Evaluation of Existing Structures

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Structural documentation of an existing building can give the engineer an idea of the building's original framing and assist with renovation decisions.

"WHAT DRAWINGS ARE AVAILABLE OF THE ORIGINAL STRUCTURE?" That's the first question an engineer is likely to ask when confronted with a modification, rehabilitation, or retrofit of an existing structure. Such documentation goes a long way in helping to assess a structure's capacity to accommodate existing or anticipated loads. Structural drawings generally include physical plan layout, framing member sizes, references to material strengths, and design loads. This information is paramount to assessing the capabilities of the existing structure and determining what must be done to accommodate the project requirements.

The scope of investigation necessary to confirm existing drawings or to develop as-built information is a matter of engineering judgment: What type of framing system was used? Does the project involve only a small portion of a structure, or a major portion? Will the lateral-force-resisting system be affected by the proposed modifications? Is a change in occupancy planned? Is an increase in loading anticipated? Is a change in framing layout necessary? What is the age of the structure? All of these factors will likely influence the investigation.

Paper Trail

If structural drawings of a building are available, then the first task generally becomes a matter of confirming that the existing structure physically represents what is shown on the documents. If documentation is not available, the task then becomes much more difficult. This may necessitate an extensive field investigation program to develop as-built information. Understanding the nature of the structural framing systems and the thought processes of the building's original engineers should be a great help in developing the necessary information to evaluate the system capacities.

Any field investigation will require that structural components be physically accessible. Architectural enclosures of the structure (ceilings, walls, column finishes, etc.) will likely need to be removed in the areas slated for inspection. In a steel frame structure, once the coverings are removed and structural steel framing becomes visible, the investigator can make measurements of beam layouts and spacing, beam depths, flange thicknesses, and widths. Arrangements of applicable lateral-force-resisting systems, such as bracing, moment frames, or steel systems combined with concrete shear walls, can be viewed. This also provides an opportunity to take material samples for testing if necessary.

The Way Things Were

Familiarity with the types of framing systems and associated design parameters used during a certain era of construction gives a better understanding of what to look for when evaluating a structure. Economical and successful structural concepts have a tendency to be copied, so it is not surprising to find similar construction types used extensively during any particular era of construction. The height of a building was one factor that would have a large influence on the type of construction, and developments in construction technology played a major role in what height a building could achieve.

Very early structures were mostly bearing-wall systems supporting short-span horizontal framing. Masonry bearing walls supporting timber framing were common, as were complete vertical and horizontal wood framing systems. The desire to build to greater heights, often using masonry bearing walls, was enabled by the thickening of the masonry walls, especially at the base. As building heights increased, significant floor space was absorbed by the bearing walls.

In the late 1800s, structural steel changed the character of "high-rise" construction. Compared to previous commonly available structural materials, this new material was stronger, both in terms of tensile and compressive properties. The post and beam steel framing system was used to permit longer spans and greater building heights. As buildings became higher, the lateral-force-resisting system also became more critical, and steel framing systems were developed using moment frames and vertical bracing. This was the beginning of the common skeletal frame type of construction. The 10-story Home Insurance Building, constructed in Chicago in 1885, was the first structure supported entirely by a steel frame in the U.S. and is often referred to as the first skyscraper.

Floor framing also varied widely depending on the construction era. As steel skeletal frame construction evolved, so did floor system types in order to accommodate increasing spans. Flat tile-arch systems were widely used in conjunction with embedded steel beams in the late 19th and very early 20th centuries. Concrete joist systems, formed with metal pans and supported by a skeletal steel frame encased in concrete, became quite common in the 1920s. Following World War II, metal deck systems were introduced that could function as stay-in-place forms used without shoring.

Material Considerations

A prime factor in the evaluation process is the strength of the steel that was used to construct the building. If the era of construction is known, one can get a fairly good idea of the steel material strengths that were likely used. This can be accomplished by researching historical documents such as previous AISC specifications and manuals and American Society for Testing and Materials (ASTM) material standards. A historical summary of ASTM standards was compiled for AISC and published in a book titled

Table 1 ASTM and AISC History				
	ASTM			AISC
Year	Standard	T.S. (ksi)	Y.P. (ksi)	Basic Working Stress
1901	A9 Buildings	60-70	0.5 T.S.	—
1909	A9 Buildings	55-65	0.5 T.S.	—
1923	A9 Buildings	55-65	0.5 T.S.	18
1924	A9 Buildings	55-65	0.5 T.S.	18
1933	A9 Buildings	60-72	0.5 T.S. (not less than 33)	18
1936	A9 Buildings	60-72	0.5 T.S. (not less than 33)	20
1939	A7 Buildings (and Bridges)	60-72	0.5 T.S. (not less than 33)	20
1942	A7 WPB Emergency Standards			24
1960	A7	60-72	0.5 T.S. (not less than 33)	20
	A36 (Supp.)	58-80	36	22
1963	A7	60-72	0.5 T.S. (not less than 33)	20
	A36	58-80	36	$0.6F_y$
	A440	varied	varied	$0.6F_y$
	A441	varied	varied	$0.6F_y$
	A242	varied	varied	$0.6F_y$
1967	A7 discontinued			
1968	A36	58-80	36	$0.6F_y$
	A572	varied	varied	$0.6F_y$
	A588	varied	varied	$0.6F_y$

Iron and Steel Beams 1873 to 1952. AISC's *Design Guide 15* expands on this publication and includes a summary of documents through 2000. The design guide also contains additional historical information on AISC specifications and construction manuals, and has superseded *Iron and Steel Beams*.

