Selection of Structural Steel For Welded Construction

1. INTRODUCTION

With today's continuing progress in welding technology and the rapid expansion of welded construction, along with the development of new and better steels, the engineer or architect has a multiplicity of choices for a given project. The following information is designed to aid him in selecting the proper structural steel for his needs. . . on the basis of strength and cost.

In November of 1961, the American Institute of Steel Construction adopted a new "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings". This Specification, which was revised in April 1963, includes design specifications for six American Society for Testing Materials grades of steel with specified minimum yield points ranging from 32,000 to 50,000 psi.

In addition to the steels specifically included in the AISC Specification, a number of proprietary structural steels are now being offered by various steel producers. These steels have specified minimum yield points ranging from 45,000 to 100,000 psi.

As a result, the engineer or architect today is faced with a problem he rarely encountered 10 years before: the selection of the proper structural steel that is best suited to his needs. Furthermore, since welded construction is increasingly being used for all types of structures, the designer must be assured that the welding of these steels is performed in a manner which will provide sound welds economically.

A. KNOWING THE STRUCTURAL STEELS

2. STEEL CLASSIFICATIONS

In the design of buildings, bridges, and similar structures, the engineer or architect is concerned primarily with three groups of structural steels:

A. Carbon Steels
B. High-Strength Low Allow Steels
C. Heat-Treated Constructional Alloy Steels

The first two of these categories include the six basic ASTM grades of structural steel included in the AISC Specification. The mechanical properties and chemistry limitations for these six ASTM grades are shown in Tables 1A and 1B.

Field welding of vertical member to bottom chord of Vierendeel truss for 17-story Foundation House in Toronto, Canada. Truss is built of high-strength, low-alloy steel with 55,000 psi minimum yield strength.

3. CARBON STEELS
ASTM Grades A7, A373, and A36

The carbon steels for the structural field include ASTM Grades A7, A373, and A36. The principal strengthening agents in these steels are carbon and manganese. Specified minimum yield points range from 32,000 psi for A373 to 36,000 for A36.

ASTM A7

The first ASTM specification for steel used in building construction was proposed in 1900, and was adopted one year later as the "Standard Specification for Steel for Buildings." When the ASTM adopted a numbering system for its specification in 1914, "Standard Specifications for Steel for Buildings" was designated as ASTM A9. The designation "ASTM A7" was given to "Standard Specifications for Steel for Bridges." In 1936 the ASTM combined A7 and A9 into one specification, ASTM A7, "Standard Specifications for Steel for Bridges and Buildings."

This specification was written to provide an economical as-rolled steel which would assure specific minimum strength requirements. The current version requires minimum tensile strength of 60,000 psi and minimum yield point of 33,000 psi. There are no limitations on chemistry except the sulphur and phosphorus maxima. The specification also includes a maximum tensile strength and minimum elongation requirements.

The most economical way to produce a steel of this nature is through the use of carbon and manganese in varying amounts. Carbon may be found in these steels in percentages ranging from a low of approximately 0.10 per cent to a maximum of 0.33 per cent or in some cases, even higher. Manganese is generally added to provide increased strength with less carbon to avoid the hardenability effect of high carbon in the steel. The manganese also improves hot rolling characteristics of the steel during production.

ASTM A373

With the increased use of welding after World War II, it became necessary to limit the carbon and manganese in A7 steel to screen out "high side" heats that sometimes presented welding problems.

In 1954, ASTM A373, "Structural Steel for Welding" was written. This specification limits the carbon and manganese, in addition to the maxima for phosphorus and sulphur, to insure good welds using stand-

TABLE 1A—A Comparison of Steels for Construction
ASTM Carbon Steels

ASTM Grade	Thickness		Min. Yield Point psi	Tensile Strength psi	Chemical Requirements (Ladle) Per Cent: C Max.	Mn	P Max.	S Max.	Si Max.	Cu Min.	V Min.	Other
A7	Shapes		33,000	60,000 to 75,000			0.04(1)	0.05		(2)		
	Plates & Bars	To 1½" incl.		60,000 to 72,000								
		Over 1½"		60,000 to 75,000								
A373	Shapes	Other than Group A(3)	32,000	58,000 to 75,000	0.28		0.04	0.05		(2)		
		Group A (3)				0.50/0.90						
	Plates	To ½" incl.			0.26							
		Over ½" to 1" incl.			0.25							
		Over 1" to 2" incl.			0.26	0.50/0.90			0.15/0.30			
		Over 2" to 4" incl.			0.27							
	Bars	To 1" incl.										
		Over 1"			0.28	0.50/0.90						
A36	Shapes		36,000	58,000 to 80,000	0.26		0.04	0.05	0.15/0.30	(2)		
	Plates	To ¾"			0.25							
		Over ¾" to 1½" incl.				0.80/1.20						
		Over 1½" to 2½" incl.			0.26							
		Over 2½" to 4" incl.			0.27	0.85/1.20						
		Over 4" to 8" incl.			0.29							
	Bars	To ¾" incl.			0.26							
		Over ¾" to 1½" incl.			0.27	0.60/0.90						
		Over 1½" to 4" incl.			0.28							

(1) Based upon basic steelmaking process.

(2) When copper steel is specified, the min. copper is 0.20%.

