Stability Analysis and the 2005 AISC Specification

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

Here's a brief look at the background to the stability requirements in the 2005 AISC specification.

IN TODAY'S ENGINEERING PRACTICE, THERE IS NO SUCH THING AS A "NORMAL" OR "STANDARD" STRUCTURAL ANALYSIS. Advanced analysis methods that were regarded as research tools a few years ago have entered some design offices, while other practices are still using the same (except bigger and faster) analysis tools they had a generation ago. This is especially true in the area of stability, where direct, rigorous second-order analysis is routine in some practices but not in others. This range in analysis options is especially important in the area of stability because of the close interrelationship between stability design and analysis.

The provisions regarding analysis, and especially stability, in the 2005 AISC *Specification for Structural Steel Buildings* represent a significant departure from earlier editions. The new specification recognizes the wide range of analyses in common use. It spells out the general safety- and reliability-based requirements that must be satisfied by all structural designs—giving designers the freedom to select or devise their own methods of analysis and design within these constraints—and also provides "prescriptive" methods for those (possibly a large majority of designers) who prefer that approach.

This paper discusses the logical basis of the new specification requirements for stability, and outlines the three alternative prescriptive methods that are specified.

R. Shankar Nair, Ph.D., P.E., S.E. is the recipient of AISC's 2007 T.R. Higgins Lectureship Award. Nair is a principal and senior vice president of Teng & Associates, Inc. in Chicago.

In a career that has focused on structural design of large architectural and civil engineering projects, he has developed the structural concepts for numerous tall buildings and major bridges, including the longest tied arch in the world and a 1047-ft tall building now under construction in Chicago. His work has received many awards, including four AISC/NSBA Prize Bridge awards and six Structural Engineers Association of Illinois Most Innovative Structure awards.

He has served as chairman of the Council on Tall Buildings and Urban Habitat and is, at present, a member of the AISC Specification Committee and chairman of its Stability Task Committee. He is a winner of AISC's Lifetime Achievement Award and a member of the National Academy of Engineering.

Nair present this paper as part of a recent talk at NASCC: The Steel Conference in New Orleans.

This article has been excerpted from a paper presented at The Steel Conference, April 18-21 in New Orleans. The complete paper will be available online later this month at **www.aisc.org/epubs**.

Table 1. Comparison of Analysis and Design Options.

	Direct Analysis Method	Effective Length Method	First-Order Analysis Method
Specification reference	Appendix 7	Section C.2.2a	Section C.2.2b
Limits on applicability?	No	Yes	Yes
Type of analysis	Second-Order	Second-Order	First-Order
Member stiffness	Reduced EI & EA	Nominal EI & EA	Nominal EI & EA
Notional lateral load?	Yes	Yes	Additional lateral load
Column effective length	K=1	Sidesway buckling analysis	K=1

The most versatile and powerful of these methods is the Direct Analysis Method. An appendix to this paper offers a model specification reformulated around the Direct Analysis Method alone, making it easier to understand and use. This represents the direction in which the AISC specification appears to be evolving; the stability section of the next edition is likely to resemble this model specification.

General Requirements

The chapter of the specification on "Design Requirements" (Chapter B) specifies that the design of structural components must be consistent with the assumptions made in the structural analysis used to determine the required strengths of the components. There are no other constraints on the method of analysis.

The chapter on "Stability Analysis and Design" (Chapter C) specifies that the design of the structure for stability must consider all of the following:

- Flexural, shear, and axial deformations of members.
- All other component and connection deformations that contribute to displacements of the structure.
- P-Δ effects, which are the effects of loads acting on the displaced location of points of intersection of members in the structure. (In typical building structures, this is the effect of loads acting on the laterally displaced location of floors and roofs.)
- P-δ effects, which are the effects of loads acting on the deformed shape of individual members.
- Geometric imperfections, such as initial out-of-plumbness.
- The reduction in member stiffness due to inelasticity (including residual stress effects) and, in particular, the effect of this stiffness reduction on the stability of the structure.

When the required strengths of members have been determined from an analysis that considers all the above effects, the members can be designed using the provisions for design of individual members (provided in Chapters D, E, F, G, H, and I).

The specification states explicitly that any method of analysis and design that considers all the specified effects is permissible, and then presents certain specific approaches that account for the last four of the listed effects (P-Δ effects, P-δ effects, geometric imperfections, and inelasticity).

