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ABSTRACT

The present AISI effective width approach for determining flexural section capacities of sections with slender webs requires an iterative approach. A simplified method, called the Reference Section Method or RSM, which eliminates the need for iteration is presented and discussed. The reference section is defined as one that is similar to the actual section except for the web height. This simplified method is based on the premise that the flexural capacity of a section with slender webs is proportional to that of a reference section with compact web. The ratio of the web height of the actual section to that of the reference section defines the constant of proportionality. To demonstrate the applicability of the RSM, parametric study is performed on channel joist/rafters (MSMA sections). The capacities of the sections predicted using the RSM are compared to the AISI predicted capacities. Although the results using RSM compares well with that using the AISI specification, refinement is still possible through experimental research.

INTRODUCTION

Relatively high and unstable prices for lumber today are making light gage steel framing a popular alternative to timber framing in residential and commercial structures. One of the biggest hurdles the light gage steel industry is currently facing is the limited amount of published data on the subject of design and construction details for light gage steel systems. Design guides like the AISI (1991) Cold-Formed Steel Design Manual and the recent APA (1993) design aid, "Fastening of Wood Structural Panels to Steel Framing", provide some recommendations for design, (design which is primarily member based). In the design of flexural members, for example floor and roof joists (see Figure 1), the designer needs to check lateral stability, flange local buckling (FLB) , web local buckling (WLB), and possible shear buckling.

The design procedures for lateral buckling, FLB, and shear buckling are relatively simple and usually require a single direct calculation. Web local buckling on the other hand requires an iteration to determine what part of the web is ineffective. Typically, approximately three to four iterations are needed before the web stabilizes sufficiently. As an alternative to having to check for WLB, sections such as C-shaped sections with lips, can be manufactured with small enough

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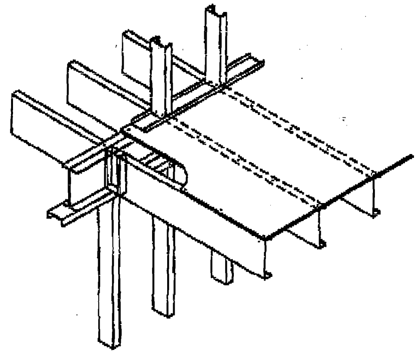

Figure 1. Floor joist framing detail.

h/t ratios, where h is the height of the web and t is its thickness. Although small h/t ratios are structurally desirable, they may not be economical. At the design load, we may require that there is no web local buckling. However, at ultimate, where the main intention of the code is to protect life, the engineer may want to consider excursions of behavior which includes WLB.

Under the present AISI specification, design for WLB can be tedious because of the need to iterate to determine the centroid of the effective section. To avoid this iterative procedure, a new method, called the Reference Section Method or RSM is proposed in this paper. In the following sections, the RSM is discussed and comparison are made between the nominal capacities predicted using the AISI (1986) specification and using the RSM.

Reference Section Method

Reference Section Method or RSM is an approximate method to determine flexural capacities of sections that undergo local and post-local plate buckling failure modes in the compression flange and web elements. In particular, the method accounts for the effect of slender webs on the section capacities without the need for an iterative process. The method is only applicable to sections whose initial yielding is in the compression flange, and assumes that the effective width approach is used to account for slender compression flanges.

The premise in RSM is that flexural capacities of sections with slender webs increase linearly with the web heights. Consider two sections that are otherwise identical except for their web