(3) Group A comprises the following wide flange beams (nominal sizes):

36 x 16½	30 x 15	21 x 13	10 x 10
36 x 12	30 x 10½	14 x 16	
36 x 15¾	27 x 14	14 x 14½	
33 x 11½	24 x 14	12 x 12	

ard high speed welding procedures. However, the limits on carbon and manganese at that time necessitated a slight reduction in the strength of the steel, and the minimum yield point was placed at 32,000 psi. The specification further requires that plates over one inch thick be produced fully killed to insure a homogeneous steel in these heavier thicknesses.

With the establishment of A373 by the ASTM as a steel for welded construction, the Bureau of Public Roads designated this grade to be used for welded bridges.

ASTM A36

By 1960 the mapor producers of A7 steel had begun to realize the fruits of the modernization and expansion of their facilities after the war. Through improvements in quality control and through better heating and rolling techniques, they could produce an A7 type steel to a higher strength level while maintaining carbon and manganese within the limitations desirable for economical welding.

As a result of these improvements, ASTM A36 "Structural Steel" was proposed, and was adopted in 1960. This specification imposed controls on carbon and manganese to insure economical welding and specified a minimum yield point of 36,000 psi, a 10 per cent increase over A7. In 1962, A36 was revised to place further limitations on carbon and manganese and was subsequently accepted by the Bureau of Public Roads for welded bridges.

In essence, the new A36 specification combines all of the advantages of A373 in a steel which has a higher minimum yield point than A7, yet costs no more than A7 in shapes and costs only slightly more than A7 in plates.

4. HIGH-STRENGTH LOW ALLOY STEELS ASTM Grades A242, A440, and A441

The high-strength grades of steel, ASTM A242, A440, and A441, have minimum specified yield points varying from 42,000 psi to 50,000 psi depending on the thickness of the material.

ASTM A242

During the 1930's, a number of steel producers began offering proprietary grades of high-strength low alloy steels containing, in addition to carbon and manganese, such elements as vanadium, chromium, copper, silicon, and nickel. These steels were offered with specified minimum yield points from 42,000 psi to 50,000 psi. In addition, many of these steels provided greatly improved corrosion resistance over ASTM A7.

By 1941 it became apparent that a specification was desirable for these steels, and in that year the American Society for Testing Materials wrote A242, "High-Strength Low Alloy Structural Steel", ASTM A242 is primarily a strength specification with specified minimum yield points of:

- 50,000 psi for material up to and including ¾ inch thick
- 46,000 psi for material over ¾ inch thick to 1½ inches thick, inclusive
- 42,000 psi for material over 1½ inches thick to 4 inches thick, inclusive.

The chemical requirements are quite liberal. An attempt is made to insure economical welding of these steels by limiting carbon and manganese content. However, the presence of other elements such as silicon, copper, chromium, phosphorus, and nickel, which are often added to provide improved strength and corrosion resistance, may require a special welding procedure for some of these steels.

In addition, the specification requires that "these steels have enhanced corrosion resistance equal to or greater than carbon steels with copper." Carbon steels with copper—or "copper bearing" steels, as they are frequently called—have twice the atmospheric corrosion resistance of A7 steel. There are, however, certain proprietary grades of A242 having over four times the atmospheric corrosion resistance of A7 steel.

Consequently, in ordering A242 steel, the producer must be consulted to insure that the steel can be economically welded and has improved corrosion resistance if these properties are desired.

ASTM A440

In 1959 ASTM wrote Specification A440, "High-Strength Structural Steel", to provide a more economical high strength steel than A242 for structures to be riveted or bolted.

The same strength requirements are specified as for A242. The chemical requirements allow higher carbon and manganese contents than A242, so that the required strength can be reached without the addition of more expensive alloying elements. The specification limits the sulphur and phosphorus, and requires that the steel be "copper bearing" to improve its corrosion resistance over that of A7.

Because of the increased carbon and manganese contents, A440 requires special welding precautions. It is not recommended for economical welded construction.

ASTM A441

In 1960 ASTM A441, "High-Strength Low Alloy Structural Manganese Vanadium Steel", was written to provide an economically weldable high strength steel.

A441 specifies the same strength requirements as A242. The chemical requirements limit carbon and manganese to the same levels as A242, but add 0.02 per cent minimum vanadium to obtain the desired strength levels without the need for more expensive alloy additions. As in the case of A440, the Specification limits the sulphur and phosphorus, and requires that the steel be "copper bearing" to improve its corrosion resistance over that of A7.

5. HIGH-STRENGTH LOW ALLOY STEELS

Proprietary Grades

Proprietary grades of high-strength low alloy steels are available which are similar to the ASTM high-strength grades but differ in certain respects. These steels have specified minimum yield points ranging from 45,000 psi to 65,000 psi. Although these steels are widely used in manufacturing, they have only recently begun

