Sensitivity of Elasto-Plastic Material Models for Strain-Based Seismic Design of Nuclear Fragile Components

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1. Introduction

In current ASME Nuclear Codes and Standards (Nonmandatory Appendix F, Paragraph F-1341.2 and Mandatory Appendix XXVII, Paragraph XXVII-3340) allows the elasto-plastic analysis in Level D Service Load such as SSE(Safe Shutdown Earthquake) [1]. As one of the efforts to develop the numerical elasto-plastic seismic analysis method, the sensitivity of the inelastic material models used for seismic time history analysis is investigated for one of the nuclear seismic fragile components.

The inelastic material models investigated in this paper are Chaboche's kinematic hardening model[2], Voce isotropic hardening model, and bilinear kinematic hardening model. Basically, the elasto-plastic seismic time history analysis is aimed to adapt the strain-based seismic design. Therefore, this study will focus on the accumulated equivalent plastic strain responses during the entire seismic time history.

2. Exampled Component

The pressure surge nozzle is selected as an example of application. As shown in Fig. 1, nozzle base metal is SA508 low alloy steel and safe-end and pipe are stainless steel.

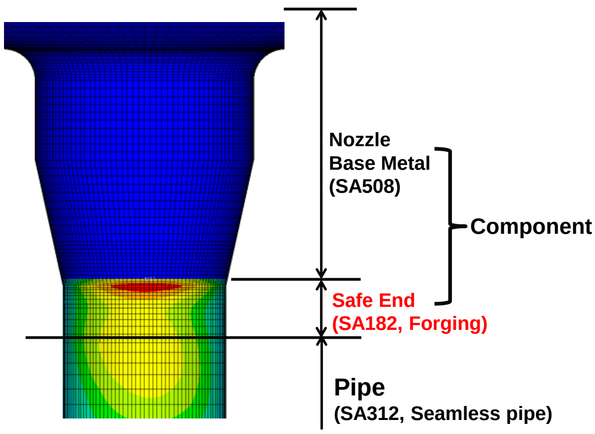

Fig.1 configuration of PZR surge nozzle and materials

3. Inelastic Material Models

The elasto-plastic material models used in this study are as follows;

- Bilinear kinematic hardening model
- Chaboche's kinematic hardening model
- Voce isotropic hardening model

Fig.2 presents the bilinear kinematic hardening model both for nozzle and pipe materials.

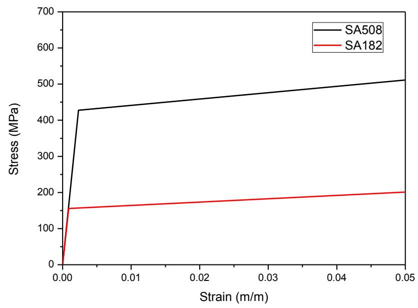

Fig.2 Curves for bilinear material model

For the Chaboche's kinematic hardening model, the revolution of back stress is given as,

$$\dot{\alpha}_{ij} = \sum_{k=1}^{n} (\dot{\alpha}_{ij})_k = \sum_{k=1}^{n} \left(\frac{2}{3} C_k \dot{\varepsilon}_{ij}^{p} - \gamma_k (\alpha_{ij})_k \dot{p} \right).$$

In above equation, the superposition parameter $n = 3$.

For the Voce isotropic hardening model, the revolution drag stress is given as,

$$\dot{R} = b(Q - R)\left|\dot{\varepsilon}^{vp}\right|.$$

Fig. 3 shows the strain-controlled material behavior used in this study.

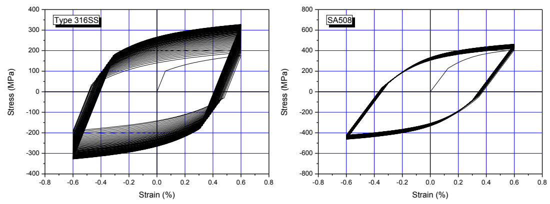

Fig.3 Combined Chaboche and Voce model

4. Results and Discussions

Fig.4 presents the coupled finite element model including the nozzle and piping system which will cause seismic nozzle load.

The maximum accumulated equivalent plastic strain occurs at the safe-end region as shown in Fig.5.