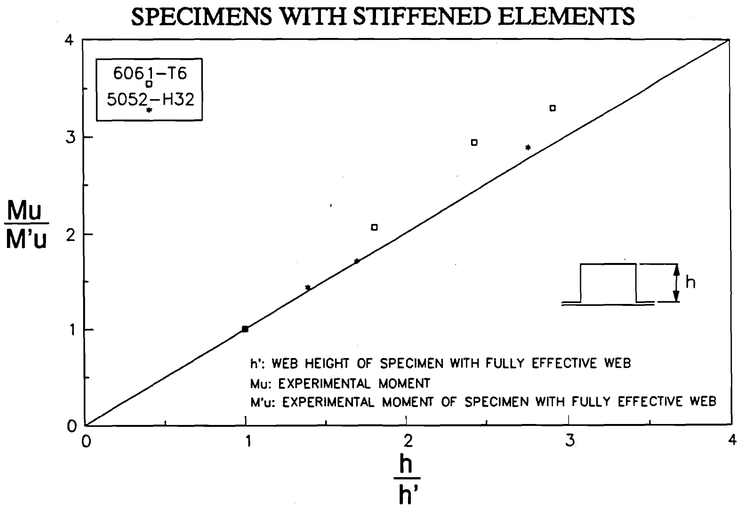

Figure 2. Experimental evidence to support the Reference Section Method

heights. Let their web heights be denoted by h and h′ (h > h′), and their respective section capacities be denoted by M_n and M_n'. Then, the above premise states that

$$M_n = M_n' \frac{h}{h'} \tag{1}$$

If h′ is the height below which the web is considered compact, then M_n' can be determined readily using the AISI specification without an iterative approach. Having determined M_n', M_n can be determined using Equation (1). That is, the capacity M_n is determined with reference to capacity M_n'. For this reason, this method is called the Reference Section Method.

Experimental evidence to support the validity of the RSM for aluminum sections with stiffened flange elements is shown in Figure 2 [Sooi (1993)]. The figure shows the results of a series of beam tests on specimens with stiffened compression elements, and fabricated using two different aluminum alloys (6061-T6 and 5052-H32). Within each alloy group, the only nominal difference in the specimens is the web height. The reference specimen in each alloy group is taken as that with the smallest web height, and these webs are compact. All specimens failed through local and post-local buckling of the compression flange and web elements. The experimental section capacities, M_u, and web heights, h, shown in Fig. 2 have been normalized by the respective values (M_u' and h′) of their reference sections. It can be concluded from Fig. 2 that the section flexural capacities increase linearly with web heights, confirming the validity of Eqn.(1)

PROCEDURES TO DETERMINE SECTION CAPACITY USING RSM

The procedures to determine section flexural capacity using RSM are as follow:

1. For a given section, determine the web height h′ where h′ is the height below which the web is compact. The reference section is defined as one that is similar to the given section except that the web height is h′. (Equations to determine h′ are discussed below).

2. Determine the effective flange width of the reference section using the AISI specification.

3. Determine the capacity of the reference section, M_n', based on the effective flange width only. Note that an iterative approach is not needed since the web is fully effective.

4. Determine the capacity of the given section, M_n, using Eqn.(1).

RSM can be a very useful design aid when detail analysis are not feasible. For example, assume that an engineer has determined that a chosen section with capacity M_n and web height h has insufficient capacity to carry the ultimate moment M_u. The engineer could easily choose a deeper section using Eqn.(1) (by substituting M_n, h and M_u for M_n', h′ and M_n respectively) without having to go through detail analysis.

Application of the RSM to determine section capacity requires a simple equation to estimate the web height h′ in Procedure (1). This equation has been established experimentally for aluminum sections with stiffened compression flange [Sooi (1993)]. The following section establishes a simple equation for C-shaped cold-formed steel section using parametric study. Equations for other cold-formed shapes can be determined in a similar way.

PARAMETRIC STUDY

To investigate the applicability of the RSM to light gage steel sections, a series of Metal Stud Manufacturers Association (MSMA) joist sections, as indicated in Figure 3, were analyzed using the present AISI specification. Plate thicknesses of 16 gage and 18 gage, and yield stresses of 33 ksi and 50 ksi were used for each of the three section. That is, four parametric studies were carried out for each section for a total of 12 studies. In each study, the web height varies but the material properties and other sectional dimensions remain constant. constant. The matrix used in the parametric study is shown in Table 1.