TABLE 1B—A Comparison of Steels for Construction
ASTM High-Strength Steels

ASTM Grade	Thickness		Min. Yield Point psi	Tensile Strength psi	Chemical Requirements (Ladle) Per Cent: C Max.	Mn	P Max.	S Max.	Si Max.	Cu Min.	V Min.	Other
	Shapes	Group I (1)	50,000	70,000 min.								
		Group II (1)	46,000	67,000 min.								
A440		Group III (1)	42,000	63,000 min.	.28	1.10/1.60	.04(2)	.05	.30	.20		
	Plates & Bars	To ¾" incl.	50,000	70,000 min.								
		Over ¾" to 1½" incl.	46,000	67,000 min.								
		Over 1½" to 4" incl.	42,000	63,000 min.								
	Shapes	Group I (1)	50,000	70,000 min.								
		Group II (1)	46,000	67,000 min.								
		Group III (1)	42,000	63,000 min.								
A441	Plates & Bars	To ¾" incl.	50,000	70,000 min.	.22	1.25 max.	.04	.05	.30	.20	.02	
		Over ¾" to 1½" incl.	46,000	67,000 min.								
		Over 1½" to 4" incl.	42,000	63,000 min.								
		Over 4" to 8" incl.	40,000	60,000 min.								
	Shapes	Group I (1)	50,000	70,000 min.								
		Group II (1)	46,000	67,000 min.								
		Group III (1)	42,000	63,000 min.								
A242	Plates & Bars	To ¾" incl.	50,000	70,000 min.	.22	1.25 max.		.05				(3)
		Over ¾" to 1½" incl.	46,000	67,000 min.								
		Over 1½" to 4" incl.	42,000	63,000 min.								

(1) Groups I, II, III are defined as follows:

Group I	Group II		Group III	
	Wide Flange Shapes		Wide Flange Shapes	
	Nominal Size*, in.	Wt. per ft., lb.	Nominal Size*, in.	Wt. per ft., lb.
All shapes except those listed in Groups II & III	36 x 16½	All weights	14 x 16	210 to 426 incl.
	33 x 15¾	All weights		
	14 x 16	142 to 211 incl.		
	12 x 12	120 to 190 incl.		
	Angles over ¾" thick			

*Nominal depth and nominal width of flange

(2) Based on basic steelmaking process.

(3) The choice and use of alloying elements to produce the required strength or to improve corrosion resistance, or both, will vary with the manufacturer.

to be used in the design of buildings and bridges.

The first of this group of high-strength steels was commercially produced in 1958. At that time it was found that minor additions of columbium to plain carbon steel produced as-rolled yield points up to 60,000 psi in the thinner gauges in a weldable grade of steel. These "columbium steels", as they were called, were produced to specified minimum yield points of 45,000 psi, 50,000 psi, 55,000 psi, and 60,000 psi in limited thicknesses.

In 1962 another group of high-strength low alloy steels was introduced commercially which extended these high strengths to a broad range of thicknesses in plates and shapes. These steels resulted from the discovery that the addition of small amounts of nitrogen combined with vanadium in a carbon-manganese steel produced an increase in strength much greater than would be expected from the effects of these two elements individually, while eliminating the deleterious effects of adding nitrogen alone.

Similar high-strength steels are now available from several producers, in a wide range of shapes and plates with specified minimum yield points of 45,000, 50,000, 55,000, 60,000 and 65,000 psi. (See Table 1C). And the Bureau of Public Roads, in cooperation with the steel producers concerned, is currently (January, 1966) preparing a specification for these steels to allow their use in welded highway bridges.

The proprietary grades of high-strength steels are presently (January 1966) limited in their use in building and bridge construction because of code and specification requirements. These steels do not as yet have an ASTM designation. However, these steels offer the advantage of providing high strength at economical prices in a variety of yield points and they enable designers to obtain the strength they need without the necessity of paying for considerably more strength than required. Furthermore, the chemistry of these steels is controlled for economical welding. Consequently, engineers are taking advantage of the economies to be gained in the use of these steels and have used them on a great variety of structures including many buildings and several bridges.

6. HEAT-TREATED CONSTRUCTIONAL ALLOY STEELS

Proprietary Grades

In 1953, the first of the high-strength, heat treated, constructional alloy steels was marketed. These are low-carbon, quenched and tempered alloy steels with specified minimum yield points ranging from 90,000

TABLE 1C—A Comparison of Steels for Construction

Proprietary High-Strength Low Alloy Steels (1)

Mfr's Grade Classification	Thickness		Min. Yield Point psi	Tensile Strength psi	Chemical Requirements (Ladle) Per Cent N Max.	C Max.	Mn Max.	P Max.	S Max.	V Min.	Cu Min.
45	Shapes		45,000	65,000 min.		.22	1.25	.04	.05	.02	(2)
	Plates	To 1½" incl.									
50	Shapes	To ¾" incl. (3)	50,000	70,000 min.		.22	1.25	.04	.05	.02	(2)
		Over ¾" (3)			.015						
	Plates	To ¾" incl.									
		Over ¾" to 1½" incl.			.015						
55	Shapes	To ⅜" incl. (3)	55,000	70,000 min.		.22	1.25	.04	.05	.02	(2)
		Over ⅜" (3)			.015						
	Plates	To ⅜" incl.									
		Over ⅜" to ¾" incl.			.015						
60	Shapes	To ¾" incl. (3)	60,000	75,000 min.	.015	.22	1.25	.04	.05	.02	(2)
	Plates	To ⅜" incl.									
65	Shapes	To ⅜" incl. (3)	65,000	80,000 min.	.015	.22	1.25	.04	.05	.02	(2)
	Plates	To ⅜" incl.									

(1) Chemistry of high-strength low alloy steels varies with producers. This Table is based on Bethlehem V Steels as of January, 1964.

(2) When copper steel is specified, the minimum copper is 0.20%.

