Expected Yield Stress and Tensile Strength Ratios for Determination of Expected Member Capacity in the 2005 AISC Seismic Provisions

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The AISC *Seismic Provisions for Structural Steel Buildings* (AISC 2002, 2005), hereafter referred to as the AISC Seismic Provisions, employ a "capacity-design" methodology for many seismic systems (for example, special moment frames, special concentrically braced frames, and eccentrically braced frames). That is, the required strength of most elements is set to equal or exceed forces corresponding to the expected capacity (available strength) of certain designated yielding members. This methodology serves to confine ductility demands to members that have specific requirements to ensure ductile behavior; furthermore, the methodology serves to ensure that within that member, the desired, ductile mode of yielding governs and other, nonductile modes are precluded.

Such a capacity-design methodology requires calculation of the expected capacity of such designated yielding members. To this end, the expected yield stresses of various steel materials have been established by a survey of mill certificates and the ratio of expected to specified minimum yield stress has been included in the AISC Seismic Provisions as R_y (AISC, 2002, 2005). The expected capacity of the designated yielding member is defined as R_y times the nominal strength of the member based on the desired yield mode; this expected strength is amplified to account for strain hardening in some cases.

Where this capacity-design methodology is employed to preclude nonductile modes within the designated yielding member, it is reasonable to use the expected material strength in the determination of the member capacity. For limit states based on yield, the factor, R_y, applies equally to the designated yielding member capacity used to compute the required strength and to the strength with respect to the limit states to be precluded. An example of this condition is yielding of the beam outside the link in an eccentrically braced frame; the required strength is based on yield of the link beam, and yield limit states, such as combined flexure and compression outside the link, can be expected to be similarly affected by increased material strength. The factor, R_y, is not applied to members other than the designated yielding member.

Similarly, fracture limit states within the designated yielding member are affected by increased material strength. Such limit states include block shear fracture and net section fracture of braces in special concentrically braced frames, where the required strength is calculated based on the brace expected yield strength in tension. However, it cannot be assumed that tensile strength is increased proportionally to yield stress, so the factor, R_y, is not applicable to fracture limit states. There is therefore the need for a factor specifically for the expected tensile strength ratio. [The terms "tensile strength" and "yield stress" are defined in the AISC *Specification for Structural Steel Buildings* (AISC, 2005a), consistent with ASTM terminology; both refer to material stresses (in other words, force divided by area.)]

In the 2005 AISC Seismic Provisions, such a factor for the ratio of expected tensile strength to the specified minimum tensile strength, R_t , has been added for use in calculating a modified strength for fracture limit states within designated yielding members. Additionally, for these provisions, some revisions have been made to the expected yield stress ratios, R_y, from the 2002 AISC Seismic Provisions. These changes were based on a survey of recent mill certificates, as well as a review of published tensile property surveys.

BACKGROUND

Expected Yield Stress Ratio, R_y

R_y is defined in the 2002 and 2005 AISC Seismic Provisions as the ratio of the expected yield stress to the specified minimum yield stress, F_y (AISC, 2002, 2005). As noted in previous studies, "actual properties vary randomly within a

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Table 1. R_y Values for Different Member Types (AISC, 2002)	
Application	R_y
Hot rolled structural shapes and bars	
ASTM A36 /A36M	1.5
ASTM A572 / A572M Grade 42 (290)	1.3
ASTM A992/A992M	1.1
All other grades	1.1
Hollow structural sections	
ASTM A500, A501, A618, and A847	1.3
Steel pipe	
ASTM A53/A53M	1.4
Plates	1.1
All other products	1.1

typical range and typically exceed the minimum properties" (Dexter, Graeser, Saari, Pascoe, Gardner, and Galambos, 2000). Therefore, when required for capacity design, the expected yield stress, R_yF_y, is used to calculate the strength of a designated yielding member.

R_y values from the 2002 AISC Seismic Provisions for different member types are shown in Table 1. For hot rolled structural shapes (such as W-shapes, channels, and angles), R_y varied according to material specification. Plates and hollow structural sections (HSS) and pipe within a list of specifications were assigned a value of R_y irrespective of material grade. However, based on the present study, some revisions to R_y values for HSS, pipe, and ASTM A36 plates, as well as additions for plates and bars, were proposed for the 2005 AISC Seismic Provisions.

Expected Tensile Strength Ratio, R_t

In special concentrically braced frames (SCBF) (AISC, 2005), the capacity of the connections must equal or exceed the expected yield strength in tension of the bracing member, considering material overstrength, unless the force that the system can deliver is limited by some other mode of behavior, such as foundation uplift. The expected yield strength of the brace in tension is defined as $R_yF_yA_g$ (AISC, 2002, 2005). A concern is that, with this requirement and the net section strength calculated according to 2005 Specification Section D2 (AISC, 2005a), the reduced section must often be greater than the gross section, requiring reinforcement of the section. However, with consideration of an expected tensile strength ratio, R_t, the demands for reinforcement may be reduced.

DATA ANALYSIS

The revisions for expected yield stress and tensile strength ratios were based on a synthesis of mill certificate data and existing tensile property surveys. Surveys included studies conducted by Dexter et al. (2000), Schmidt and Bartlett (2002), and Brockenbrough (2001). A more recent study was made using data requested from various fabricators and received in the form of mill certificates or summary spreadsheets (Liu, 2003). The majority of the mill certificates were dated 2001 and 2002. Geographically, sources were primarily domestic. Limited pipe and HSS data originated from Korea. Additional data for sheets, plates, and bars, provided by various metal building manufacturers, were studied by Harrold (2004). Sources for these materials were primarily domestic. These latest studies are presented herein.

