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A MULTIAXIAL CYCLIC PLASTICITY MODEL FOR STEELS WITH YIELD PLATEAU

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1. INTRODUCTION

In the present paper, a uniaxial two-surface model proposed by authors in Ref. 1) is extended to multiaxial stress state. Furthermore, the comparison between the experiment and prediction by the present model is given.

2. THE PROPOSED MULTIAXIAL TWO-SURFACE MODEL

1) Loading and Bounding Surface

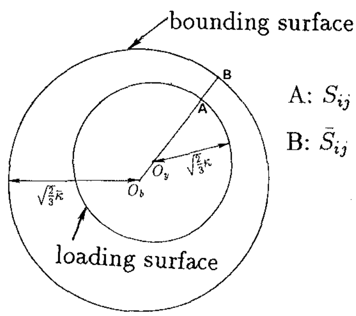
The Von Mises type of loading surface adopted in the present paper is:

$$f(\sigma_{ij}, \alpha_{ij}, \kappa) = \frac{3}{2}\{(S_{ij} - \alpha_{ij})(S_{ij} - \alpha_{ij})\}^2 - \kappa^2 = 0 \quad (1)$$

Similarly, the bounding surface is:

$$F(\bar{\sigma}_{ij}, \beta_{ij}, \bar{\kappa}) = \frac{3}{2}\{(\bar{S}_{ij} - \beta_{ij})(\bar{S}_{ij} - \beta_{ij})\}^2 - \bar{\kappa}^2 = 0 \quad (2)$$

where σ_{ij} and S_{ij} are the stress and deviatoric stress components on the loading surface while $\bar{\sigma}_{ij}$ and $\bar{S}_{ij}$ are on the bounding surface; κ and $\bar{\kappa}$ represent the radii of the loading and bounding surfaces respectively; α_{ij} and β_{ij} indicate the center of the two surfaces(see Fig. 1).



O_y: α_{ij}, center of the loading surface
O_b: β_{ij}, center of the bounding surface

Fig. 1 Loading and bounding surfaces

2) The Motion of Two Surfaces

Based on the uniaxial two-surface model in Ref. 1), the motion of the bounding surface can defined as follwos.

$$d\beta_{ij} = \frac{2}{3}E_0^P d\varepsilon_{ij}^p \quad (3)$$

where E_0^P is the is the slope of the bounding line in the uniaxial case; $d\varepsilon_{ij}^p$ represents the increment of plastic strain. In the present model, it is assumed that the centers of the two surfaces and the loading point always keep on one line during the motion(see Fig. 1). As the result, there exists the following relation between the loading and bounding surface(see Fig. 1)

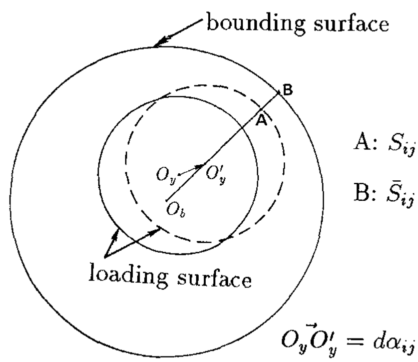
$$S_{ij} - \beta_{ij} = \Gamma(S_{ij} - (\alpha_{ij} + d\alpha_{ij})) \quad (4)$$

where Γ is a scalor and expressed as follows.

$$\Gamma = \begin{cases} \frac{3}{2}\|S_{ij} - \beta_{ij}\|^2/\kappa^2 & if \quad (S_{ij} - \beta_{ij})(S_{ij} - \alpha_{ij}) \geq 0 \\ -\frac{3}{2}\|S_{ij} - \beta_{ij}\|^2/\kappa^2 & otherwise \end{cases}$$

Therefore, the motion of the loading surface is obtained.

$$d\alpha_{ij} = (S_{ij} - \alpha_{ij}) - (S_{ij} - \beta_{ij})/\Gamma \quad (5)$$