(3) For shapes, the thickness shown indicates web thickness.

to 100,000 psi, and ultimate strengths ranging from 105,000 to 135,000 psi, depending upon thickness. Originally these steels were available only in plates because of difficulties encountered during heat treating in maintaining the straightness of shapes. By 1961 many of these difficulties had been overcome, and these steels are now offered in certain structural shapes.

Because of the higher price of these steels, their use in building construction has so far been rather limited. However, they have been used to considerable advantage in several large bridges built in recent years, and in other types of structures. The major applications of these steels in construction occur when unusually high loads are encountered, particularly in tension members.

Heat-treated constructional alloy steels have the ASTM designation of A514-64. Where local codes permit the use of these steels and when loads are of sufficient magnitude, and tension loads are encountered or lateral buckling is restrained, economies can be gained through the use of the heat-treated constructional alloy steels.

B. SELECTING THE RIGHT STRUCTURAL STEEL

7. BASIS FOR SELECTION

With the adoption by the AISC of design specifications covering the use of six ASTM steels (A7, A373, A36, A440, A441, and A242), designers are now able to choose the particular steel which is best suited to the job at hand. However, before designers can take advantage of these steels, some insight must be acquired as to where each can be used to the greatest advantage.

To aid the designer in this selection, we shall compare the five ASTM steels recommended for welded construction on the basis of price, and also on what we call "yield strength per dollar".

We shall also present guides to aid in recognizing those situations wherein the use of high-strength steels has proven to be advantageous.

8. COMPARISON BASED ON PRICE

Price is, of course, a factor in the selection of a steel. Table 2A (for shapes) and Table 2B (for plates) show the comparative prices of the five ASTM structural steels and proprietary high strength, low alloy steels.

Carbon Steels

In carbon steel shapes, A36 steel is the same price as A7, has a 10 per cent higher specified minimum yield point, and can be welded with high speed, low cost procedures. The maximum carbon content is only 0.26 per cent. A373 has a higher maximum carbon content (0.28 per cent), a higher price, and a lower yield strength than A36. In shapes, therefore, A36 is by far the best bargain of the carbon steels.

In plates, the advantage of A36 is not quite as pronounced as in shapes. However, because of its higher specified minimum yield point, relative ease of welding, and the requirement that the steel be produced fully killed in thicknesses over 1½ inches thick, A36 is the best buy for construction purposes.

High-Strength Steels

In the high strength steels, for material thicknesses up to ⅝" inclusive, A441 is the same price as A440. For thickness over ⅝" to ¾" inclusive, A441 is only slightly more expensive than A440. Since A440 steel is not generally recommended for economical welding, A441 is a more versatile and useful steel for construction purposes.

The A242 grades are substantially higher in cost than A441. Consequently, it would be uneconomical to use A242 unless improved corrosion resistance is desired. If this property is desired, it should be so specified; mere reference to the A242 specification does not assure improved corrosion resistance.

9. COMPARISON BASED ON YIELD STRENGTH PER DOLLAR

Price alone does not always give an accurate picture of the possible cost advantage of one steel over another, particularly where a difference in yield point is involved. Table 3A (for shapes) and Table 3B (for plates) compare the five ASTM structural steels on the basis of comparative yield point per dollar of cost, with A36 steel used as the basis for comparison.

Although such a comparison gives a more accurate picture than a comparison of price alone, a comparison of steels on the basis of the strength-to-price ratio must be made with the following qualifications:

a. Strength-price values are based on minimum yield point. Where factors other than yield point (such as limitations due to deflection, buckling or lateral stability) determine the allowable stress, strength-price values based on minimum yield point are not a valid comparison.

TABLE 2A—A Comparison of Prices of Steels for Construction
Base Price Plus Grade Extra Only, October, 1963 (1)
Structural Shapes

	Grade	Group and Thickness (2)		Min. Yield Point psi	$ Per Ton	Differential Over A36	Comparative Price (3)	Comparative Yield Strength per Dollar (4)
ASTM Carbon Steels	A36			36,000	114	0	1.00	1.00
	A7			33,000	114	0	1.00	0.92
	A373	Other Than Group A (5)		32,000	117	+3	1.03	0.86
		Group A (5)			121	+7	1.06	0.84
ASTM High-Strength Steels	A441	Group I (6)	To 3/8" incl.	50,000	133	+19	1.17	1.19
			Over 3/8" to 3/4" incl.		139	+25	1.22	1.14
			Over 3/4"		147	+33	1.29	1.08
		Group II (6)	To 3/4" incl.	46,000	139	+25	1.22	1.05
			Over 3/4"		147	+33	1.29	0.99
		Group III (6)	To 3/4" incl.	42,000	139	+25	1.22	0.96
			Over 3/4"		147	+33	1.29	0.90
	A242 (7)	Group I (6)		50,000	164	+50	1.44	0.96
		Group II (6)		46,000				0.89
		Group III (6)		42,000				0.81
Proprietory High-Strength Low Alloy Steels (8)	45	To 3/8" incl.		45,000	125	+11	1.10	1.14
		Over 3/8" to 3/4" incl.			130	+16	1.14	1.10
		Over 3/4"			137	+23	1.20	1.04
	50	To 3/8" incl.		50,000	128	+14	1.12	1.24
		Over 3/8" to 3/4" incl.			134	+20	1.18	1.18
		Over 3/4"			142	+28	1.25	1.11
	55	To 3/8" incl.		55,000	135	+21	1.18	1.29
		Over 3/8" to 3/4" incl.			141	+27	1.24	1.23
		Over 3/4"			151	+37	1.32	1.16
	60	To 3/8" incl.		60,000	142	+28	1.25	1.33
		Over 3/8" to 3/4" incl.			150	+36	1.32	1.26
	65	To 3/8" incl.		65,000	152	+38	1.33	1.36

(1) These figures are for comparative purposes only, and are not to be used for pricing purposes. Figures are based on Bethlehem Steel Company prices, October, 1963.