Shapes and Material Specifications

A summary of the shapes, material specifications, and number of samples analyzed is presented in Table 2. The range of types and numbers of specimens was dictated by responses to requests for data from fabricators and mills. Shapes included W-shapes, channels, angles, plates, round and rectangular HSS, and steel pipe. Of the W-shapes sampled, only about 7% would be classified as heavy shapes, with flange thicknesses exceeding 2 in. Channel data was limited, with web thicknesses ranging from 0.184 to 0.51 in.

From the study by Liu (2003), plate thicknesses ranged from 0.1875 to 4 in. Specimens less than 0.5 in. thick generally qualified as bars; however, information about plate width was not always provided. From the study by Harrold (2004), material thicknesses ranged from 0.093 to 1 in. Bar flats ranged in thickness from 0.187 to 1 in.; width ranged from 5 to 12 in. Plates ranged in thickness from 0.182 to 1 in. Material with a thickness less than what qualifies as plate per ASTM was classified as sheet.

Data for angles were obtained from mill certificates as well as from summaries provided by manufacturers. The summary data were already assembled by thickness ranges of 0.25 to 0.50 in. (formerly referred to as Group 1), greater than 0.50 in. to 0.75 in. (formerly referred to as Group 2), and greater than 0.75 in. (formerly referred to as Group 3), without mention of the actual thickness or leg size.

Rectangular HSS shapes had a maximum width of 20 in. and a maximum thickness, t, of 0.625 in. Square HSS sections were included in this database. The maximum D/t ratio was on the order of 70. D is defined as the diameter of the shape before it is rolled into the final square or rectangular shape:

$$D = \frac{4}{\pi}\left(\frac{b+c}{2}\right) \tag{1}$$

Table 2. Summary of Shapes and Material Specifications				
Shape	**Material Specification**	**Specified Minimum Yield Stress (ksi)**	**Specified Minimum Tensile Strength (ksi)**	**Number of Samples**
W-shape	A36 A572 Gr. 50 A992	36 50 50	58 65 65	56 8 112
Angle	A36 A572 Gr. 50 A588	36 50 50	58 65 70	1668 232 75
Channel	A36	36	58	22
Plate, Bar	A36 A572 Gr. 50 A529 Gr. 50 A529 Gr. 55 A572 Gr. 55 A1011 SS Gr. 55 A1011 HSLAS Gr. 55	36 50 50 55 55 55 55	58 65 70 70 70 70 70	43 35 550 1328 1307 102 301
HSS (round) HSS	A500 Gr. B A500 Gr. B	42 46	58 58	645 309
Pipe	A53 Gr. B	35	60	228

where b and c are the outside dimensions of the short and long sides, respectively (Schmidt and Bartlett, 2002). Round HSS shapes, similarly, had maximum width of 20 in., maximum thickness, t, of 0.5 in., and maximum D/t ratio on the order of 50, where D is the nominal diameter. Pipes had a maximum thickness of 0.6 in., with a maximum D/t of 45.

Material specifications included ASTM A36, A572 Grade 50, A992, and A588 for angles; A500 Grade B for HSS sections; and A53 Grade B for pipes. ASTM A529 Grade 50, A529 Grade 55, A572 Grade 55, A1011 SS Grade 55, and A1011 HSLAS Grade 55 specifications were also included for sheet, plate, and bar (Harrold, 2004). All A529 Grade 50 and A529 Grade 55 samples qualified as bars, as did roughly 40% of the A572 Grade 55 samples. Often, a heat of steel met more than one specification. Where a mill listed more than one specification for a heat, one specification was assigned for analysis. If both A992 and A572 Grade 50 specifications were satisfied, the data were listed as A992. If ASTM A36, A572 Grade 50, and A992 were all satisfied, the data were listed as A36 and analyzed as such.

Summary of Key Statistics

Key statistics such as mean, coefficient of variation, maximum, minimum, and confidence level were calculated. For ease of comparison between material specifications, all data are listed in terms of ratios of actual to specified minimum yield stress or tensile strength. Summaries of key statistics for yield stress and tensile strength are given in Tables 3 and 4, respectively. Coefficient of variation (COV) was chosen over other measures of variance so that the data could be directly compared to existing material surveys. For the given sample, there is 95% confidence that the data will be in the reported interval.

SUMMARY OF RESULTS

In some cases, results simply verified the R_y values in the 2002 AISC Seismic Provisions. Results motivating changes to the R_y values are presented here. A summary of results for R_t values for the various shapes is also presented. As evidenced by the 2002 AISC Seismic Provisions, the yield ratios demonstrate dependence on material specification. Relationships of yield stress and tensile strength ratios to geometric properties, such as thickness or D/t ratio, were also investigated.