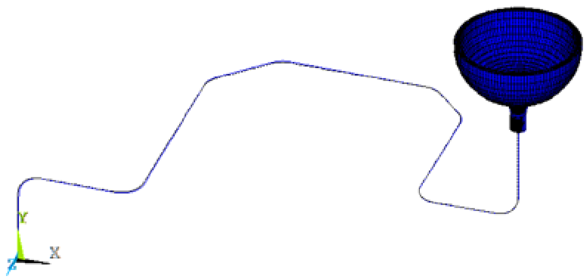

Fig.4 Coupled finite element model

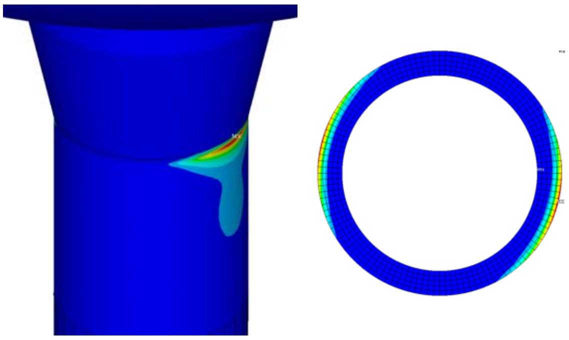

Fig.5 Accumulated equivalent plastic strain contour

Fig.6~Fig.8 present the axial directional stress-strain responses for (1) bilinear model, (2) Chaboche's kinematic only, and (3) Chaboche's kinematic + Voce isotropic respectively. As shown in results, we can see that more sophisticate inelastic model gives less accumulated plastic strain results. As expected, the isotropic hardening model, which increases the cyclic yield point, affects in way of reducing the plastic strain accumulations.

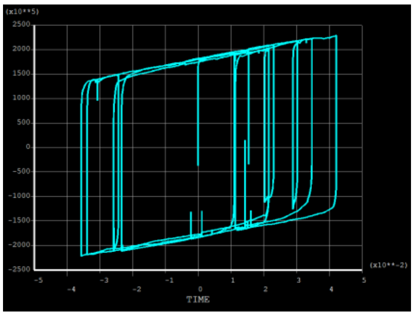

Fig.6 Stress-strain response (Bilinear model)

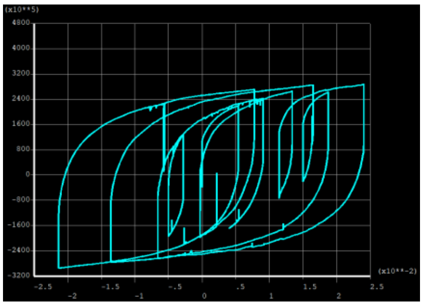

Fig.7 Stress-Strain response (Chaboche's kinematic only)

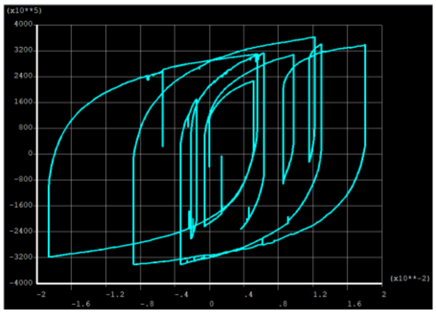

Fig.8 Stress-strain response (Chaboche + Voce)

The time history responses of plastic strain accumulations are shown in Fig.9. AS shown in figure, the bilinear kinematic model results in too conservative plastic strain to be used in the elasto-plastic seismic design. And

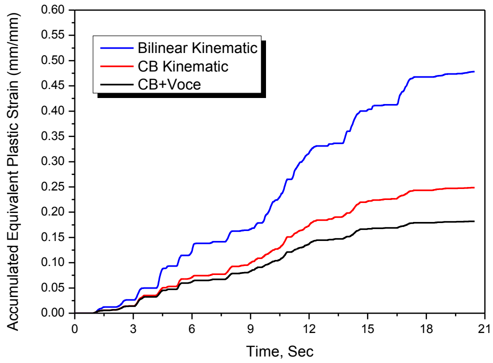

Fig.9 Comparison of material models

5. Conclusions

In this paper, we investigate the sensitivity of elsato-plastic material models in calculation of the accumulated equivalent plastic strain by the elasto-plastic seismic time history analysis in order to adapt the strain-based seismic design. As conclusions, the bilinear material model is so simple to be used for design but may not give the benefit of inelastic seismic analysis. It is necessary to develop the detailed inelastic material models in order to keep the advantage of strain-based seismic design.

Acknowledgement

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REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Appendices, 2017.

[2] Chaboche, J.L.,"Constitutive Equations for Cyclic Plasticity and Cyclic Viscoplasticity," Int. J. Plasticity, Vol. 5 pp.247-302. 1989.