(2) Indicates web thickness.

(3) The ratio of the price of the steel to the price of A36.

(4) The yield strength of the steel per unit price of the steel (dollars per ton) compared to the yield strength per unit price for A36.

(5) See Table 1A, Note 3, for definition of Group A.

(6) See Table 1B, Note 1, for definition of Groups I, II, and III.

(7) Based upon Bethlehem's Mayari R A242 steel, which has an atmospheric corrosion resistance of at least 4 to 6 times that of plain carbon steel.

(8) Based on Bethlehem V Steels.

TABLE 2B—A Comparison of Prices of Steels for Construction
Base Price Plus Grade Extra Only, October, 1963 (1)
Structural Plates

Grade		Thickness	Min. Yield Point psi	$ Per Ton	Differential Over A36	Comparative Price (2)	Comparative Yield Strength Per Dollar (3)
ASTM Carbon Steels	A36	To 3/4" incl.	36,000	114	0	1.00	1.00
		Over 3/4" to 1 1/2" incl.		120			
		Over 1 1/2" to 8" incl.		135			
	A7	To 3/4" incl.	33,000	113	−1	0.99	0.93
		Over 3/4" to 1 1/2" incl.			−7	0.94	0.98
		Over 1 1/2" to 4" incl.		128		0.95	0.96
	A373	To 1/2" incl.	32,000	114	0	1.00	0.89
		Over 1/2" to 3/4" incl.		118	+4	1.04	0.85
		Over 3/4" to 1" incl.			−2	0.98	0.91
		Over 1" to 1 1/2" incl.		131	+11	1.09	0.82
		Over 1 1/2" to 4" incl.		133	−2	0.99	0.90
ASTM High-Strength Steels	A441	To 3/8" incl.	50,000	130	+16	1.14	1.22
		Over 3/8" to 3/4" incl.		136	+22	1.19	1.17
		Over 3/4" to 1 1/2" incl.	46,000	144	+24	1.20	1.06
		Over 1 1/2" to 4" incl.	42,000	151	+16	1.12	1.04
		Over 4" to 8" incl.	40,000	164	+29	1.21	0.91
	A242 (4)	To 3/4" incl.	50,000	161	+47	1.41	0.99
		Over 3/4" to 1 1/2" incl.	46,000		+41	1.34	0.95
		Over 1 1/2" to 4" incl.	42,000	163	+28	1.21	0.96
Proprietary High-Strength Low Alloy Steels (5)	45	To 3/8" incl.	45,000	122	+8	1.07	1.17
		Over 3/8" to 3/4" incl.		127	+13	1.12	1.12
		Over 3/4" to 1 1/2" incl.		134	+14	1.12	1.12
	50	To 3/8" incl.	50,000	125	+11	1.10	1.26
		Over 3/8" to 3/4" incl.		131	+17	1.16	1.20
		Over 3/4" to 1 1/2" incl.		139	+19	1.16	1.20
	55	To 3/8" incl.	55,000	132	+18	1.16	1.32
		Over 3/8" to 3/4" incl.		138	+24	1.21	1.26
	60	To 3/8" incl.	60,000	139	+25	1.22	1.37
	65	To 3/8" incl.	65,000	149	+35	1.31	1.38

(1) These figures are for comparative purposes only, and are not to be used for pricing purposes. Figures are based on Bethlehem Steel Company prices, October, 1963.

(2) The ratio of the price of the steel to the price of A36.

(3) The yield strength of the steel per unit price of the steel (dollars per ton) compared to the yield strength per unit price for A36 steel in the same thickness.

(4) Based upon Bethlehem's Mayari R A242 steel, which has an atmospheric corrosion resistance of at least 4 to 6 times that of plain carbon steel.

(5) Based on Bethlehem V Steels.

b. Strength-price values are based on equivalent thicknesses of material. Use of a high-strength steel will usually result in a thinner section than that required with A36. Since the thinner material may be sold at a lower unit price, actual savings may therefore be greater than indicated by comparative strength-price ratios. It is also true that using higher strength, thinner sections will permit a reduction in weld size which offsets increased cost of preheat or other special welding procedures.

c. Strength-price values are based on material costs and do not include freight, fabrication, or erection.

Carbon Steels

Based on price alone, A36 was found to be the best buy in shapes and a good buy in plates. If we make our comparison on the basis of strength-to-price ratio, as in Table 3, A36 is found to be a better value than either A7 or A373 in both shapes and plates.