Yield Stress and Tensile Strength Ratios for W-shapes

Analysis verified that the ratio of actual to specified minimum yield stress is dependent on material specification for W-shapes (Figure 1), as reflected by the expected yield stress ratios in the 2002 AISC Seismic Provisions. For tensile strength, however, the ratios are comparable for all

Table 3. Statistics for Actual to Specified Minimum Yield Stress						
Shape	**Material Specification**	**Ratio of Actual to Specified Minimum Yield Stress**				
		Mean	**COV**	**Max.**	**Min.**	**Confidence (95%)**
W-shape	A36	1.57	0.05	1.74	1.40	0.023
	A572 Gr. 50	1.20	0.05	1.28	1.13	0.051
	A992	1.10	0.05	1.25	1.00	0.010
Angle	A36	1.34	0.07	1.77	1.08	0.005
	A572 Gr. 50	1.29	0.07	1.64	1.03	0.011
	A588	1.29	0.05	1.53	1.15	0.016
Channel	A36	1.36	0.06	1.53	1.23	0.039
Plate, Bar	A36	1.39	0.07	1.55	1.11	0.032
	A572 Gr. 50	1.16	0.07	1.36	1.04	0.030
	A529 Gr. 50	1.22	0.05	1.37	1.03	0.004
	A529 Gr. 55	1.10	0.05	1.29	1.00	0.003
	A572 Gr. 55	1.13	0.08	1.56	1.00	0.004
	A1011 SS Gr. 55	1.12	0.06	1.30	1.00	0.012
	A1011 HSLAS Gr. 55	1.15	0.08	1.38	1.00	0.010
HSS (round)	A500 Gr. B	1.36	0.07	1.56	1.18	0.042
HSS	A500 Gr. B	1.31	0.08	1.71	1.03	0.012
Pipe	A53 Gr. B	1.59	0.11	2.07	1.16	0.022

Table 4. Statistics for Actual to Specified Minimum Tensile Strength						
Shape	**Material Specification**	**Ratio of Actual to Specified Minimum Tensile Strength**				
		Mean	**COV**	**Max.**	**Min.**	**Confidence (95%)**
W-shape	A36	1.29	0.03	1.38	1.20	0.011
	A572 Gr. 50	1.20	0.04	1.26	1.13	0.040
	A992	1.12	0.04	1.28	1.01	0.009
Angle	A36	1.22	0.04	1.38	1.08	0.003
	A572 Gr. 50	1.38	0.06	1.59	1.09	0.010
	A588	1.27	0.05	1.41	1.13	0.014
Channel	A36	1.18	0.04	1.26	1.11	0.019
Plate, Bar	A36	1.23	0.04	1.34	1.15	0.016
	A572 Gr. 50	1.26	0.07	1.42	1.05	0.032
	A529 Gr. 50	1.22	0.05	1.38	1.07	0.004
	A529 Gr. 55	1.22	0.01	1.43	1.00	0.004
	A572 Gr. 55	1.15	0.01	1.47	1.00	0.004
	A1011 SS Gr. 55	1.08	0.01	1.24	1.01	0.009
	A1011 HSLAS Gr. 55	1.10	0.01	1.36	1.00	0.007
HSS (round)	A500 Gr. B	1.24	0.04	1.41	1.10	0.023
HSS	A500 Gr. B	1.27	0.04	1.52	1.06	0.006
Pipe	A53 Gr. B	1.16	0.06	1.35	1.01	0.008

material specifications (Figure 2). Figure 2 demonstrates no clear dependence on thickness. No difference was found for the ratios of actual to specified minimum yield stress or tensile strength for heavy shapes; however, the number of heavy shapes sampled was limited.

Yield Stress and Tensile Strength Ratios for Angles

Analysis also verified the current yield stress ratios for angles in the 2002 AISC Seismic Provisions. Meanwhile, no clear relationship was found between either the yield or tensile ratios and angle thickness. Figure 3 shows the similarities for tensile strength ratios within a material specification. There appears to be some relationship of tensile strength ratio to material specification, but data for ASTM A572 Gr. 50 and A588 angles were relatively limited.

Yield Stress and Tensile Strength Ratios for Channels

The data, although limited, also verified yield stress ratios for channels in the 2002 AISC Seismic Provisions. Figure 4 shows for channels what appears to be a general trend for all shapes; there does not appear to be a relationship between tensile strength ratio and thickness.

Yield Stress and Tensile Strength Ratios for Plates

For plates, as for W-shapes, it appears that there is a strong dependence on material specification, with a markedly different mean yield stress ratio for A36 steel (Figure 5). The higher stress ratio is particularly evident for plates 0.5 in. or thinner. This effect based on thickness is not apparent for ASTM A572 Gr. 50 plate. The steel production method may play a role. For economic reasons, plates 72 in. wide or less

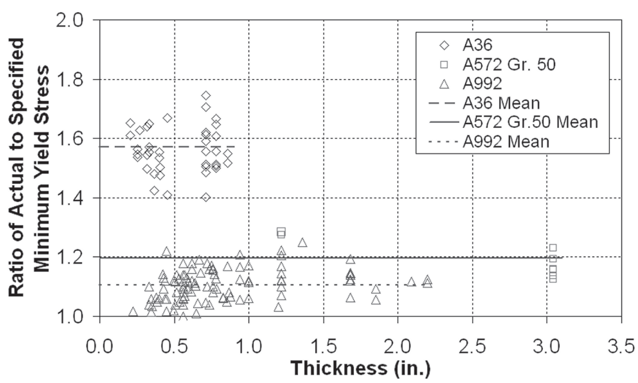

Fig. 1. Ratio of actual to specified minimum yield stress for W-shapes versus flange thickness, for different material specifications.

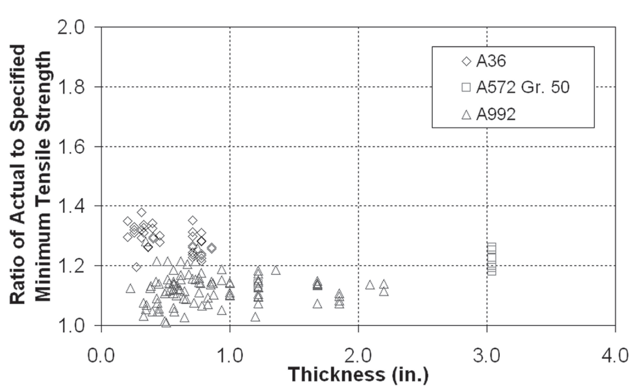

Fig. 2. Ratio of actual to specified minimum tensile strength for W-shapes versus flange thickness, for different material specifications.

