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Investigation on slenderness ratios of built-up compression members

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Abstract

This study provides a direct experimental verification of the AISC slenderness ratio formulas for built-up compressive members. The comparison on various code-specified slenderness ratios or provisions, which used in the AISC-ASD, AISC-LRFD, AS-4100, and CSA S16-01, are presented. The 0.75 rule, which states that the slenderness ratio of component element of built-up member should not exceed three-fourths times the governing slenderness ratio of built-up member, seems justified according to the tests. The governing slenderness ratio of built-up member could be either the modified or the unmodified one — as specified in the AISC Specifications. The test results indicate that the built-up members with component slenderness ratio of 0.75 to 1.0 times the governing slenderness ratio (modified or unmodified) could also furnish a quite encouraging design outcome. The use of separation ratio (α) in built-up compression members results in the decrease of design strength when compared to one with no use of separation ratio.

Keywords: Compressive member; Built-up member; LRFD; Slenderness ratio

1. Introduction

Despite the vast availability of researches in the general subject of columns, there is little focus on built-up columns. The AISC-ASD Specification [1] provides no specific provision for the design of built-up columns except stating that the slenderness ratio of each component element should not exceed three-fourths times the governing slenderness ratio of the built-up member for preventing the premature failure of an individual component. The AISC-LRFD Specification [2] was the first AISC Specification to introduce the equations E4-1, E4-2, and E4-3 to the design profession but without considering the section separation ratio (α). Aslani and Goel [3,4] presented a modified formula by considering the section separation ratio (α), which was included in the latter editions of AISC. In the 2005 AISC Specification [5], the requirement for not exceeding three-fourths times the governing slenderness ratio of a built-up member is still applied. The slenderness ratio equations of the 2005 AISC Specification [5] are currently being used with the consideration of component effective slenderness ratio Ka/r_i. The requirement of the effective slenderness ratio Ka/r_i for each component not exceeding three-fourths times the governing slenderness ratio of the built-up member as specified in the current AISC Specification [5] was further discussed and investigated by Duan, Reno and Uang [6]. They recommended that lacing including flat bars, angles, channels, or other shapes employed as lacing, or batten plates shall be so spaced that the slenderness ratio l/r of the flange included between their connections shall not exceed three-fourths times the governing slenderness ratio for the laced member as a whole. It is noted that this revised limitation on effective slenderness ratio has been included in the 2005 AISC Specification. In the AISC Specifications, the governing slenderness ratio of a built-up member has been interpreted differently in various publications including Smith [7], Segui [8], and McCormac [9]. For the design of built-up columns, Segui employed the governing slenderness ratio without using the modified equation E6-1 and E6-2 from the 2005 AISC Specification [5] when he evaluated the component slenderness ratio, which should not exceed three-fourths times the governing slenderness ratio. While, Smith and McCormac used the modified equations. In the Australian Code (AS-4100) [10], the maximum slenderness ratio of a main component, based on its minimum radius of gyration and the length between consecutive points where lacings or battens are attached, shall not exceed the smaller of 50 or 0.6 times the slenderness ratio of the member as a whole. The Canadian Code (CSA S16-01) [11] states that