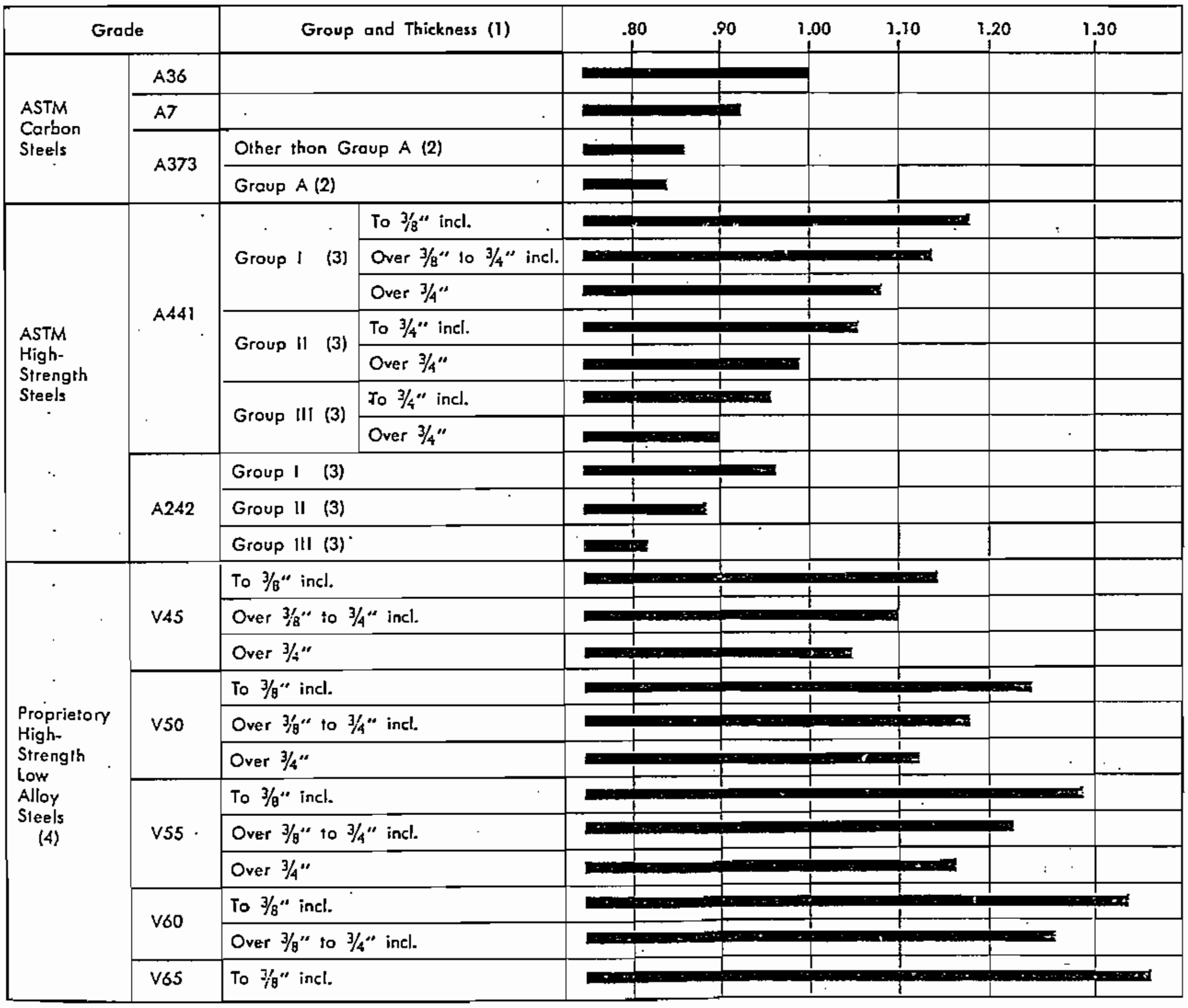
High-Strength Steels

Where full advantage can be taken of higher yield point levels, A441 is a better buy than A36, except for Group II* shapes over ¾ inch thick (web thickness) and for Group III* shapes.

The A242 steels are not recommended for economical design unless high corrosion resistance is a major requirement.

* Refer to note 1 on Table 1B.

TABLE 3A—Comparative Strength-to-Price Ratios
Comparative Yield Strength Per Dollar*
Structural Shapes



*The yield strength of the steel per unit price of the steel (dollars per ton) compared to the yield strength per unit price for A36.

(1) Indicates web thickness.

(2) See Table 1A, Note 3, for definition of Group A.

(3) See Table 1B, Note 1, for definition of Groups I, II, and III.

(4) Based on Bethlehem V Steels.

10. WHEN TO CONSIDER THE HIGH-STRENGTH STEELS

A36 is recommended as the most economical of the carbon steels. When advantage can be taken of the higher yield point levels of A441, the use of this steel rather than A36 can result in savings.

Tension Members

High-strength steels can usually be used to advantage in tension members, where a significant increase in design stress can result from increased yield strength. However, where connections are made with bolts or rivets rather than by welding, some advantage of the high-strength steels is lost because of the reduced net area at the holes.