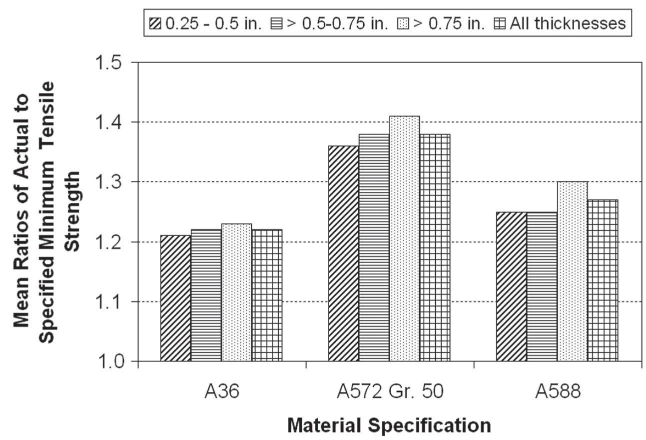

Fig. 3. Comparison of mean ratios of actual to specified minimum tensile strength for angles of different material specifications and thickness groups.

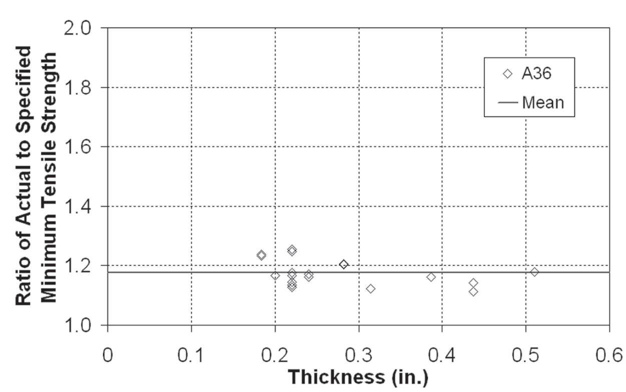

Fig. 4. Ratio of actual to specified minimum tensile strength versus web thickness for A36 channels.

and 0.5 in. thick or less typically comes from flattened coil. These strip mill plates are water cooled and are not cross-rolled. This may result in a "leaner" chemistry than plate produced without coiling and the potential for somewhat different typical mechanical properties (Mahaney, 2003). Meanwhile, as with shapes, there seems to be no clear relationship of the tensile strength ratio to either material specification or thickness (Figure 6).

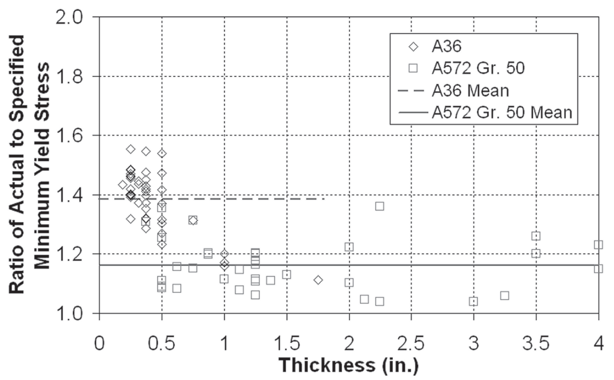

Fig. 5. Ratio of actual to specified minimum yield stress versus plate thickness for A36 and A572 Grade 50.

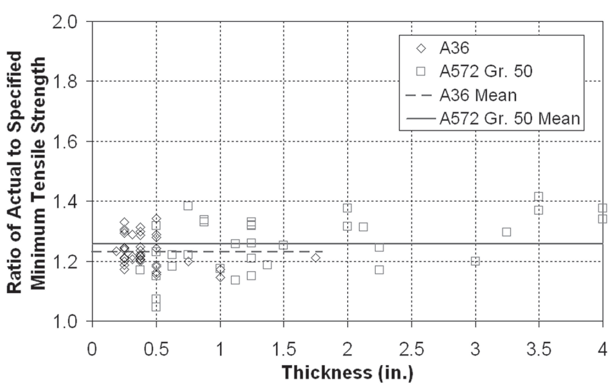

Fig. 6. Ratio of actual to specified minimum tensile strength versus plate thickness for A36 and A572 Grade 50.

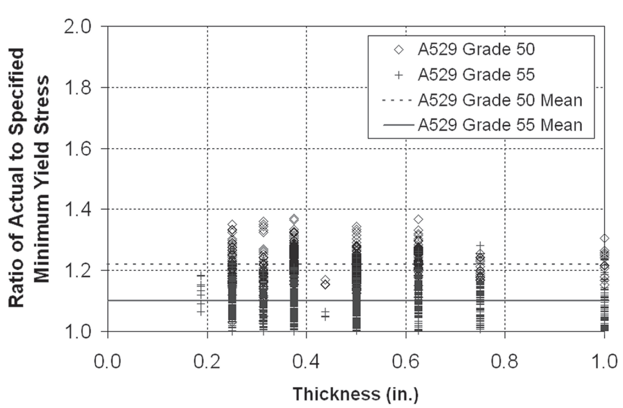

Fig. 7. Ratio of actual to specified minimum yield stress versus plate thickness for A529 Grade 50 and 55.

