Technical Note

Unbraced Length Requirements for Steel Special Cantilever Column Systems

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ABSTRACT

AISC *Seismic Provisions* Section E6.4b for steel special cantilever column systems (SCCS) requires clarification based on inquiries to the AISC Steel Solutions Center. In the 2016 edition, it is unclear if bracing is required for all special cantilever columns or for columns with unbraced lengths that exceed the maximum beam brace spacing of L_b per Section D1.2a for moderately ductile members. Instead of using Equation D1-2, which is applicable to I-shaped beams only, equations for SCCS columns have been derived for both I-shaped members and rectangular HSS or box-shaped members. The proposed revision provides specific situations when bracing is required.

Keywords: AISC *Seismic Provisions*, steel special cantilever column system, bracing.

INTRODUCTION

ASCE/SEI 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, hereafter referred to as ASCE/SEI 7 (ASCE, 2016), specifies two steel cantilevered column systems: special cantilever column systems (SCCS) and ordinary cantilever column systems (OCCS), where the values of the response modification factor, R, are 2½ and 1¼, respectively. Although these systems have an R factor less than 3 due to a lack of system redundancy, they are required to satisfy the requirements in the AISC *Seismic Provisions for Structural Steel Buildings*, hereafter referred to as the AISC *Seismic Provisions* (AISC, 2016a). OCCS are intended to provide a minimal level of inelastic rotation capability at the base of the column. This system is permitted in Seismic Design Categories B and C and to heights not exceeding 35 ft. OCCS are also permitted in Seismic Design Categories D, E, and F with a height limit of up to 65 ft when meeting the requirements of ASCE 7, Section 12.2.5.6. A low R value of 1¼ is assigned due to the system's limited inelastic capacity and lack of redundancy. OCCS have two requirements beyond those in the AISC *Specification for Structural Steel Buildings*, hereafter referred to as the AISC *Specification* (AISC, 2016b). First, columns shall be designed using the load combinations, including the overstrength seismic load. Second, the required axial strength, P_{rc}, shall not exceed 15% of the available axial strength, P_c, for the load combinations, including the overstrength seismic load.

SCCS are intended to provide a limited level of inelastic rotation capability at the base of the column. This system is permitted in Seismic Design Categories B through F but is limited to heights not exceeding 35 ft. The required axial strength has the same limitation as OCCS to help reduce the likelihood of collapse. The column members are required to satisfy the width-to-thickness ratios for highly ductile members. However, the lateral bracing requirement for moderately ductile members is required due to the relatively low inelastic demand expected and the practical difficulty in achieving bracing in many of these structures. The purpose of the bracing is to restrain lateral-torsional buckling (LTB) of the column.

According to AISC *Seismic Provisions* Section D1.2b, the maximum beam brace spacing for highly ductile members is

$$L_b = 0.095 r_y E \big/ \left(R_y F_y\right) \tag{1}$$

and according to Section D1.2a, the maximum beam brace spacing for moderately ductile members is

$$L_b = 0.19 r_y E \big/ \left(R_y F_y\right) \tag{2}$$

Although not specifically stated in AISC *Seismic Provisions* Section D1.2, these two requirements are intended for doubly symmetric I-shape beams. For the next edition of the AISC *Seismic Provisions*, new maximum brace spacing for SCCS with I-shaped columns as well as rectangular HSS or box-shaped columns are proposed.

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BASIS OF CURRENT SEISMIC BEAM BRACING REQUIREMENTS

A review of the historical development of Equation 1 for beam design is first presented. The maximum spacing limits for lateral bracing of beams in the earlier editions of the AISC *Seismic Provisions* are based on the lateral bracing requirement for I-shaped sections using plastic design from AISC LRFD *Specification* Section F1.1 (AISC, 1986):

$$L_{pd} = \frac{3{,}600 + 2{,}200(M_1/M_p)}{F_y} r_y \tag{3}$$

where M_1 is the smaller moment at the end of the unbraced length, M_p is the plastic moment (replaced by M_2 in later editions), and M_1/M_p is positive when moments cause reverse curvature. Note that Equation 3 is based on tests of continuous beams for a target rotation capacity of 3, where the rotation capacity is defined as the ratio between plastic rotation and yield rotation (Bansal, 1971; Yura et al., 1978). Introducing the modulus of elasticity, E, to normalize F_y, Equation 3 is converted to the following form, which is AISC *Specification* Equation A-1-5 (AISC, 2016b):

$$L_{pd} = \left(0.12 - 0.076\frac{M_1'}{M_2}\right)\frac{E}{F_y} r_y \tag{4}$$

where M_1' is the effective moment at the end of the unbraced length opposite from M_2, M_2 is the larger moment at the end of the unbraced length, $M_1' = M_1$ when the midspan moment is not larger than the average of M_1 and M_2, and $M_1' = M_2$ is negative when moments cause reverse curvature. Assuming that (1) the effect of the gravity load component is small and can be ignored and (2) the inflection point due to the seismic effect is at the midspan of a moment frame beam, M_1/M_2 equals +1.0 per Equation 3 [see Figure 1(a)]. However, for seismic applications, the AISC *Seismic Provisions* implicitly assume a conservative seismic moment diagram like that shown in Figure 1(b) with M_1/M_2 equal to −½. Substituting this latter moment ratio and introducing the modulus of elasticity, *E,* into Equation 3 gives the following:

$$L_b = \frac{2500 r_y}{F_y} = 0.086\frac{r_y E}{F_y} \tag{5}$$

To include the R_y factor in Equation 5 with an assumed value of 1.1, Equation 5 becomes Equation 1 for highly ductile beams since the 2016 edition of the AISC *Seismic Provisions*, which is required for beam design in special moment frames (SMF).

