Preservation Engineering: Early Steel Framing

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Structural steel was unique among the new materials introduced to structural engineering in the nineteenth century; it did not represent new technology. Unlike cast iron, wrought iron, and reinforced concrete, engineers and contractors did not need to learn a new set of design methods, connection and fabrication techniques, and framing types. When steel was introduced as a readily-available product in the 1870s, it was used as a one-for-one substitute for wrought iron. Between the 1830s (when rolled wrought iron became commercially available), the 1850s (when I sections were first rolled), and the 1870s, iron use became quite sophisticated, with built-up sections for columns and girders and complex riveted connections for wind bracing. The people who began using steel framing simply followed the existing path.

The beginning of common steel framing is usually marked by the 1875 opening of the Edgar Thomson plant of the Carnegie Iron (later Carnegie Steel) company. This was the first plant dedicated to the production of rolled steel members; raw steel production had been revolutionized by the Bessemer and open-hearth processes of 1850s. Steel produced in the 1870s and 1880s was often metallurgically closer to wrought iron than to modern steel, but we will follow the designers and builders of the era and call their steel "steel." Nearly all of the components of steel technology developed out of the wrought-iron techniques that began in the 1850s.

The first commercial steel use began in the 1870s and included standardized angle, channel, and I-beam shapes, riveted connections to create rigidity, and brackets to support eccentrically-located beams at columns. Connection details, member design, and frame design developed simultaneously, leading to recognizably mature technology by the 1920s.

An important break in steel framing development took place after World War II as the result of changes in frame analysis and floor systems. First, the development of modern curtain walls and interior partitions, in lieu of masonry, removed an important source of inadvertent lateral stiffness. Second, the development of composite metal deck and spray-on fireproofing meant the end of wood-formed floors in steel-framed buildings. This break marks the difference between early and modern steel framing.

Material and Sections

As with any new material, there was wide variation in steel material prior to 1900. Chemical composition was different from one manufacturer to the next, particularly with regard to the presence of impurities such as silicon and phosphorus. Mechanical properties varied with the chemical properties, and with the proprietary shapes fabricated by each manufacturing company. In 1896, the Association of American Steel Manufacturers (AASM) issued a specification for the physical properties of steel and for the standardized L, C, and I shapes (*Figure 1*). This promoted the use of steel by turning it into a generic commodity, which meant that designers and builders were no longer tied to specific manufacturers and that future competition between manufacturers would be based largely on price. The importance of a national standard was emphasized by the speed

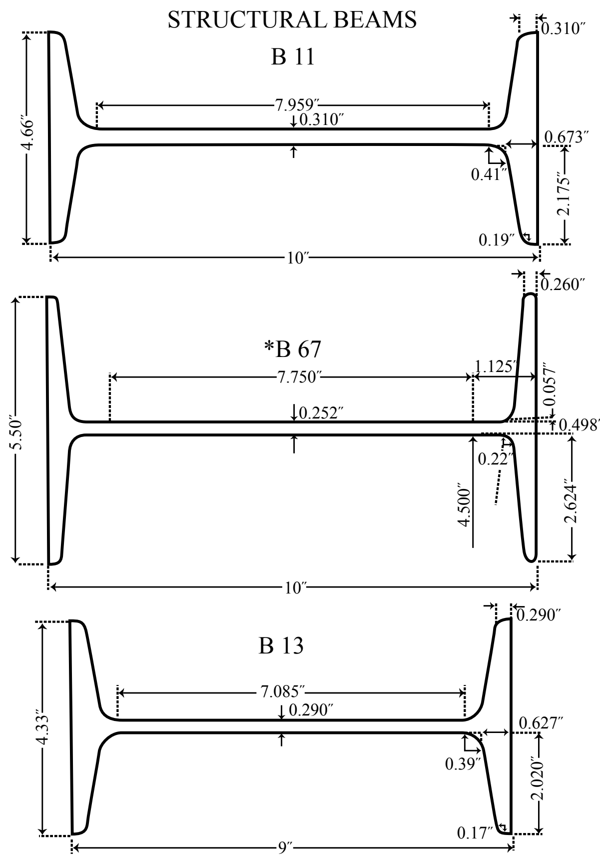

Figure 1: Typical AASM-based steel sections.

Section Index	Depth of Beam, Inches	Weight per Foot, Pounds	Flange Width, Inches		Web Thickness, Inches	
			Decimal	Fractional	Decimal	Fractional
B 11	10	40.0	5.099	5 3/32	0.749	3/4
		35.0	4.952	4 61/64	0.602	39/64
		30.0	4.805	4 13/16	0.455	29/64
		25.0	4.660	4 21/32	0.310	5/16
*B 67	10	22.25	5.500	5 1/2	0.252	1/4
B 13	9	35.0	4.772	4 49/64	0.732	47/64
		30.0	4.609	4 39/64	0.569	9/16
		25.0	4.446	4 29/64	0.406	13/32
		21.0	4.330	4 21/64	0.290	19/64

* Supplementary Beam.

with which control of the standards was shifted from an industry group – the AASM – to a neutral organization, the American Society for Testing and Materials (ASTM).