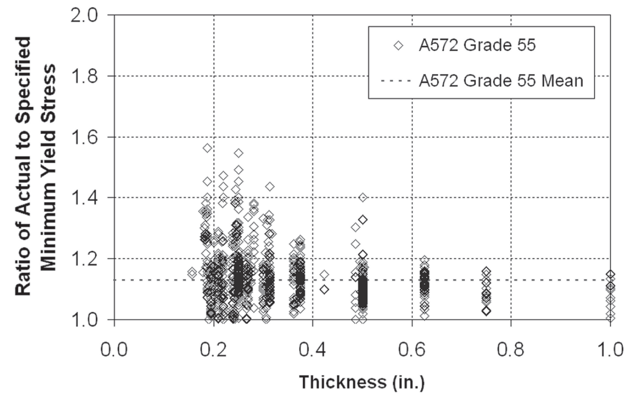

Fig. 8. Ratio of actual to specified minimum yield stress versus plate thickness for A572 Grade 55.

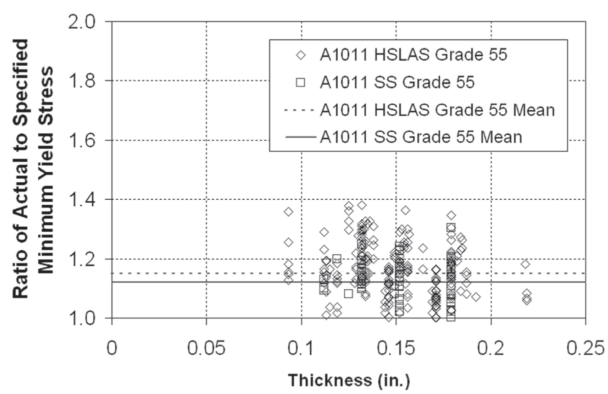

Fig. 9. Ratio of actual to specified minimum yield stress versus plate thickness for A1011 HSLAS and SS Grade 55.

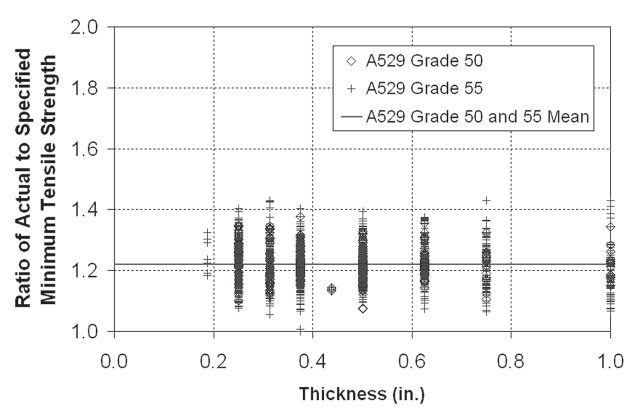

Fig. 10. Ratio of actual to specified minimum tensile strength versus plate thickness for A529 Grade 50 and 55.

For A529 Grade 50, A529 Grade 55, A572 Grade 55, A1011 SS Grade 55, and A1011 HSLAS Grade 55 plate, there is also little dependence on material thickness for mean yield stress ratio (Figures 7, 8, and 9). Thinner material appears to have slightly higher mean yield stress ratio, although not markedly so. Similar trends are seen for mean tensile strength ratios (Figures 10, 11, and 12).

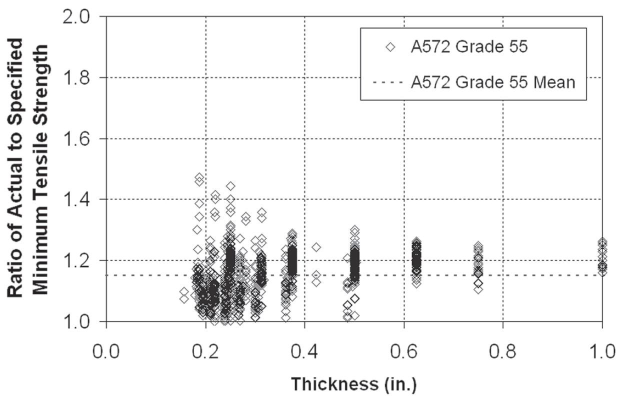

Fig. 11. Ratio of actual to specified minimum tensile strength versus plate thickness for A572 Grade 55.

Yield Stress and Tensile Strength Ratios for Round and Rectangular HSS

Both round and rectangular HSS exhibit some trend of yield ratio with respect to *D/t* (Figures 13 and 15, respectively). As with all other steel shapes, the tensile ratios appear to be relatively insensitive to changes in thickness or *D/t* ratio (Figures 14 and 16, respectively).

Because the ratios R_y and R_t apply to the designated yielding members, it is necessary to consider the types of sections that are used for such seismic applications. Designated yielding members are required to comply with special compactness limits, λ_{ps} (AISC, 2005). With seismic applications in mind, the yield and tensile strength ratios were reexamined with consideration for seismically compact HSS sections, with lower width-thickness, or *b/t*, ratios. Results would

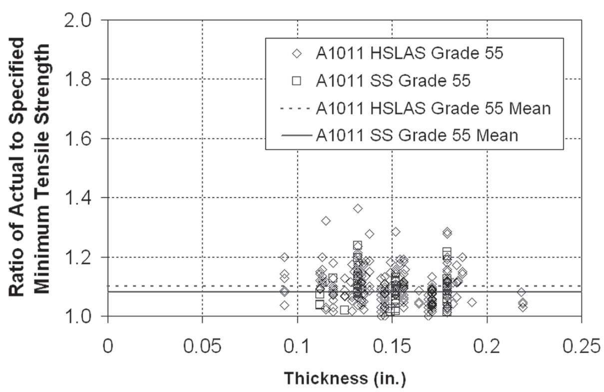

Fig. 12. Ratio of actual to specified minimum tensile strength versus plate thickness for A1011 HSLAS and SS Grade 55.