Figure 4 shows a typical AISI calculated capacities of MSMA sections as a function of web heights. The AISI calculated capacities are denoted as M-AISI. It appears that M-AISI varies linearly as the web height increases, confirming the premise of RSM.

The section capacities are also calculated using the AISI specification but assuming that the web is fully effective regardless of the h/t ratios. These capacities are denoted as M-AISI (Eff Web). Let λ_h' be defined as an equivalent web slenderness ratio given by

$$\lambda_h' = \frac{h}{t}\sqrt{\frac{F_y}{E}} \qquad (2)$$

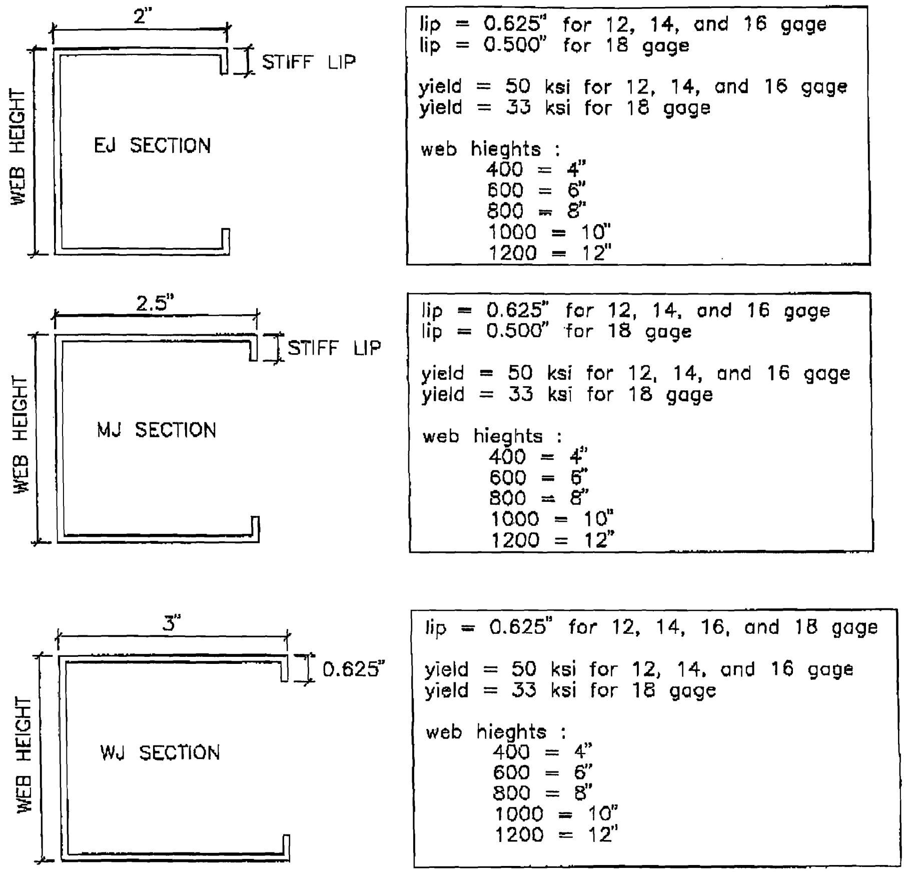

Figure 3. MSMA joist sections

Table 1. Summary of parametric tests results.

Section	h′ [in]	t [in]	Fy [ksi]	M-AISI [k-in]	M-AISI (EFF WEB) [k-in]	M-AISI (Eff Web) / M-AISI	λ_w'
WJ series	7	0.0451	33	38.41	38.90	1.013	5.19
WJ series	8.25	0.0566	33	64.37	64.57	1.003	4.88
WJ series	4.75	0.0451	50	31.66	32.20	1.017	4.34
WJ series	6.25	0.0566	50	60.20	61.02	1.014	4.55
MJ series	7.5	0.0451	33	41.42	41.79	1.009	5.56
MJ series	9.5	0.0566	33	73.20	74.15	1.013	5.61
MJ series	5.5	0.0451	50	37.95	38.16	1.006	4.08
MJ series	7.25	0.0566	50	70.58	71.58	1.014	4.28
EJ series	7.75	0.0451	33	41.65	41.69	1.001	5.75
EJ series	10	0.0566	33	75.82	76.47	1.009	5.91
EJ series	6	0.0451	50	41.19	41.42	1.006	4.45
EJ series	7.75	0.0566	50	73.75	74.90	1.016	4.58

