I-112 SECOND-ORDER INELASTIC ANALYSIS OF STEEL FRAMES

TOMA, Shouji Hokkai-Gakuen University
CHEN, Wai-Fah Purdue University

1. INTRODUCTION

While the Allowable Stress Design (ASD) is based on the first yielding of members, the Limit State Design (LSD) is based on the full plastic moment capacity of members. The LSD essentially requires inelastic analysis. However, most of the current LSD specifications are based on elestic analysis or simple plastic hinge method from which the equivalent limited loads (or sectional forces) are obtained including second-order and inelastic effects. In U.S.A. and Europe, prominent research activities are focussed on the development of practical design tools and procedures based on the second-order inelastic analysis. The structural committees in U.S.A., AISC TG117 (chaired by W. McGuire, Cornell University) and SSRC TG29 (chaired by D. W. White, Purdue University), are working on the development of design procedures based on the second-order inelastic analysis. In ECCS, the drafted LSD specifications[1)] and in Australia, the LSD specifications[2)] are published.

The second-order inelastic analysis requires the use of computers because of its complexity. All the design specifications currently in use are based on the technology of calculators. However, engineers now use at least personal computers. Thus, the codification must be adjusted to follow the design procedures based on the use of personal computers.

The present paper describes briefly the state-of-the-art of the second-order inelastic analysis of steel frames, especially from the desgin point of view.

2. PLASTIC ZONE THEORY

The most sophistcated analytical method for frame analysis is called plastic zone theory. As seen in Fig. 1, members are discretized into a number of segments and the sections are further divided into fiber elements. The yield criterion is typically limited here to the consideration of axial stress only. In this process, the analysis considers a gradual spread of plastic zones as the loads approach the ultimate strength. Also, the theory includes all possible causes of non-linearity such as residual stresses, initial out-of-plumbness and out-of-straightness, etc. Out-of-plane instability is usually not taken into account.

An "exact" solution might be given only by the test, but it is almost impossible to test many types of steel frames. A sophistcated solution such as plastic zone theory may possibly take its place. Although the plastic zone theory may be considered to be "exact" solution, it is too troublesome for the engineers to use in a daily work. A simpler method needs to be developed for practical design.

3. MODIFIED PLASTIC HINGE METHOD

Simple plastic hinge method is simple to use, but its accuracy may be questionable. Researches are now focussed on the improvement of accuracy of the plastic hinge concept[3)-5)]. In the conventional F. E. M. formulation for non-linear analysis, the force-deformation relation is expressed in the following incremental form in the usual notation,

$$\{\Delta F\} = [K_T]\{\Delta u\} \quad (1)$$

The tangent stiffness $[K_T]$ can be modified to include geometrical and material non-linearity as follows:

$$[K_T] = [K_e] + [K_G] + [K_P] \quad (2)$$

where $[K_e]$ = elestic stiffness matrix
$[K_G]$ = geomerical stiffness matrix
$[K_P]$ = stiffness degradation matrix due to spread of yielding

In the simple plastic hinge method, the stiffness changes abruptly from elastic to null at the formation of plastic hinge (Fig. 2). In the modified plastic hinge method, the stiffness is modified by the geometrical stiffness matrix to diminish gradually from the first yielding to the full capacity. If linear variation of the stiffness is assumed between the first yielding and the full plastic capacity as shown in Fig. 2, the stiffness degradation parameter ρ can be expressed by[3)]

$$0 \le \rho = \frac{M - M_{yc}}{M_{pc} - M_{yc}} \le 1.0 \qquad (3)$$

The modified plastic hinge method is expected to offer both simplicity and accuracy to the LSD and be used as a practical tool for the engineers.

4. CALIBRATION FRAMES

Simplified methods need to be verified by calibrating with benchmark problems which are considered as "exact". Each researcher uses different frames to show their analytical results. There is a need for well-established calibration frames, so that researchers can compare their results based on the same analytical assumptions. In Europe, three types of such frames have been selected and the analytical results are provided[5)]. In U.S.A., some possible frames for the calibration frame are being studied[6)].

5. CONCLUSIONS

Researchers in frame design can always provide accurate method for predicting the strength using sophistcated computer programs. This always brings complexity in designing, yet practicing engineers prefer simplicity in use. It appears that the modified plastic hinge concept provides a good compromise between accuracy in prediction and simplicity in use. This new design procedures will bring a drastic change in structural design from the current member-based-desgin to the upcoming system-based-design where the familiar factors such as the effective length factor K, the moment amplification factors B_1 and B_2, and the equivalent moment factor C_m will no longer be necessary.

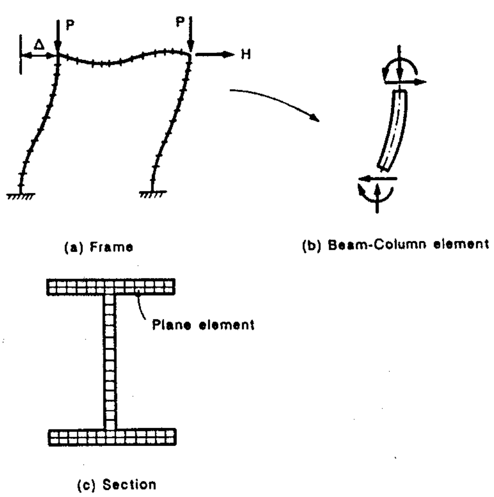

Fig. 1 Plastic Zone Theory

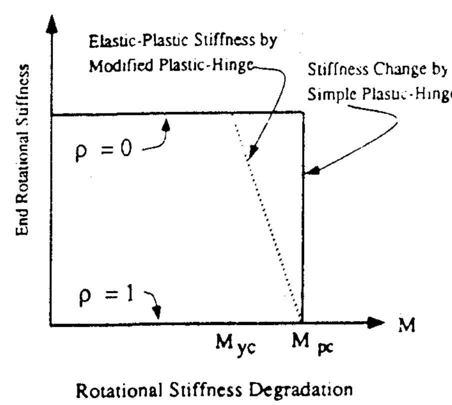

Fig. 2 Stiffness Degradation

REFERENCES

1) European Convention for Constructional Steelwork (ECCS), Editorial Draft, Issue 3, Eurocode No. 3, April 1990. 2) Australian Standards, AS4100, Section 4 Methods of Structural Analysis, October 1990. 3) King, W. S., White, D. W., and Chen, W. F., "A Modified Plastic Hinge Method for Second-Order Inelastic Analysis of Steel Rigid Frames," Structural Engineering Report, No. CE-STR-90-17, Purdue University, West Lafayette, IN. 1990, 34 pp. 4) Deirlein, G. G., and McGuire, W., "A Concentrated Plasticity Approach to Inelastic Design", Proc. of 1991 ASCE Structures Congress, ASCE, Indianapolis, April 29-May 1, 1991. 5) Vogel, U., "The Stability of Framed Structures," excerpted from "Frame and Slab Structures," G. S. T. Armer and D. B. Moore (editors), Butterworths, London, 1989, pp. 29-56. 6) Toma, S., and Chen, W. F., "Calibration Frames for Second-Order Inelastic Analysis of Frame Structures," Structural Engineering Report, Purdue University, 1991.