Beams

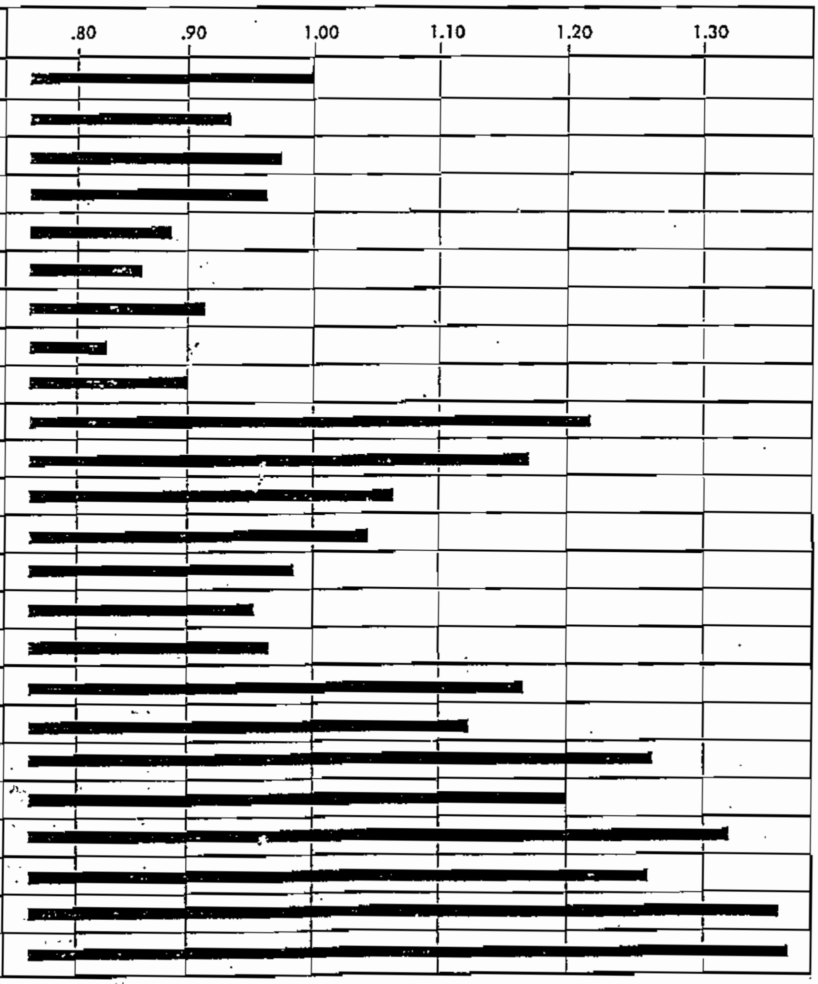
The use of high-strength steels in beam design is usually limited to applications where deflections are either unimportant or can be minimized by special design procedures. The modulus of elasticity is the same for all these steels. Consequently, if we compare two beams of the same section and length, one an A36 beam loaded to a design stress of 24,000 psi and one an A441 beam loaded to a design stress of 33,000 psi, the A441 beam will deflect 38 per cent more than the A36 beam.

Columns and Compression Members

In columns and compression members, the slenderness ratio (L/r) will usually limit the allowable design

TABLE 3B—Comparative Strength-to-Price Ratios
Comparative Yield Strength Per Dollar (1)
Structural Plates

Grade		Thickness
ASTM Carbon Steels	A36	
	A7	To 3/4″ incl.
		Over 3/4″ to 1 1/2″ incl.
		Over 1 1/2″ to 4″ incl.
	A373	To 1/2″ incl.
		Over 1/2″ to 3/4″ incl.
		Over 3/4″ to 1″ incl.
		Over 1″ to 1 1/2″ incl.
		Over 1 1/2″ to 4″ incl.
ASTM High-Strength Steels	A441	To 3/8″ incl.
		Over 3/8″ to 3/4″ incl.
		Over 3/4″ to 1 1/2″ incl.
		Over 1 1/2″ to 4″ incl.
	A242	To 3/4″ incl.
		Over 3/4″ to 1 1/2″ incl.
		Over 1 1/2″ to 4″ incl.
Proprietary High-Strength Low Alloy Steels (2)	V45	To 3/8″ incl.
		Over 3/8″ to 1 1/2″ incl.
	V50	To 3/8″ incl.
		Over 3/8″ to 1 1/2″ incl.
	V55	To 3/8″ incl.
		Over 3/8″ to 3/4″ incl.
	V60	To 3/8″ incl.
	V65	To 3/8″ incl.



(1) The yield strength of the steel per unit price of the steel (dollars per ton) compared to the yield strength per unit price for A36 steel in the same thickness.

(2) Based on Bethlehem V Steels.

stress and often preclude advantageous use of high-strength steels.

For instance, if we consider an unbraced column length of 11 feet and compare the required column size of A36 and A441 for loads of 100ᵏ, 400ᵏ, and 1600ᵏ we find savings as given in Table A.

TABLE A

Load (Kips)	Comparative Factors	ASTM A36	ASTM A441
100ᵏ	Size	8WF24	8WF24
	wt. Savings/ft.		0
	Cost Savings/ft.*		—$.22
400ᵏ	Size	12WF79	12WF58
	wt. Savings/ft.		21
	Cost Savings/ft.*		+$.74
1600ᵏ	Size	14WF287	12WF246
	wt. Savings/ft.		41
	Cost Savings/ft.*		—$1.25

* Saving of A441 over A36; (+) indicates a saving (based on prices in effect Oct., 1963). These values include base price and grade extra (shown in Table 2B) plus section and length extras.

Although there is a saving in weight using A441, the cost saving is variable and often nil. Because of the heavy section required for the 1600ᵏ load, A441 has a minimum specified yield point of only 42,000 psi.

Weight Savings

The judicious use of high-strength steels will almost always result in an overall reduction in weight of the structure. Whenever this weight reduction can be translated into savings in the cost of foundations, supporting structures, or in handling, transportation, or erection costs, then the high-strength steels can and should be used to advantage.

Savings In Fabrication Costs

Whenever the need for built-up sections can be avoided through the use of high-strength steels, savings in fabricating costs can be realized. A common example is in the lower tier columns of multi-story buildings.