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Notation

A_g gross cross-sectional area
a distance between connectors
C_c column slenderness ratio separating elastic and inelastic buckling
E Young's modulus
F_a allowable axial compressive stress
F_{cr} critical compressive stress
F_y yield stress
F_u tensile strength
h distance between centroids of individual components perpendicular to the member axis of buckling
KL effective length
$(KL/r)_m$ modified column slenderness ratio of built-up member acting as a unit
$(KL/r)_o$ column slenderness ratio of built-up member acting as a unit
$(KL/r)_{(0)}$ unmodified slenderness ratio of built-up member acting as a unit
$(KL/r)_{(1)}$ modified slenderness ratio of built-up member acting as a unit based on Bleich (1952)
$(KL/r)_{(2)}$ modified slenderness ratio of built-up member acting as a unit as per the 1986 LRFD
$(KL/r)_{(3)}$ modified slenderness ratio of built-up member acting as a unit as per the 2005 LRFD
$(KL/r)_{(4)}$ modified slenderness ratio of built-up member acting as a unit as per the 1998 AS-4100
$(KL/r)_{(5)}$ modified slenderness ratio of built-up member acting as a unit as per the 2001 CSA S16-01
$(L/r)_o$ column slenderness ratio of built-up member acting as a unit, assuming $K = 1$
$(l_e/r)_{bn}$ slenderness ratio of a battened compression member about the axis normal to the plane of the battens
$(l_e/r)_{bp}$ slenderness ratio of a battened compression member about the axis parallel to the plane of the battens
$(l_e/r)_c$ slenderness ratio of the main component in a laced or battened compression member
$(l_e/r)_m$ slenderness ratio of the whole battened compression member
P_a allowable axial compressive load
P_{cr} critical axial compressive load
P_n nominal axial compression strength
P_u design axial compressive load
a/r_i largest column slenderness of individual components
r_i minimum radius of gyration of individual component
r_{ib} radius of gyration of individual component relative to its centroidal axis parallel to member axis of buckling
α separation ratio $= h/(2r_{ib})$
ρ_e equivalent slenderness ratio of built-up member
ρ_o slenderness ratio of built-up member acting as an integral unit
ρ_i maximum slenderness ratio of component part of a built-up member between interconnectors

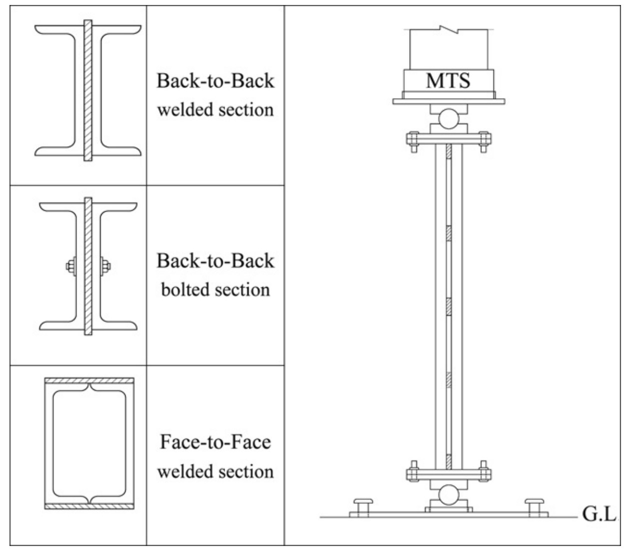

Fig. 1. Specimen sections and typical test setup.

compression members composed of two or more shapes in contact or separated from one another shall be interconnected in such a way that the slenderness ratio of any component, based on its least radius of gyration and the distance between interconnections, shall not exceed that of the built-up member.

2. Previous studies

Work on the buckling strength of built-up columns has been done over the years. Zahn and Haaijer [12] determined the number of connectors and the accompanying design strength for double-angle columns. Temple and Elmahdy [13] investigated the buckling mode of built-up member. Their paper also shows the derivation of the equivalent slenderness ratio equation and its applicability. Temple and Elmahdy [14] concluded that the slenderness ratio of the main member between connection points has a significant effect on the compressive resistance and that Timoshenko's equivalent slenderness ratio [15] when used in conjunction with the Canadian Code (CSA S16-1) gives the best results. Temple and Elmahdy [16] pointed out that the equation proposed by either Timoshenko and Gere [15] or Bleich [17] does not contain an effective length factor in term of component slenderness (l/r). Duan and Chen [18] proposed a unified formula with the local effective length factor K_m that considered the shear effect for the slenderness ratio of built-up members, $K_m = 1.0$ for snug-tight bolted connectors, and 0.65, for welded connectors and fully tightened bolted connectors as required for slip-critical joints. Temple and Elmahdy [19] showed that the use of an equivalent slenderness ratio equation was