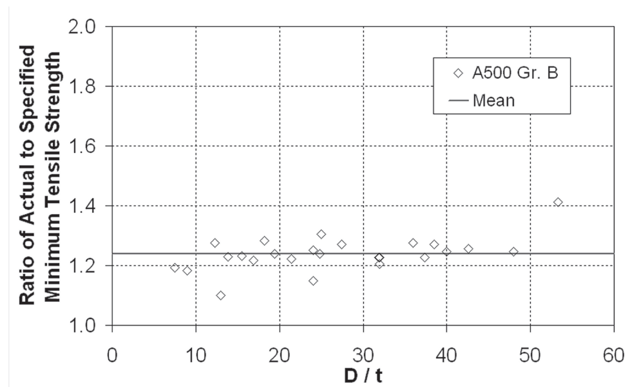

Fig. 14. Ratio of actual to specified minimum tensile strength versus D/t *ratio for round HSS.*

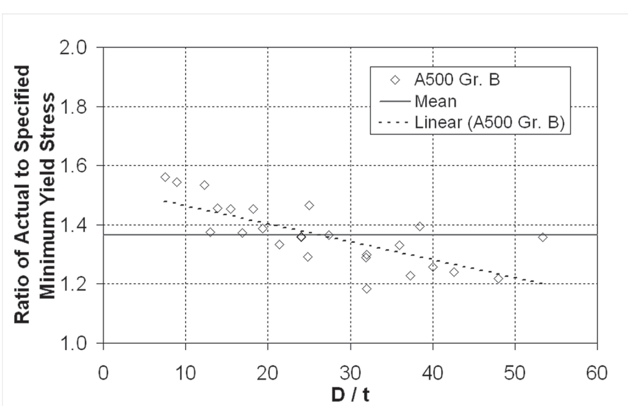

Fig. 13. Ratio of actual to specified minimum yield stress versus D/t *ratio for round HSS.*

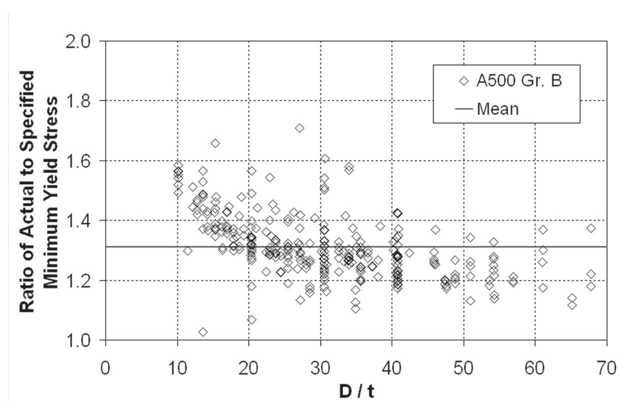

Fig. 15: Ratio of actual to specified minimum yield stress versus D/t *ratio for rectangular HSS.*

Table 5. Rectangular HSS Yield Stress Ratios					
	Data Count	Ratio of Actual to Specified Minimum Yield Stress			
		Mean	Std. Dev.	Max.	Min.
$b/t < \lambda_p$	113	1.37	0.010	1.66	1.03
$b/t < \lambda_{ps}$	65	1.42	0.013	1.66	1.03
All	309	1.31	0.006	1.71	1.03

Table 6. Rectangular HSS Tensile Strength Ratios					
	Data Count	Ratio of Actual to Specified Minimum Tensile Strength			
		Mean	Std. Dev.	Max.	Min.
$b/t < \lambda_p$	113	1.29	0.005	1.48	1.17
$b/t < \lambda_{ps}$	65	1.31	0.007	1.48	1.18
All	309	1.27	0.003	1.52	1.06

suggest that a higher R_y be proposed for HSS. Yield stress and tensile strength ratios for compact sections only were compared to ratios for all specimens. Results are shown in Tables 5 and 6. Figure 17 shows yield stress ratio versus b/t ratio. Both λ_p and λ_{ps} are presented as limits for compact and seismically compact sections. λ_p for HSS for plastic analysis is $0.939\sqrt{E/F_y}$, and λ_{ps} is $0.64\sqrt{E/F_y}$ (AISC, 1999, 2002, 2005). The difference is more apparent for yield stress ratio than tensile strength ratio, with higher mean values for compact sections. Calculations for round HSS showed similar results. For round HSS specimens with $D/t < \lambda_p$, the mean yield stress ratio was 1.45 as compared to 1.36 for all specimens, and the mean tensile ratio was 1.22 as compared to 1.24 for all.

Yield Stress and Tensile Strength Ratios for Pipe

Yield and tensile ratios for pipe show the most scatter and have the highest coefficients of variation of all shapes. There is no clear relationship to thickness or D/t ratio (Figure 18). As with the other shapes, the ratios of actual to specified minimum tensile strength for pipes show less scatter (Figure 19).