O_y: α_{ij}, center of the loading surface
O_b: β_{ij}, center of the bounding surface
O'_y: center of the new loading surface

Fig. 2 Motion of the two surfaces

3) Calculation of the Plastic Modulus in Constitutive Equation

In the present model, the plastic modulus E_0^P is assumed to have the same expression as in the uniaxial two-surface model in Ref. 1), i.e.,

$$E^P = E_0^P + h\frac{\delta}{\delta_{in} - \delta} \tag{6}$$

where δ is defined as the distance between the two surfaces along the direction $(S_{ij} - \beta_{ij})$(as shown in Fig. 2); the parameters E_0^P, h and δ_{in} have the same meaning as in the uniaxial model in Ref. 1). It can be known that when the two surafces contact, δ will be equal to zero and the two surfaces are tangential to each other.

3. MODIFICATION OF THE EQUATIONS CONCERNING THE ACCUMULATED EFFECTIVE PLASTIC STRAIN

In order to extend the uniaxial model to the multiaxial case easily, the equations in Ref. 1) concerning the accumulated effective plastic strain(as abbreviated to A.E.P.S.) are modified. For example, A.E.P.S. used in the calculation the elastic range(i.e. Eq.(6) in Ref. 1) is repaced by the *accumulated plastic strain* $\bar{\varepsilon}^p$, which can be expressed as follows.

$$\bar{\varepsilon}^p = \int d\varepsilon^p = \int \sqrt{\frac{2}{3} d\varepsilon_{ij}^p d\varepsilon_{ij}^p} \tag{7}$$

While 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.) $\bar{\varepsilon}_{max}^p$ as shown in Eq. (8).

$$\bar{\varepsilon}_{max}^p = \{\sqrt{\frac{2}{3}\varepsilon_{ij}^p \varepsilon_{ij}^p}\ \}_{max} \tag{8}$$

In the calcualtion of the bounding surface radius, the following equatuion is adopted for the loading path after the i-th reversal loading point.

$$\bar{\kappa}_i = \bar{\kappa}_\infty + (\bar{\kappa}_0 - \bar{\kappa}_\infty)\exp(-\zeta W_i^P) \tag{9}$$

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.

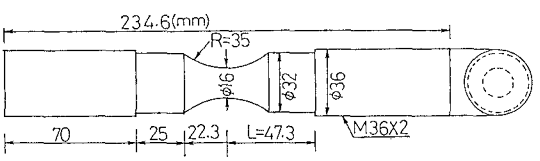


Fig. 3 The specimen in the experiment

5. EXAMPLES

The proposed model has been implemented with finite element method based on the program FEAP. The specimen shown in Fig. 3 is used to examine the applicability of the present model, which is loaded in longitudinal direction cyclically. Since the section of the specimen is not uniform, there exists multiaxial stress state in it. The comparision between the experiment and prediction with the proposed model is shown in Fig. 4. It can be seen that a good agreement between the experiment and prediction has been obtained.

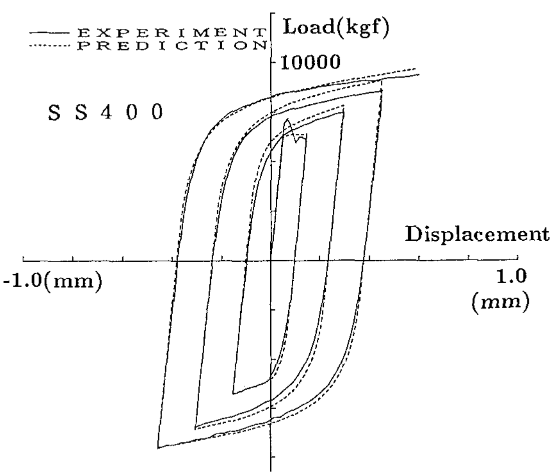


Fig. 4 The comparison between the experiment and prediction

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.