Simple and Direct

BY R. SHANKAR NAIR, PH.D, P.E., S.E.

The Direct Analysis Method will become the primary method of design for stability in the next AISC *Specification*.

THE DIRECT ANALYSIS METHOD (DAM) OF DESIGN for stability was introduced in the 2005 AISC *Specification for Structural Steel Buildings* (AISC, 2005) to cheers from stability professionals, who recognized it as the most rational and transparent stability design method yet proposed in the U.S.—and to the consternation of many practitioners, who imagined that the arcane art of stability design was about to get even more complicated. But as this brief article will show, the consternation was unwarranted. The DAM is really simple; it consists of just these steps:

- A second-order analysis
- Use of reduced stiffness in the analysis
- Application of a "notional load" in the analysis under certain circumstances
- Strength check of members using $K = 1$ for compressive strength

Second-Order Analysis

Second-order analysis was already required in the 1999 AISC *Specification* (AISC, 1999); this is not a new requirement unique to the DAM. Both P-Δ effects (the effects of loads acting on the displaced locations of joints or nodes in the structure) and P-δ effects (the effects of loads acting on the deformed shapes of individual members) must be considered.

Almost all computer programs that claim to do second-order analysis handle P-Δ effects adequately, but some do not consider P-δ effects. For many (if not most) real-world buildings, it is acceptable to use a program that neglects the effect of P-δ on the overall response of the structure: If the ratio of second-order drift to first-order drift is less than 1.5, and no more than one-third of the total gravity load on the building is on columns that are moment-connected in the direction of translation being considered, the error in a P-Δ-only analysis will be negligible. (It is necessary in all cases to consider the effect of P-δ on individual compression members.)

Instead of doing a rigorous second-order analysis, the designer still has the option of using the familiar "B_1 and B_2" procedure, in which the results of a first-order analysis are amplified by factors B_1 and B_2 to account for second-order effects. Factor B_1, calculated for each beam-column and each direction of bending of the beam-column, accounts for P-δ effects; B_2, calculated for each story of the building and each direction of lateral translation of the story, accounts for P-Δ effects. First-order analysis amplified by B_1 and B_2 is second-order analysis.

The second-order analysis must be conducted for LRFD load combinations. (Note that the principle of superposition does not apply; results for different loads cannot be superimposed.) If ASD is being used, the analysis must be conducted under 1.6 times the ASD load combination and the results divided by 1.6 to obtain the forces and moments for ASD strength checks of components.

Reduced Stiffness in the Analysis

A factor of 0.8 has to be applied across the board to all stiffnesses in the analysis. An additional factor, τ_b, has to be applied to the flexural rigidity of framed columns in which the axial force (under LRFD load combination or 1.6 times ASD combination) is greater than half the yield force.

In lieu of applying the additional reduction factor τ_b (if there are indeed columns to which the additional factor is applicable), the designer may apply at each floor an additional lateral load of 0.001 times the vertical load applied on that floor.

Application of Notional Loads

A "notional load" (which is an additional lateral load intended to simulate the effects of initial out-of-plumbness of

R. Shankar Nair, Ph.D., P.E., S.E. is a principal and senior vice president of Teng & Associates, Inc. in Chicago. He is a member of the AISC Specification Committee and chairman of the Stability Task Committee.

COMPARISON OF STABILITY DESIGN METHODS			
	Direct Analysis Method	Effective Length Method	First-Order Analysis Method
Type of analysis	Second-Order	Second-Order	First-Order
Member stiffness in analysis	Reduced EI & EA	Nominal EI & EA	Nominal EI & EA
Notional lateral load?	In some cases	In some cases	Yes; always
Column effective length in strength check	$K = 1$	Sidesway buckling analysis	$K = 1$

the building) must be applied under certain conditions. When required, the magnitude of the notional load on each floor is 0.002 times the vertical load applied on that floor.

If the ratio of second-order drift to first-order drift (a ratio reasonably approxi-mated by the B_2 multiplier) is greater than 1.5, notional loads must be included in all load combinations. If the ratio is less than 1.5, notional loads need to be applied only in gravity-only load combinations; they need not be applied in combination with other lateral loads.

Member Strength Checks

When the forces and moments in members have been determined from the analysis outlined above (second-order reduced stiffness notional loads when applicable), member capacities can be checked using an effective length factor, K, of unity for members subject to compression.

Comparison with Other Methods

The 2005 AISC *Specification* offers three alternatives for the design of structures for stability. The Direct Analysis Method is in Appendix 7. The main body of the *Specification*, in Chapter C, prescribes two methods: the Effective Length Method (ELM) in Section C2.2a and the First-Order Analysis Method (FAM) in Section C2.2b. (Unfortunately, neither method is identified by these names in the *Specification*.) The DAM is applicable to all structures; the ELM and FAM are applicable only to structures for which the ratio of second-order drift to first-order drift is less than 1.5.

The only significant difference between the Direct Analysis Method and the Effective Length Method is that where the DAM uses reduced stiffness in the analysis and $K = 1$ in the member strength check, the ELM uses nominal stiffness in the analysis and K is determined from a sidesway buckling analysis in the strength check of columns in moment frames. In this author's experience, K is rarely calculated properly for real buildings (as opposed to the isolated plane frames typically used in academic exercises).

The First-Order Analysis Method uses mathematical manipulation to achieve approximately (and conservatively) the same results as the Direct Analysis Method. In the FAM, an additional lateral load is applied in a first-order analysis to simulate the effects of a B_2 multiplier, a stiffness reduction, and a notional load; B_1 multipliers are then applied explicitly to all beam columns.

Design for stability under the 1999 AISC *Specification* was generally similar to today's Effective Length Method except that the limit on applicability of the ELM (ratio of second-order drift to first-order drift less than 1.5) and the requirement for a notional load in gravity-only load combinations were not present.

Looking Ahead

In the 2010 AISC *Specification*, now in the later stages of balloting by the AISC Committee on Specifications, the Direct Analysis Method will be the primary method of design for stability; it will be presented in Chapter C while the Effective Length Method and the First-Order Analysis Method will be in an appendix.

The "B_1 and B_2" procedure for approximate second-order analysis will be in a separate appendix, to emphasize that unlike the DAM, ELM and FAM, which are methods of design (defined as the combination of analysis and component strength checking), the B_1–B_2 procedure is simply an analysis technique, applicable wherever a second-order analysis is required.

The focus on the DAM as the primary method of stability design in the 2010 *Specification* offered the opportunity to expand some of the provisions beyond what is in the current *Specification*, both to improve clarity and to address issues that have arisen from use of the document. A preview of the stability design section of the 2010 *Specification* can be found in a paper by this author (Nair, 2009); the paper also outlines the rational basis of the specification provisions and offers suggestions for the modeling of structures for the application of the Direct Analysis Method. MSC

REFERENCES

AISC (1999), *Load and Resistance Factor Design Specification for Structural Steel Buildings*, American Institute of Steel Construction, Inc., Chicago.

AISC (2005), *Specification for Structural Steel Buildings*, American Institute of Steel Construction, Inc., Chicago.

Nair (2009), "A Model Specification for Stability Design by Direct Analysis," *Engineering Journal*, AISC, Vol. 46, No. 1, Chicago.