Founded in 1898, the ASTM issued standards A6, A7, and A9 by 1901, governing steel section geometry, bridge steel, and building steel, respectively. From then forward, the steel used in nearly all buildings conformed to ASTM A9 and its successors, which can be confirmed in alteration work through coupon testing. This material performs similarly to the later and more familiar A36 steel, although it has slightly lower yield and ultimate stresses, and is usually weldable with low-hydrogen electrodes.

The AASM geometric standards are still the basis for the sections it defined. The most important section outside of the AASM definitions is the wide-flange section, or as it was sometimes called to distinguish it from the narrower "I," the "H." More complex rolling techniques were needed to create wide-flange sections, and the "Grey Mill" process was introduced after 1900. Labor was relatively inexpensive in that era, so that it was generally less expensive for fabricators to build up large sections by riveting together channels, angles, and plates than to purchase wide-flange sections (*Figure 2*). As a result, Bethlehem Steel was the only major company to license the wide-flange technology and produce the sections until the 1920s. By that time, ASTM A6 had defined standard wide-flange shapes which did not include Bethlehem's slightly archaic wide-flanges with a small slope to the interior flange faces. In a separate development, rolled "Z" shapes fell out of use in the 1900s and 1910s.

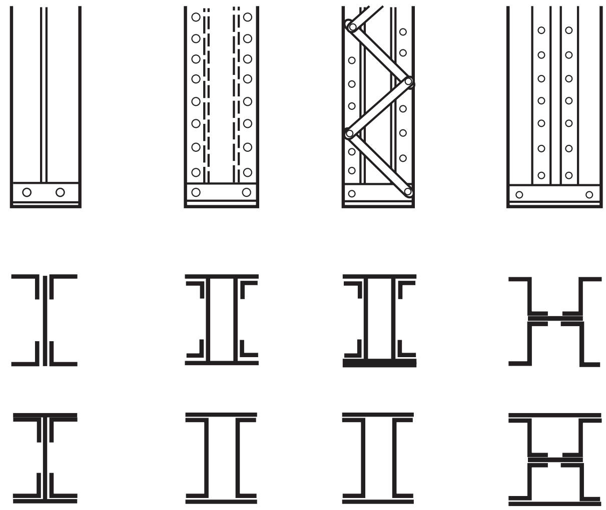

Figure 2: Left to right: Built-up I's, built-up boxes using plates, built-up latticed boxes, built-up columns using Zs.

Codes and Pre-Codes

The first edition of the American Institute of Steel Construction (AISC) specification was published in 1923, and the first design manual was published in 1927. Because the use of structural steel was still developing rapidly, new editions of the manual followed in 1934, 1937, and 1941.

In the period before the AISC specification, there was no uniform national code for steel. The governing codes were typically city and state building codes that contained explicit provisions for steel design or that referenced texts (such as *Trautwine's Engineer's Pocket Book*, which was a manual providing tabulated designs); guidance for engineers and contractors looking for more information than simply allowable stresses was found in handbooks put out by the steel companies. While the most common of these found today is the *Carnegie Pocket Manual*, they were published and distributed by every major steel producer and some fabrication companies. Because the allowable stresses varied from one local code to another, the steel company handbooks referenced both local codes and national, non-building codes such as the American Railway Engineering Association (AREA). The local code provisions varied widely, so that a single piece of steel in 1920 could have an allowable bending stress anywhere between 12 and 16 ksi (kips per square inch) depending on where it was used.

Obviously, steel structures built before 1923 may vary from the AISC specification and may therefore seem to be over-designed based on modern analysis. In addition, since it took some years for the AISC specification to be legally accepted as a nation-wide standard, buildings from the 1920s in general may show peculiarities when analyzed. The only certain way to identify the cause of such peculiarities is to reanalyze the building using both the original and current codes. For example, analyzing an existing floor beam from 1924 under the AISC specification may show it to be very conservatively designed because of the local code; cities that had conservative local codes therefore have existing buildings with larger reserve capacity than cities that had more progressive codes.

Connections

While experimental welding was used in a few buildings as early as the 1920s, it did not enter the mainstream of construction until after the 1950s. Connections in early steel buildings used individual fasteners in connection configurations that are still used today: double angles, seat angles, stiffened seats, top and bottom angles, and complex brackets. Because welding was completely absent, brackets often contain numerous angles and filler plates to "turn the corner" so that there were always two parallel planes of flanges to be fastened.