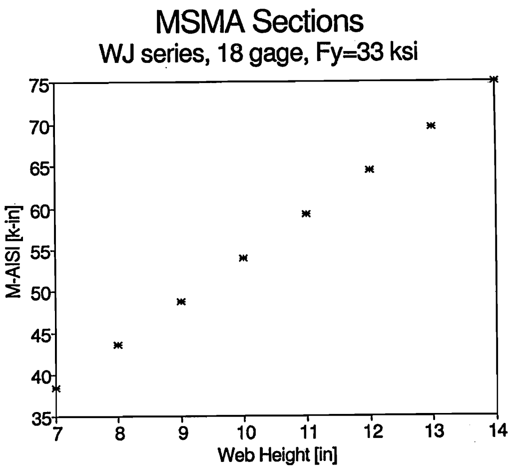

Figure 4. AISI predicted capacities of sections with slender webs as a function of web heights.

The value of λ_h' at which the M-AISI to M-AISI (Eff Web) ratio deviates from unity is the equivalent slenderness ratio below which the web is compact. This value of λ_h' is determined for all the sections studied and are shown in Table 2. The parametric studies indicate that the value of λ_h' for the MSMA sections have an average value of 5.0. Thus, the value of h′ for the MSMA sections can be defined as the value of h when λ_h' equals 5.0. That is,

$$h' = 5.0t\sqrt{\frac{E}{F_y}} \tag{3}$$

COMPARISON BETWEEN AISI SPECIFICATION AND RSM

The section capacities according to RSM can be calculated using the procedures described, and using Eqn.(3) to define h′. These capacities are denoted as M-RSM. Most of the MSMA sections are not susceptible to WLB. However, for those sections which are susceptible to WLB, the comparison between M-AISI and M-RSM are shown in Table 2 and Figure 5. Good correlations are seen between M-AISI and M-RSM for these MSMA sections. The mean M-AISI to M-RSM ratio is 0.978 and the coefficient of variation is 0.0323.

Table 2. Comparison between predicted capacities using AISI specification and using RSM.

MSMA Section	Fy [ksi]	t [in]	h′ [in]	M′ [k-in]	M-AISI [k-in]	M-RSM [k-in]	$\frac{M\text{-AISI}}{M\text{-RSM}}$	$\frac{h}{h'}$	$\frac{M\text{-AISI}}{M'}$
800EJ18	33	0.0451	6.742	34.44	42.60	40.86	1.043	1.19	1.237
1000EJ16	50	0.0566	6.874	63.38	92.33	92.20	1.001	1.45	1.457
1200EJ16	50	0.0566	6.874	63.38	109.65	110.64	0.991	1.75	1.730
800WJ18	33	0.0451	6.742	37.88	43.15	44.95	0.960	1.19	1.139
1000WJ16	50	0.0566	6.874	69.49	94.67	101.08	0.937	1.45	1.362
1200WJ16	50	0.0566	6.874	69.49	113.38	121.30	0.935	1.75	1.632
1000MJ16	50	0.0566	6.874	66.53	94.67	96.78	0.978	1.45	1.423
1200MJ16	50	0.0566	6.874	66.53	112.78	116.14	0.971	1.75	1.695
1200MJ14	50	0.0713	8.659	118.57	162.51	164.32	0.989	1.39	1.371
						Mean:	0.978		
						COV:	0.032		