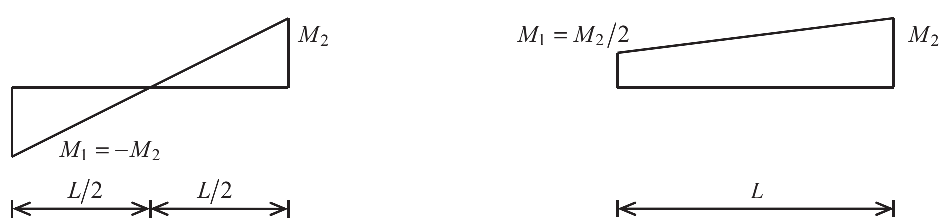
The requirement for the maximum beam brace spacing of I-shaped beams in systems like intermediate moment frames (IMF) is more relaxed than that in SMF because, according to the Commentary of the 2005 AISC *Seismic Provisions* (AISC, 2005), a lower story-drift angle (0.02 rad) is required in comparison to that required for SMF (0.04 rad). The AISC *Seismic Provisions* assume that the maximum beam brace spacing for IMF is twice that for SMF (i.e., Equation 2).

PROPOSED L_b FOR SCCS COLUMNS

The AISC *Seismic Provisions* specify a maximum brace spacing for SCCS (Equation 2), which was developed for I-shaped beams in IMF with an assumed moment gradient. Instead of using Equation 2 for columns in SCCS, the maximum brace spacing can be derived directly from the original formula (Equation 3) by using the actual moment gradient. The moment, M_1, at the top end of the column can be equal to zero. However, it can also be nonzero and can be determined easily in the design process—for example, an SCCS used as an inverted pendulum-type structure. Therefore, to accommodate the possible loading scenarios of cantilever columns, the moment ratio term is retained from the original equations. Note that F_y in the original development of Equation 3 represents the actual, not nominal, yield stress. Referring to Equation 4, which is equivalent to Equation 3 but with an opposite definition of the sign convention for the moment gradient (see Figure 1), the F_y term can be substituted for $R_y F_y$ directly for implementation in the AISC *Seismic Provisions*:

$$L_b = \left(0.12 - 0.076\frac{M_1}{M_2}\right)\frac{r_y E}{R_y F_y} \tag{6}$$

where M_1/M_2 is positive when moments cause single curvature.



(a) $M_1/M_2 = +1$ *(Eq. 3) or* $= -1$ *(Eq. 4)* *(b)* $M_1/M_2 = -½$ *(Eq. 3) or* $= +½$ *(Eq. 4)*

Fig. 1. Assumed seismic moment diagrams.

Equation 6 is applicable for SCCS I-shaped columns bent about their major axis. The AISC *Seismic Provisions* do not provide the maximum brace spacing for rectangular HSS or box-shaped members bent about their major axis. To derive L_b for this case, start with AISC *Specification* Equation A-1-7:

$$L_{pd} = \left(0.17 - 0.10\frac{M_1'}{M_2}\right)\frac{E}{F_y}r_y \geq 0.10\frac{E}{F_y}r_y \tag{7}$$

Replacing M_1' with M_1 and F_y with R_yF_y, Equation 7, for rectangular HSS or box-shaped members bent about their major axis, becomes:

$$L_b = \left(0.17 - 0.10\frac{M_1}{M_2}\right)\frac{r_yE}{R_yF_y} \geq 0.10\frac{r_yE}{R_yF_y} \tag{8}$$

APPLICATION OF CANTILEVER COLUMN BRACING

OCCS do not require bracing. SCCS require bracing to restrain LTB so that flexural yielding at the column base can be developed. The bracing is not intended to provide column stability or prevent sidesway. The LTB limit state does not apply to round HSS, square HSS, square box sections, or any cross section bent about its minor axis. Thus, exceptions are proposed for the next edition of the AISC *Seismic Provisions* to state that bracing is not required for these types of members. An additional exception is proposed to allow the usage of short columns without bracing by conservatively limiting the column length to half the maximum bracing spacing.

Point torsional bracing is likely to be the best choice for LTB bracing because lateral bracing may cause the seismic force-resisting system to behave as something other than a cantilever column system. Point torsional bracing must meet the flexural strength and stiffness requirements for beam torsional bracing in AISC *Specification* Appendix 6. As an example, point torsional bracing can be achieved by attaching beam(s) to the column, preventing torsional rotation of the column. Cantilever column systems can act as a cantilever column in one direction and can be used with other systems (moment or braced frames) in the orthogonal direction. The seismic force-resisting systems in the orthogonal direction can be used to provide the required lateral or point torsional bracing for the cantilever column system.

CONCLUSION

The proposed equations for the maximum brace spacing of SCCS are an improvement over current requirements because an appropriate moment ratio can be used. The proposed equations for major-axis bending are also specific to member cross-section types. Equation 6 is for I-sections, and Equation 8 is for rectangular HSS or box-shaped members. Clarity on the purpose of the bracing, conditions when the bracing is and is not required, and guidance on the type of bracing are provided.

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