Only three types of connectors existed: unfinished bolts, rivets, and turned bolts. Unfinished bolts, similar to the current ASTM A307 bolts, were used in the same types of connections they are used in today, relatively lightly-loaded beam-to-beam connections where stress reversals are not expected. The material properties for these bolts are available from AISC Design Guide 15, the AISC *Rehabilitation and Retrofit Guide*, for analysis, but they are rarely found in locations where the stress is critical; similar to modern practice, the connections often have as many rows of bolts as fit naturally within the beam flanges, regardless of the stress.

Rivets, following practice established in wrought-iron construction, were driven hot to provide clamping action as they cooled. While varying temperatures of the hot rivets and varying times to completion for each installation caused variation in the clamping force, rivets performed a similar function to slip-critical high-strength bolts. The material strength of rivets varied over the more than seventy years during which they were used, but in most cases the shear capacity of a rivet is fairly similar to that of a current ASTM A325N bolt of the same diameter. Exact material properties can be found in AISC Design Guide 15 and can be checked through testing as required.

Turned bolts were a method of providing bolted connections capable of accepting stress reversal in the era before high-strength bolts capable of providing clamping were available. For example, the first edition of the AISC *Steel Construction* manual specified a 10 ksi allowable shear stress in unfinished bolts and hand-driven rivets, and a 13.5 ksi shear stress for power-driven rivets and "turned bolts in reamed holes with a clearance of not more than 1⁄50 inch." (Note that the distinction between hand- and power-driven rivets was only made in the first two editions of the manual and was obviated by the general use of pneumatic hammers to drive rivets instead of mallets.)

Floor Framing

The basics of gravity framing for floors were established before steel was in use. There is little difference in form between a wrought-iron-beam floor constructed in the 1870s and a steel-beam-floor constructed in the 1920s; designs are non-composite, spans were usually 24 feet or less, spacing was five to eight feet, and depths were most commonly 10 to 15 inches. Until the mid 1900s, when Bethlehem Steel licensed European-developed rolling technology, beam sections were I-beams or built-up girders. The first wide-flange sections were used for columns and actually were called "Bethlehem columns" after the sole United States supplier.

Because deep wide-flange sections were not available for use as girders, double I-beams or riveted plate girders were commonly used for long spans and heavy loads. Double beams were also common as spandrel beams before 1920, with the wall carried mostly on the outer beam and the floor carried on the inner beam. Fitted cast-iron (or, less commonly, pipe) spacers were used to link the double beams to ensure uniform loading and deflection.

Columns

Because of the relatively slow development of heavy wide-flange sections, most columns were built up of plates, angles, and channels as late as the 1920s. The most common columns were built-up boxes of channels and plates and built-up "H"s of angles and plates, but there were many variations. Some of them, such as the Gray column (*Figure 3*), appear odd today because they were intended only for concentric loads in buildings with full cross-bracing or masonry shear walls. The box and H sections can be analyzed with little difficulty using current codes.

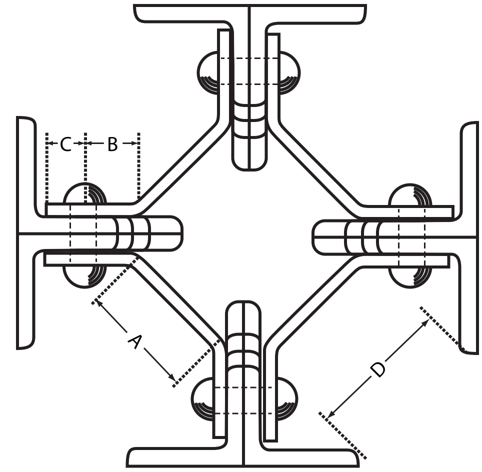

Figure 3: Gray column.

Because the "K" factor defining effective lengths for columns did not enter the AISC code until the 6th edition in 1963, earlier moment-frame columns were designed incorrectly by modern standards, since they effectively used K=1. However, the allowable stresses for column compression and bending in that era were generally lower than current codes, so the lack of K factors did not mean that the columns are necessarily undersized.

Conclusion

Of all of the materials that a current-day engineer may encounter in old buildings, structural steel is the most familiar. The basic forms of steel framing have not changed radically since the metal was introduced, largely because wrought-iron framing served as an earlier field for experimentation. While the allowable stresses in steel have increased, this has been largely offset by architecturally-influenced changes such as larger column-to-column spacing and by other limitations, such as deflection control. Old connections, which relied exclusively on rivets and bolts and, therefore, tended to be bulkier and contained far more pieces than modern welded connections, are less familiar now; the absence of a national code before the 1920s and the resulting local discrepancies in design are the least familiar remnants of the past.▪

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