Direct Analysis Method

The most generally applicable method of accounting for P-Δ and P-δ effects, geometric imperfections, and inelasticity is the Direct Analysis Method (presented in Appendix 7 of the AISC specification). It is applicable to all types of structural systems; the provisions of the Direct Analysis Method do not distinguish between braced frames, moment-resisting frames, shear wall systems, and combinations of these and other structure types. In the Direct Analysis Method:

- P-Δ and P-δ effects are accounted for through second-order analysis (either explicit second-order analysis or second-order analysis by amplified first-order analysis, for which a procedure is presented in the specification).
- Geometric imperfections are accounted for either by direct inclusion of imperfections in the analysis model or by the application of "notional loads" (which are a proportion of the gravity load, applied laterally).
- Stiffness reductions due to inelasticity are accounted for by reducing the flexural and axial stiffnesses of members by specified amounts or, at the designer's option, by a combination of reduced member stiffness and additional notional loads.

When the required strengths of members have been determined from an analysis conforming to the above requirements, individual members can be designed using an effective length factor of unity in calculating the nominal strengths of members subject to compression.

The specification provides enough direction to allow application of the Direct Analysis Method in "cook book" fashion. But it also lays out the logical basis for the provisions in a way that offers designers the option of tailoring the method to particular situations. For instance, it is spelled out that the specified 0.002 notional load coefficient to account for geometric imperfections is based on a maximum initial story out-of-plumbness ratio of 1/500; a different notional load can be used if the known or anticipated out-of-plumbness is different; the imperfections can even be modeled explicitly instead of applying notional loads.

In time, if not immediately, the Direct Analysis Method will almost certainly become the "standard" method of stability design of steel building structures.

Indirect Methods

For structures in which second-order effects are not very large (where the ratio of second-order drift to first-order drift is below a specified threshold), the specification offers two alternatives to the Direct Analysis Method.

Effective Length Method. In this method, the structure is analyzed using the nominal geometry and nominal elastic stiffness of all members; required member strengths are determined from a second-order analysis (either explicit second-order analysis or second-order analysis by amplified first-order analysis); all gravity-only load combinations include a minimum lateral load at each frame level of 0.002 of the gravity load applied at that level. Effective length factors (K) or buckling stresses for calculating the nominal strengths of compression members must be determined from a sidesway buckling analysis, except that K=1 may be used for braced frames or where the ratio of second-order drift to first-order drift is less than 1.1.

First-Order Analysis Method. This method is applicable only when the required compressive strength is less than half the yield strength in all members whose flexural stiffnesses are considered to contribute to the lateral stability of the structure. In this method, the structure is analyzed using the nominal geometry and nominal elastic stiffness of all members; required member strengths are determined from a first-order analysis; all load combinations include an additional lateral load at each frame level of a magnitude based on the gravity load applied at that level and the lateral stiffness of the structure. The nominal strengths of compression members may be determined assuming K=1; beam-column moments must be adjusted (using a formula that is provided) to account for non-sway amplification.

The alternative analysis methods and corresponding stability design requirements in the 2005 AISC specification are summarized in Table 1.

Methods of Second-Order Analysis

As noted in the discussion of alternative analysis-design approaches, the Direct Analysis Method and one of the two indirect methods require a second-order analysis of the structure. The second-order analysis can take the form of an explicit second-order analysis that includes both P-Δ and P-δ effects. Alternatively, the second-order analysis can consist of amplified first-order analysis, for which a detailed procedure is provided in the specification. (This is the "B1-B2" procedure familiar to designers from previous editions of the specification.)

Since stability is an inherently nonlinear phenomenon, it is essential that all second-order analyses be carried out at the LRFD load level. To obtain the proper level of reliability when ASD is used, the analysis must be conducted under 1.6 times the ASD load combinations and the results must then be divided by 1.6 to obtain the forces and moments for member design by ASD. (The 1.6 load multiplier must also be used, in ASD, when checking the ratio of second-order drift to first-order drift, as required under certain provisions.)

Additional Information

This outline of the analysis provisions in the 2005 AISC specification is intended primarily as an introduction to these provisions and to show the logical progression of the provisions from general requirements applicable to all structures to specific procedures that designers may choose to use for the design of typical structures. More information on the rational basis of the new specification provisions can be found in the Commentary to the specification and the references listed therein.

Further Developments

The most versatile and powerful of the three alternative methods of stability analysis and design in the 2005 AISC specification is the Direct Analysis Method. An appendix to this paper (available in the full version of this paper online at **www.aisc.org/epubs**) offers a model specification reformulated around the Direct Analysis Method alone, making it easier to understand and use. This represents the direction in which the AISC specification appears to be evolving; the stability section of the next edition is likely to resemble this model specification. A second appendix (also available with full version at **www.aisc.org/epubs**) explains the substantive differences between this model specification and the present AISC specification. MSC

Reference

AISC (2005), *Specification for Structural Steel Buildings*, ANSI/AISC 360-05, American Institute of Steel Construction, Inc., Chicago.