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I-A 12 CYCLIC INELASTIC ANALYSIS OF STEEL FRAMES USING TWO-SURFACE MODEL

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INTRODUCTION: The present paper is a sequel to the study in reference 1) and is concerned with the cyclic inelastic large displacement analysis of steel planar rigid frames modeling bridge piers using the two-surface model[2),3)] (2SM) for material nonlinearity.

METHOD OF ANALYSIS: An elastoplastic finite element formulation for beam-column, considering geometrical and material nonlinearities, was developed and implemented in the computer program FEAP used in the analysis[4)]. The developed formulation (using 2SM) accounts for the gradual variation of section properties in line with the spread of plasticity across the section and along the member length. The advantage of the proposed approach is its accuracy and avoidance of generating the moment-curvature curve required in the lump plasticity method of analysis.

NUMERICAL RESULTS: A series of numerical studies on the cyclic behavior of steel planar rigid frames are carried out and the results are compared with the test data[5)]. In this section two typical examples illustrating the capability and accuracy of the developed formulation (2SM) are presented. Local buckling, initial geometrical imperfection and residual stress are not considered in the analysis.

Specimens: The test frames were built up by welding rolled H-shaped members[5)]. They are modeled by a knee-shaped frame, with boundary and loading conditions as shown in Fig. 1, which is used in the analyses. In both examples, the height of the column h, is equal to the length of the beam L ($h = L = 750\ mm$).

Example 1: In the example 1 (series II-1[5)]), the frame is subjected to fully reversed lateral displacement cycles in the absence of axial load. Figs. 2(a) and 2(b) compare the experimental and analytical (2SM) lateral load-lateral displacement hysteretic behavior at point A (Fig. 1). In this example, both the column and beam were made of rolled H-shaped members of wide flange, $H - 100 \times 100 \times 6 \times 8$[5)]. The material used has the properties of Young's modulus $E = 206GPa$, yield stress $\sigma_y = 262MPa$, length of yield plateau $\varepsilon_{st}/\varepsilon_y = 14.6$, plastic modulus at the initial hardening $E_{st}/E = 0.015$ and ultimate stress $\sigma_u = 403MPa$. Figs. 2(a) and 2(b) show that the overall shape of the hysteresis loops for the developed formulation (2SM) are in good agreement with the experiment mainly owing to the accuracy of the 2SM.

Example 2: In the example 2 (series I-2[5)]), first the frame is subjected to constant axial load of $P/P_y = 0.33$ (P_y is the squash load of the column) and then fully reversed lateral displacement cycles are applied. Fig. 3 compares the experimental and analytical lateral load-lateral displacement hysteretic behavior at point A. In this example, the column has the same section and material properties as in the previous example. Whereas, the beam was made of rolled wide flanges, $H - 100 \times 50 \times 4 \times 6$[5)] with the material properties of $E = 206GPa$, $\sigma_y = 318MPa$, $\varepsilon_{st}/\varepsilon_y = 12.6$, $E_{st}/E = 0.013$ and $\sigma_u = 452MPa$.

Fig. 3 shows that in contrast to the prediction using the simplified elastic-perfectly plastic moment-curvature relationship[5)] (EPP model), the overall shape of the hysteresis loops for the developed formulation (2SM) are significantly in close fit to that of the experiment. One important point to notice is that, as shown in Figs. 3(a) and 3(b), the hysteresis loops are smoothly curved for the experiment and 2SM in contrast to the prediction by the EPP model [Fig. 3(c)] with sharp bendings. Since the EPP model fails to represent accurately the real cyclic behavior of structural steels, such as the yield plateau, Bauschinger effect and cyclic strain hardening. In case of the analysis using the 2SM, Bauschinger effect is taken into account accurately which cause softening of the hysteresis curve (reduction in stiffness) and leads to smoothly curved hysteresis loops. Also, the

2SM accurately treats the yield plateau and cyclic strain hardening of the material[3]. This leads to an accurate prediction of the plastified zone which in turns affects the overall response of the frame.

The cumulative absorbed energy for experiments and predictions are given in the inset of Figs. 2 and 3. Comparison of these results indicates that the 2SM closely predicts the experimentally obtained cumulative energy absorption capacity in both examples.

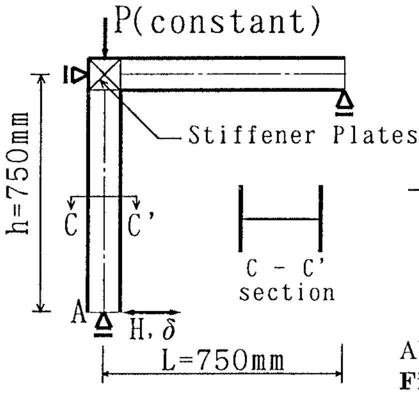
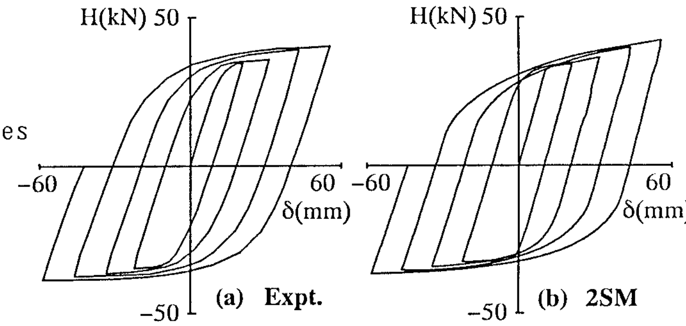
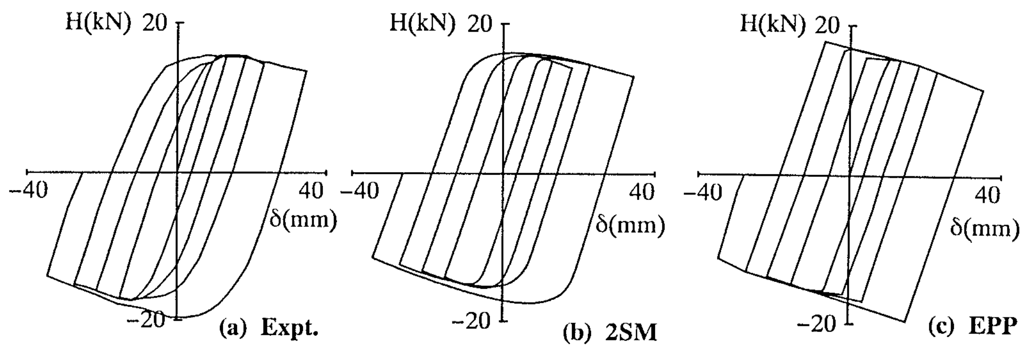


Fig. 1 Model Frame



Abs. Energy=12183 kN·mm Abs. Energy=12462 kN·mm

Fig. 2 Lateral Load H-Lateral Displacement δ, at Point A: (a) Experiment[5]; (b) Developed Formulation (2SM).



Abs. Energy=3124 kN·mm Abs. Energy=3156 kN·mm Abs. Energy=3224 kN·mm

Fig. 3 Lateral Load H-Lateral Displacement δ, at Point A: (a) Experiment[5]; (b) Developed Formulation (2SM); (c) Simplified EPP Moment-Curvature Approach[5].

CONCLUSIONS: The important conclusion is that the developed formulation (2SM) exhibits the capability of duplicating the experimental results more accurately, both quantitatively and qualitatively. Thus, it is recommended to use the 2SM where possible, since other models,such as EPP, may results in unrealistic estimates of the ductility and energy absorption capacity.

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