Proprietary Grades

Whenever high-strength steels can be used advantageously, serious consideration should be given to one or more of the proprietary steels, if these steels are acceptable under the local codes. Proprietary steels often provide increased economies over A441. For instance, if we compare the same column loads and column length (11 feet) as in Table A, we find savings for proprietary steels as given in Table B.

TABLE B

Load (Kips)	Comparative Factors	ASTM A36	Proprietary Steels* Guaranteed Min. Y.P.Ksi 50	55
100ᵏ	Size	8WF24	8WF24	8WF24
	wt. Savings/ft.		0	0
	Cost Savings/ft.**		—$.16	—$.25
400ᵏ	Size	12WF79	12WF58	12WF53
	wt. Savings/ft.		21	26
	Cost Savings/ft.**		+$.88	+$1.04
1600ᵏ	Size	14WF287	14WF211	14WF193
	wt. Savings/ft.		86	94
	Cost Savings/ft.**		+$1.80	+$2.31

* Based on Bethlehem Steel Company's V50 and V55 Steels

**Saving of grade 50 or 55 over A36; (+) indicates a saving (based on prices in effect Oct., 1963. These values include base price and grade extra (shown in Table 2B) plus section and length extras.

Although the minimum specified yield point of A441 decreases as thickness increases, yield points for the above proprietary steels are 50,000 and 55,000 psi respectively for all available thicknesses. As can be seen in Tables A and B, the effect on cost of maintaining yield point throughout a broad range of thicknesses is quite evident.

C. THE MILL TEST REPORT: A GUIDE TO WELDABILITY

11. SPECIFICATION VS ACTUAL CHEMISTRY

The preceding material on the development of the construction steels and the specifications and merits of these steels should be helpful to the engineer or architect who is searching for the most economical design.

However, to the fabricator, who must determine the procedure to use for forming, burning or welding the steel, the paramount question is: "What is the chemical composition and what are the mechanical properties of the steel that I must work with?"

Many fabricators and engineers tend to rely on the specification of the steel for the answer to this question. But such practice has in many cases led to a welding procedure based on the worst combination of chemistry (as far as welding is concerned) that the specification will allow. This practice can result in a more costly welding operation than is necessary.

A more realistic answer to the establishment of welding procedure lies in the steel's "pedigree"—the mill test report. The mill test report is a certification of the chemical composition and physical properties of the steel in a specific shipment.

To cite an example, an investigation of the mill test reports from a certain mill disclosed that the steel supplied by that mill had a carbon and manganese content considerably less than the maximum allowed under the specification. In addition, 85 per cent of the steel purchased from this mill was less than ¾ inch thick. The average chemistry for plates up to ¾ inch thick rolled on this mill compares with the allowable specification chemistry as follows:

Grade		Carbon	Manganese
A36	Specification Mill Average	0.25% max .20	— .50%
A441	Specification Mill Average	.22% max. .18	1.25% 1.10

Although the above average figures are for a particular mill, they indicate that the carbon and manganese content is usually considerably less than the maximum of the specification and will be in a range that will permit significant variations in welding procedures.

12. MILL PROCEDURE

When a mill receives an order for a particular grade of steel, production of that item is scheduled to be rolled from a heat of steel meeting the chemical requirements of the grade ordered and which it is expected will provide the mechanical properties required in the finished product.

Each ingot poured from any heat of steel is identified with the heat number, and this identity is maintained throughout all subsequent rolling mill operations.

The rolling of steel has a definite effect on the mechanical properties of the finished product. Confirming mechanical tests (tensile strength, yield point, and per cent elongation) are, therefore, made after the steel has been rolled to final section and cooled.

The mechanical properties of the section and the chemical composition of the heat are recorded on the mill test report.

The mill test report is filed by the mill for its own record and certified copies are forwarded to the customer, when requested, for his use. The report's disclosure of the particular mill order's chemistry is a valuable guide to development of the most economical and satisfactory welding procedure.

The chemistry of the steel in a structural steel fabricator's shop can thus be readily determined from the mill test report. Furthermore, where necessary the chemistry of the steel can be anticipated to a reasonable degree far in advance of shipment by referring to previous mill test reports on similar products from the same mill.

For greater economy of welding, the structural steel fabricator or erector can and should base his welding procedure on the actual chemistry of the steel he is welding, rather than upon the worst possible combination of chemistry allowed under the specification.

CHECKLIST FOR USE OF HIGH-STRENGTH STEEL

In structural steel design, A36 is generally the most versatile and economical of the construction steels. However, there are occasions where the judicious use of high-strength steels can result in overall cost and weight savings, such as:

Tension Members

The high-strength steels can usually be used to advantage in tension members except when the members are relatively small in section or when holes (i.e. for bolts or rivets) substantially reduce the net section of the member.

Beams

a. When steel dead load is a major portion of design load.

b. When deflection limitations are not a major factor in determining section.

c. When deflections can be reduced through design features such as continuity or composite design.

d. When weight is important.

e. When fabricating costs can be reduced.

f. When architectural considerations limit the beam dimensions.

Columns And Compression Members

a. When steel dead load is a major portion of design load.

b. When the slenderness ratio (L/r) of the member is small.

c. When weight is important.

d. When fabricating costs can be reduced.

e. When architectural considerations limit the column dimensions.