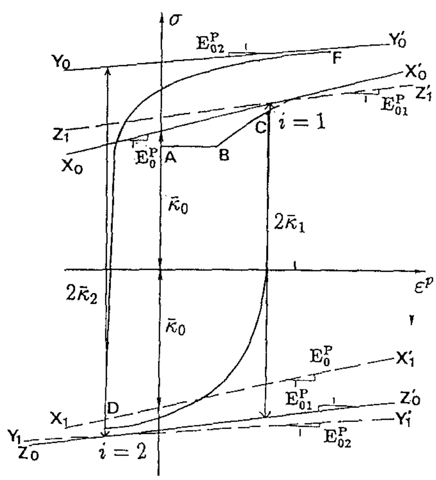

Fig. 1 Axial stress σ and plastic strain ε^p curve in one cyclic loading

accumulated from the beginning(i.e., point O in Fig. 1) until the i-th reversal loading point; E_0^P indicates the slope of initial bounding line which is obtained from the monotonic loading experiment when the stress and strain curve reaches stable state; ω is a material constant, which is determined by the change of the bounding line slope in a one loading cycle experiment(i.e. the loading type (3) in Ref. 1)). It should be noted that the slope of the bounding line is constant for one loading path and changes only after reversal of loading.

4. MOVEMENT OF BOUNDING LINE

In the cyclic loading experiment, it is observed that the stress-strain curve will reach a saturated state with the increase of plastic deformation. Therefore, the following expression is adopted in the present paper to calculate the radius $\bar{\kappa}_i$ of the bounding lines or the bounding surface after the i-th reversal loading point.

$$\bar{\kappa}_i = \bar{\kappa}_\infty + (\bar{\kappa}_0 - \bar{\kappa}_\infty)\exp(-\zeta W_i^P) \qquad (4)$$

where $\bar{\kappa}_0$ is the radius of the initial bounding lines; ζ and $\bar{\kappa}_\infty$ are the constants. They are determined from one loading cycle experiment. The radius of the bounding lines or the surface is defined as half distance between the current bounding line and the new bounding line along the stress axis passing through the reverse loading point(see $2\bar{\kappa}_1$ for the loading path CD and $2\bar{\kappa}_2$ for DF in Fig. 1). Moreover, the plastic work W_1^P and W_2^P at point C and D can be calculated from the experimental data. By solving the following nonlinear equations,

$$\begin{cases} \bar{\kappa}_1 = \bar{\kappa}_\infty + (\bar{\kappa}_0 - \bar{\kappa}_\infty)\exp(-\zeta W_1^P) \\ \bar{\kappa}_2 = \bar{\kappa}_\infty + (\bar{\kappa}_0 - \bar{\kappa}_\infty)\exp(-\zeta W_2^P) \end{cases} \qquad (5)$$

the parameters $\bar{\kappa}_\infty$ and ζ for various steels are obtained.

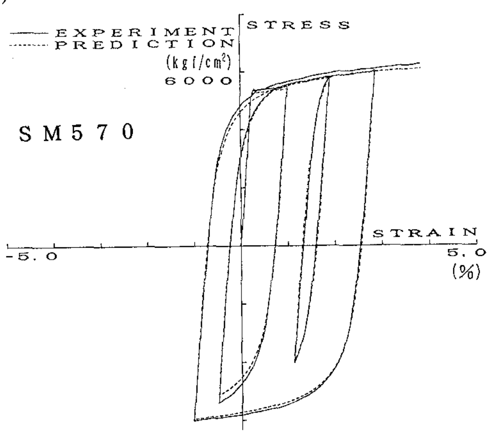

Fig. 2 The prediction with the present model

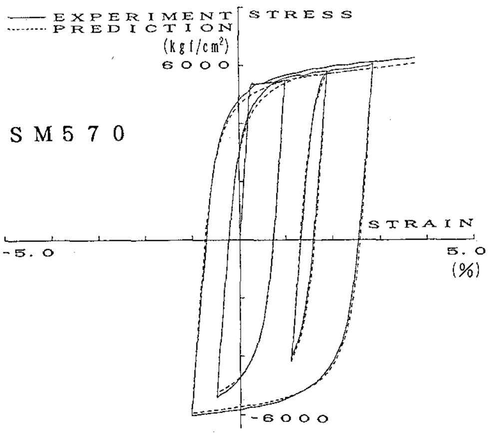

Fig. 3 The prediction with the previous model

5. EXAMPLES

With the above modifications, the prediction for various steels is obtained. One of the examples is shown in Fig. 2 for the steel SM570. The parameters used in the example are as follows.

σ_y=5.35×10^6(kgf/cm^2), ω=0.0041σ_y,
$\bar{\kappa}_0$=1.019σ_y, $\bar{\kappa}_\infty$=1.117σ_y and ζ=0.0137σ_y.

The other parameters can be seen in Table 1 in Ref. 1). At the same time, the prediction by the previously proposed model is shown in Fig. 3 for the same experiment. It can be seen that the present model is accurate enough and can be extended to general case easily.

REFERENCES

1) Shen C., Tanaka, Y., Mizuno, E. and Usami T. : A two-surface model for steels with yield plateau, Proc. of JSCE, Structural Eng./Earthquake Eng. Vol.8, No.4, 179s-188s, Jan. 1992.
2) Minagawa, M., Nishiwaki, T. and Masuda, N. : Modelling cyclic plasticity of structural steels, Proc. of JSCE, Structural Eng./Earthquake Eng., Vol.4, No.2, pp.361-370, Oct., 1987.