EXPECTED YIELD STRESS RATIO, R_y

The data generally confirmed the values for the expected yield stress ratios, R_y, in the 2002 AISC Seismic Provisions. Revisions are mainly for shapes and material specifications for which higher yield stress ratios were observed; these were HSS, pipe, and ASTM A36 plates. The sample size for A36 plates for the study discussed herein (Liu, 2003) was

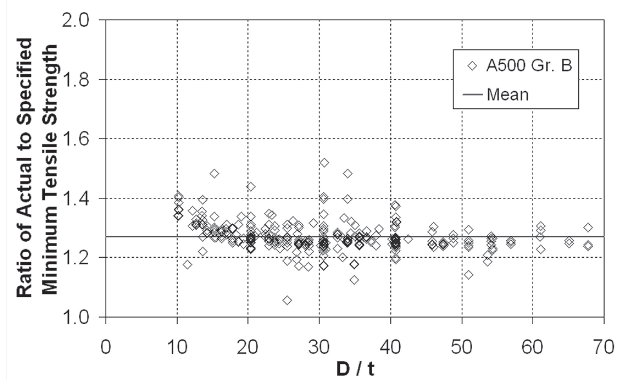

Fig. 16: Ratio of actual to specified minimum tensile strength versus D/t *ratio for rectangular HSS.*

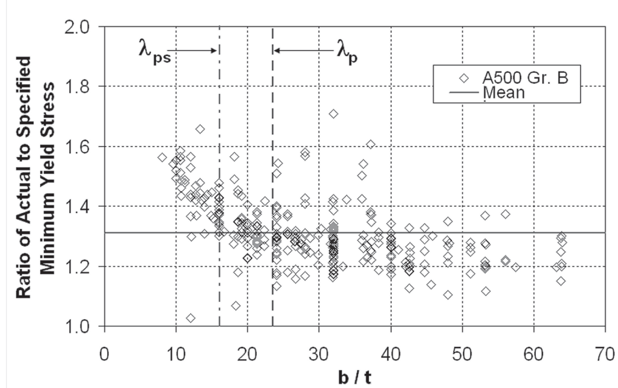

Fig. 17: Ratio of actual to specified minimum yield stress versus b/t *ratio for rectangular HSS.*

Table 7. Yield Stress and Tensile Strength Ratios for Plate (Brockenbrough, 2001)				
ASTM Designation	Nominal Thickness Range (in.)	Number of Items	Ratio of Mean to Specified Minimum Yield Stress	Ratio of Mean to Specified Minimum Tensile Strength
A36	0.188–0.75	14,900	1.30	1.17
A36	>0.75–4.00	5,871	1.20	1.23
A572 Gr. 50	0.188–0.50	1,161	1.17	1.19
A572 Gr. 50	>0.50–4.00	5,646	1.14	1.22
A572 Gr. 60	0.375–1.25	42	1.13	1.23
A588	0.312–2.00	1,501	1.18	1.15
A588	>2.00–4.00	284	1.11	1.18

relatively small. Therefore, revisions for A36 plates were partially based on a previous material survey by Brockenbrough (2001), which had a very large number of samples: 20,771 for A36; 6,807 for A572 Grade 50; and 1,785 for A588. See Table 7.

EXPECTED TENSILE STRENGTH RATIO, R_t

Data from Brockenbrough (2001) also influenced the proposed value for expected tensile strength ratio, R_t. Meanwhile, in addition to the mean values for tensile strength ratio, the mean values for ratios of yield stress (Y) to ultimate tensile strength (T) were also considered in the development of the values for R_t.

Possible R_y and R_t values, based on mean values reported in this study, were compared to the mean Y/T. The comparison showed general agreement but also highlighted expected discrepancies. Table 8 gives a comparison of the mean Y/T values and their design equivalent, expected yield stress over expected tensile strength, or R_yF_y/R_tF_u. In some cases, the R_yF_y/R_tF_u is less than the mean Y/T. This is partially due to rounding of the mean values to design values for R_y and R_t. The potential ramification for these lower R_yF_y/R_tF_u values is that net section fracture capacity could be less than the yield capacity of a member. To avoid this situation, some proposed values of R_t were modified according to the Y/T.

YIELD STRESS AND TENSILE STRENGTH RATIOS IN THE 2005 AISC SEISMIC PROVISIONS

The following specifications regarding expected yield stress and tensile strength are found in the 2005 AISC Seismic Provisions (AISC, 2005) in Section 6.2. Also, values for R_y and R_t are shown in Table 9 as taken from the 2005 AISC Seismic Provisions, Table I-6-1.

> When required in these *Provisions,* the *required strength* of an element (a member or a connection) shall be determined from the *expected yield stress,* R_yF_y, of an adjoining member, where F_y is the specified minimum yield

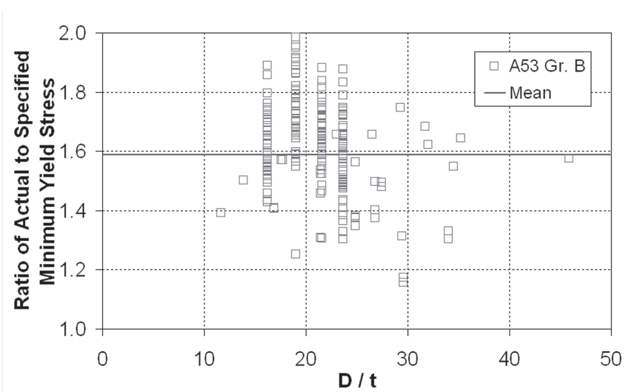

Fig. 18: Ratio of actual to specified minimum yield stress versus D/t *ratio for steel pipe.*

