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GETTING FILLED IN ON COMPOSITE COLUMNS

A look at changes to composite column design in the 2016 AISC *Specification*.

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THE RECENTLY RELEASED 2016 AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360-16, available at **www.aisc.org/specifications**) contains a number of important enhancements and revisions relevant to the design of steel-concrete composite columns.

Changes include an expansion and clarification of the *Specification*'s scope as it pertains to composite columns, improved provisions for the assessment of stability and member strength and an enhanced treatment of load transfer. This information, contained primarily within Chapter I, represents the AISC Committee on Specifications' efforts to incorporate relevant new research while increasing usability and design efficiency.

Expanded Scope

When it comes to the evolution of the *Specification*'s scope, three changes were made that broaden and clarify the range of composite columns that is covered. First, the glossary definition of filled composite members has expanded. While filled composite members were previously limited to fabricated hollow structural sections (HSS) filled with structural concrete, the *Specification* now also applies to filled composite members constructed with box sections (square or rectangular doubly symmetric members made with four plates welded together at the corners). This change is based on an evaluation of available experimental results on composite columns constructed with both fabricated HSS sections and built-up box sections, which indicated similar performance for both configurations.

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Second, for filled composite members used as columns, it has been clarified that neither longitudinal nor transverse reinforcement are required, even in cases where longitudinal reinforcement is provided (due to the confining effect of the steel section). This change simply adds an explicit statement of the original intent, since the majority of experimental data on which the filled composite member provisions are based are from specimens without any internal reinforcing.

Third, the maximum permitted yield stress of reinforcing bars has increase from 75 ksi to 80 ksi to match a corresponding increase in permitted strength in ACI 318.

Stability and Axial Strength

Many of the more substantial changes to the composite column provisions pertain to how stability and member axial strength are assessed. The direct analysis method was introduced in Appendix 7 of the 2005 *Specification* and moved to Chapter C in the 2010 version. A key component of the direct analysis method is member stiffness reductions that must be made when determining required strengths. Previously, these adjustments were only defined for bare structural steel members. In the 2016 *Specification*, the newly added Section I1.5 explicitly defines the stiffness to be used for composite columns within the direct analysis method. For example, the flexural stiffness of composite columns under net compression is taken as $0.8\tau_b EI_{eff}$, where EI_{eff} is the effective stiffness defined for the computation of axial strength in Section I2, and $0.8\tau_b$ is the adjustment specified within Chapter C. The factor, τ_b, has been specially defined for composite columns as a constant 0.8, resulting in the use of $0.64EI_{eff}$ for flexural stiffness. These new provisions were based on analytical research following the same methods used in the original development of the direct analysis method for bare steel members.

The effective stiffness, EI_{eff}, equations have also been revised based on the same research and a reevaluation of experimental data. Previously, the effective stiffness was taken as the summation of the stiffness from each component (steel, concrete and reinforcement) based on gross cross-sectional properties with reduction factors applied to the concrete contribution and to the reinforcement contribution for encased composite members. The form of the equations remains the same, but the factors have been updated to reflect the new research. For encased composite members, the effective stiffness increases significantly both with the removal of the factor on the reinforcement contribution and an increase to the concrete contribution factor, C_1. For filled composite members, the effective stiffness may decrease slightly corresponding to the lower concrete contribution factor, C_3, for steel ratios below 15%. The changes to the concrete contribution factors are shown in Figure 1. However, note that the definition of steel ratio used in the equations has also changed in the new provisions.

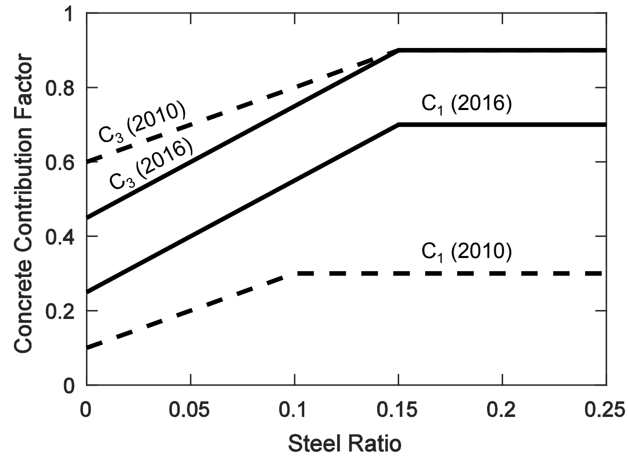


Figure 1. Change in the concrete contribution factor.

Interaction Strength

In addition to the base member axial and flexural strength revisions, two new methods for determining the strength of composite columns under combined axial load and bending moment have been added.

For filled composite members with non-compact or slender steel compression elements, it was previously required that the interaction diagram defined in Section H1.1 be used. A new option for the evaluation of strength under combined flexure and axial compression has been developed for these sections, in which an interaction surface consisting of a generalized bilinear curve with an anchor point computed based on cross-sectional properties is constructed, as shown in Figure 2. The shape of the interaction surface better represents the location of the balance point for these generally concrete-dominant members.