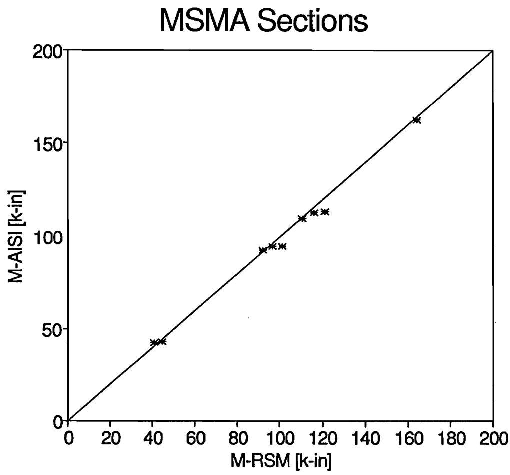

Figure 5. Comparison between capacities calculated using AISI specification and using RSM.

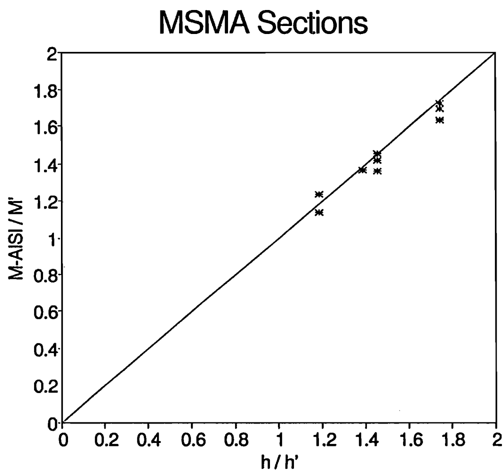

Figure 6. Verification of Eqn.(1) for MSMA sections through comparison between normalized M-AISI and normalized web heights.

In figure 6, M-AISI is normalized by the flexural capacity of the reference section M′ and the web height h is normalized by the corresponding height of the reference section h′ given by Eqn.(3). The straight line relationship between the normalized values indicates the validity of Eqn.(1) for MSMA sections.

It should be noted that the above parametric studies are only valid for MSMA or similar C-shaped sections. Because of the potential of RSM, it is recommended that an experimental program be undertaken to fully investigate the λ_h' parameter for these and other sections commonly used for cold-formed structures.

CONCLUSION

A simplified method, called Reference Section Method (RSM), to account for web local buckling in a particular section without the need for iteration is proposed in this paper. A reference section is defined as one that is similar to that particular section except for the web height which is sufficiently short so that the reference section has compact web. Flexural capacity of such reference section is readily determined without an iterative approach. The premise in RSM states that the capacity of the particular section is proportional to that of the reference section, the ratio of their web heights being the constant of proportionality. This premise is verified for MSMA sections through a parametric study. The study also indicates that MSMA sections with equivalent web slenderness ratio, λ_h', of 5.0 can be used as reference sections. Using these reference sections, flexural capacities calculated using RSM correlates well with those calculated using the AISI specifications. Experimental program should be carried out to investigate the λ_h' parameter for the commonly used sections in cold-formed structures.

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NOTATIONS

E:	Modulus of elasticity.
F_y:	Yield stress.
h:	web height measured between toe of radius.
h′:	web height of a reference specimen.
M_u:	Ultimate flexural capacity.
M_n:	Nominal flexural capacity.
M_n':	Nominal flexural capacity of a section with web height h′.
t:	thickness of plate element.
λ_h':	equivalent web slenderness ratio.

M-AISI:	section flexural capacity calculated using the AISI specification.
M-AISI (Eff Web):	section flexural capacity calculated using the AISI specification, assuming that the web is fully effective.
M-RSM:	section flexural capacities calculated using the Reference Specimen Method.

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SUMMARY

Reference Section Method (RSM) is a simplified method to account for local web buckling without iteration. The premise is that capacities of sections with slender webs are proportional to that of reference sections with compact webs. This premise is verified through a parametric study.