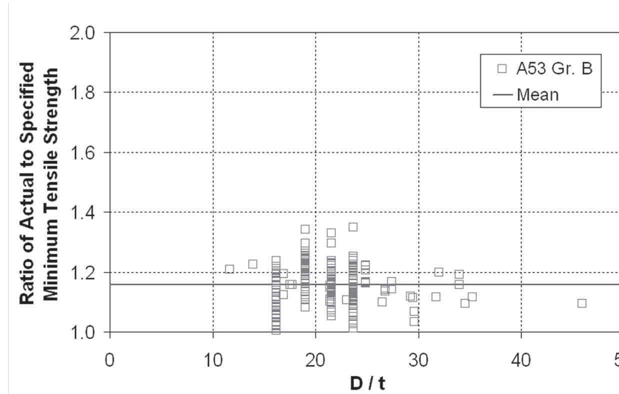

Fig. 19: Ratio of actual to specified minimum tensile strength versus D/t *ratio for steel pipe.*

Table 8. Comparison of Y/T and R_yF_y/R_tF_u			
Shape	**Material Specification**	**Mean Y/T**	**R_yF_y/R_tF_u***
W-shape	A36 A572 Gr. 50 A992	0.76 0.77 0.76	0.72 0.65 0.77
Angle	A36 A572 Gr. 50 A588	0.68 0.72 0.73	0.72 0.71 0.71
Channel	A36	0.72	0.72
Plate, Bar	A36 A572 Gr. 50 A529 Gr. 50 A529 Gr. 55 A572 Gr. 55 A1011 SS Gr. 55 A1011 HSLAS Gr. 55	0.70 0.71 0.72 0.71 0.78 0.81 0.82	0.67 0.65 0.71 0.72 0.79 0.79 0.79
HSS (round) HSS	A500 Gr. B A500 Gr. B	0.80 0.82	0.72 0.79
Pipe	A53 Gr. B	0.80	0.78

* Values of R_y and R_t based on reported mean values for yield stress and tensile strength ratios.

Table 9. R_y and R_t Values for Different Member Types [Table I-6-1 (AISC, 2005)]		
Application	**R_y**	**R_t**
Hot-rolled structural shapes and bars:		
• ASTM A36/A36M	1.5	1.2
• ASTM A572/572M Grade 42 (290)	1.3	1.1
• ASTM A572/572M Grade 50 (345) or 55 (380), ASTM A913/A913M Grade 50 (345), 60 (415), or 65 (450), ASTM A588/A588M, ASTM A992/A992M, A1011 HSLAS Grade 55 (380)	1.1	1.1
• ASTM A529 Grade 50 (345)	1.2	1.2
• ASTM A529 Grade 55 (380)	1.1	1.2
Hollow structural sections (HSS):		
• ASTM A500 (Grade B or C), ASTM A501	1.4	1.3
Pipe		
• ASTM A53/A53M	1.6	1.2
Plates:		
• ASTM A36/A36M	1.3	1.2
• ASTM A572/A572M Grade 50 (345), ASTM A588/A588M	1.1	1.2

stress of the grade of steel to be used in the adjoining members and R_y is the ratio of the *expected yield stress* to the specified minimum yield stress, F_y, of that material.

The *available strength* of the element shall be ϕR_n for LRFD and R_n/Ω for ASD, which shall be equal to or greater than the *required strength,* where R_n is the *nominal strength* of the connection. The *expected tensile strength,* R_tF_u, and the *expected yield stress,* R_yF_y, are permitted to be used in lieu of F_u and F_y, respectively, in determining the *nominal strength,* R_n, of rupture and yield limit states within the same member that required strength is determined.

User Note: In several instances a member, or a connection limit state within that member, is required to be designed for forces corresponding to the expected strength of the member itself. Such cases include brace fracture limit states (block shear rupture and net section fracture in the brace in SCBF), the design of the beam outside of the link in EBF, etc. In such cases it is permitted to use the expected material strength in the determination of available member strength. For connecting elements and for other members, specified material strength should be used.

The values of R_y and R_t for various steels are given in Table I-6-1. Other values of R_y and R_t shall be permitted if the values are determined by testing of specimens similar in size and source conducted in accordance with the requirements for the specified grade of steel.

CONCLUSIONS

Conclusions are as follows:

- Values of R_y, the ratio of expected to specified minimum yield stress, a value necessary for the capacity-design methodology required for many systems by the AISC Seismic Provisions, have been established for steel materials used in designated yielding members. For HSS sections, the value of R_y was dependent on the member width-thickness ratio; the ratio for use with seismic design is based on sections that comply with width-thickness limitations in the AISC Seismic Provisions.

- R_y can be used in calculating the nominal strength of the yielding limit states that are to be avoided in designated yielding members (the desired yielding limit state is to be designed using the specified minimum yield stress). For this application of R_y, the same values determined for capacity design can be applied. (Limit states such as combined flexural-compression yielding in the beam outside the link are to be avoided, and the available strength of those limit states can be calculated using R_y.)

- For fracture limit states in the designated yielding members, the expected material tensile strength is required. To this end, values of R_t, the ratio of expected to specified minimum tensile strength, have been established.

- R_t is used exclusively to calculate an increased available strength. Furthermore, expected yield-to-tensile ratios based on mean values of R_y and R_t were shown to be exceeded by measured yield-to tensile ratios for some steel materials used in designated yielding members. In consideration of these issues, conservative estimates of R_t have been proposed for inclusion in the AISC Seismic Provisions.

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