The second new method is for assessing the nominal strength of composite cross sections. The new method, called the effective stress-strain method, as defined in Section I1.2d, is similar to the strain compatibility method but allows for stress-strain relationships that account for phenomena that are not strictly a material response, such as local buckling of the steel section and concrete confinement. An example of such a stress-strain relationship is shown in Figure 3, where the compression response of the steel section has been altered to include the effects of local buckling.

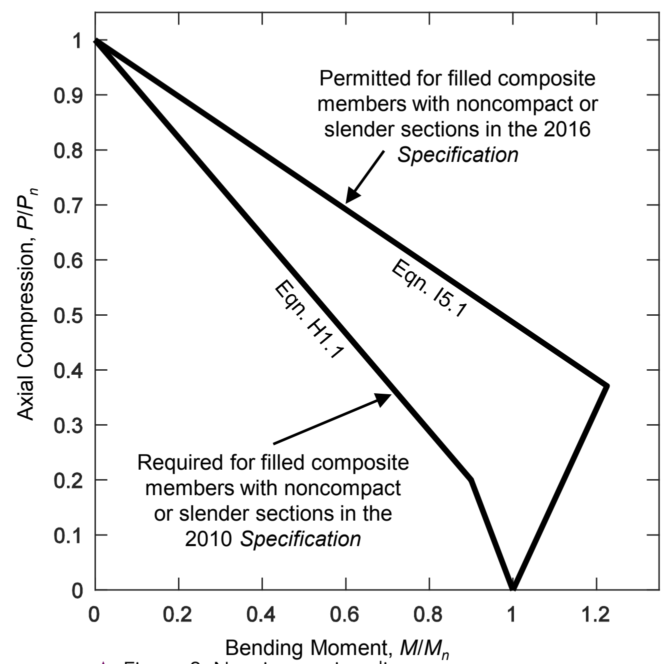


Figure 2. New interaction diagram.

Load Transfer

The direct bond interaction provisions in Section I6.3c have undergone a major revision for the 2016 *Specification*. Based on a reevaluation of available experimental data, new equations have been developed for bond strength as a function of cross-sectional dimensions. A sample of the experimental results from push-out tests on round filled composite members is

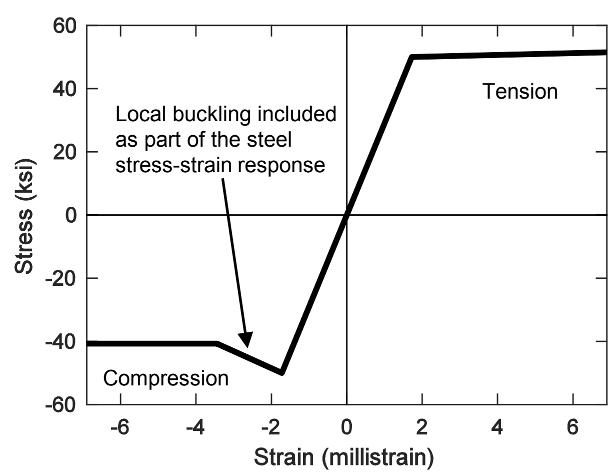


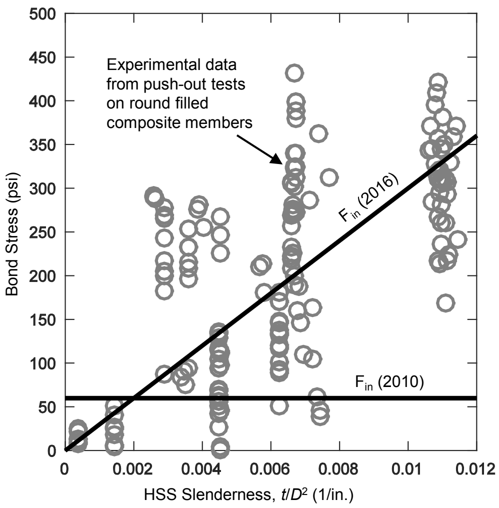
Figure 3. Effective stress-strain relationship.

shown in Figure 4, where t is the HSS thickness and D is the outside diameter of the round HSS.

Additionally, the area over which the bond stress acts has been updated to be the product of the load introduction length and the entire interface perimeter, and the load introduction length has been updated to be consistent with requirements of other load transfer mechanisms. The use of the whole interface perimeter is in contrast to previous editions of the *Specification*, where the cross section was partitioned into quarters for the calculation of strength. Correspondingly, the required strength must now be determined as the sum of the reactions from all members framing into the column at a given level. With the new provisions, bond strength becomes a more viable option for load transfer, particularly for smaller and thicker HSS and box sections with light to moderate applied loads.

Revisions were also made to the treatment of external force application to better address non-compact and slender cross sections. For slender filled composite members, external forces must be applied directly to the concrete to prevent localized thin-wall failures. These forces are then transferred to the steel section using a ratio involving the critical buckling stress of the steel elements as opposed to their full yield strength as in previous editions of the *Specification*.

Figure 4. Change in the bond stress, F_{in}.



Future Direction

Composite column design is a field of expanding research and rapid advancement, and the committee is already beginning to look forward to the next *Specification* cycle. Among the topics the committee is investigating for potential future updates are higher-strength materials, improved interaction diagrams for composite beam-columns and addressing long-term effects of creep and shrinkage. As always, the intent of both recent and future changes is to maintain safety, increase reliability and promote efficiency.