Metal structural components could be found in the U.S. as early as the 1830s. These were of cast iron, a material of high compressive strength, low tensile strength, no clearly defined yield point, and brittle character. More ductile forms of cast iron were developed and used in the 1850s, and later wrought iron in the 1870s. Cast iron structural components, mostly columns, were used into the early 20th century, but rarely in structural framing after about 1910. Structural steel, more ductile than cast iron—and with more significant tensile capacity—was introduced in the 1870s and quickly began replacing cast iron for structural applications.

Major producers of metal structural products developed load tables and published catalogs of information for the products they individually produced. Material standardization evolved when ASTM was founded in 1898 to address frequent rail breaks that were problematic in the then growing railroad industry. This work led to standardization of the steel used in rail construction. In 1900, ASTM developed standards for structural steel materials: ASTM A7 for bridges and ASTM A9 for buildings. These standards defined minimum requirements for the steel materials used in these applications, bringing uniformity to the varying standards published by the individual producers of the time.

The ASTM A7 and A9 standards were consolidated in 1939 into one ASTM A7 standard for bridges and buildings. This remained the primary structural steel standard until the early 1960s when ASTM A36 became the predominant structural steel used for building construction. Other types of high-strength, low-alloy steels were also developed and permitted for use in the 1960s. Often, these higher-strength steels would be used for applications such as columns with significant axial load in high-rise buildings, or for specialized considerations such as weathering steels. ASTM A992, adopted in 1998, is the current standard for the common W-shapes used today.

The most tracked minimum requirements of the ASTM standards for steel are the tensile and yield strengths of the material, which were and still are the basis of state requirements in design standards for structural steel. A review of the ASTM standards for the time era of a particular construction project will give a good idea of these basic yield and tensile strength parameters that were likely required at the time. Note that there is no guarantee that some produced steel materials may have failed to meet the ASTM minimum requirements, particularly during the infancy of the material standardization process.

Depending on the project parameters, it is an engineering judgment call whether some testing may be warranted to confirm that the strength of the materials meets ASTM minimum requirements. Keep in mind that the results of any test are only representative of that particular piece and may even vary as to where the sample was taken from the piece. Therefore, it is again a judgment call as to how many pieces should be sampled to give a level of confidence that the steel likely met the minimum ASTM requirements of the time. If structural drawings or project specifications are available that set requirements for the steel type, this may be an influencing factor in determining test program requirements.

Steel Consistency

As previously mentioned, allowable load tables were developed by individual companies for products made in the late 1800s and early 1900s. In 1921 AISC was founded to bring consistency to the design and construction standards for structural steel used in building construction, and the first AISC *Standard Specification for Structural Steel for Buildings* followed in 1923. This document stipulated allowable stresses based on structural steel conforming to the ASTM A9-21 Standard, which had a minimum required tensile strength of 60,000 psi and a minimum required yield point of 30,000 psi. The AISC *Code of Standard Practice*, which followed in 1924, included section properties and load tables of 24-in. standard beams produced at the time. The first edition of *Steel Construction Manual*, commonly called the AISC manual, was first published in 1927 and included section properties and load table information for an expanded variety of shapes produced at the time.

Table 1 reflects the historical summary of milestone events in relation to ASTM and AISC documents for structural steel for buildings. The allowable stresses for structural steel reflects the consistent pattern of increase in yield strength as new steel materials were developed. One exception occurred in 1942 when the War Production Board issued National Emergency Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings. During World War II, it was deemed that buildings of a temporary or emergency character could be constructed under this specification without risk, and that such buildings would lend themselves to long-time service if designed so that reinforcement to critical elements could be added in the future.

The 1963 AISC specification revised its format of stating allowable design stresses in terms of one grade of steel, to a generic format applicable to the types of steel that were then permissible under the specification. For example, where previous specifications gave the basic allowable working stress in the format of 22 ksi for A36 steel, the new format used the form $0.6F_y$. Another major revision in the 1963 spec recognized the ability of compact shapes to achieve flexural plastic capacity if adequately braced. A 10-percent increase in flexural capacity (to $0.66F_y$) for such shapes was permitted. This was an embedded form of the current permitted use of plastic section modulus for such compact shapes.

The Shape of Things

Iron and Steel Beams, *Design Guide 15*, and a more recently developed AISC shapes database CD are all good tools for either correlating field measurements to a particular shape designation or confirming a size shown on a set of old drawings. Determining the appropriate section properties to be used in the evaluation of the existing member is one of the initial steps in the theoretical evaluation process.

Note that there have been many different designations used for various steel shapes throughout the era of steel construction, some of which are not used today. Early steel construction commonly included a beam shaped like an "I" and referred to as an I-beam. This shape has relatively narrow flange widths in comparison to the section depth, and the inside surfaces of the flanges have a taper. Today, these are designated as S-shapes.

More efficient shapes with wider flanges and mostly parallel flange surfaces were produced starting around 1927 by Carnegie Steel Company, which later became part of U.S. Steel. These were called CB-Sections, or Carnegie Beams. Most structural steel beams produced and used in the U.S. today are a form of the CB-Section, commonly called wide-flange beams and officially designated as W-shapes.

Some common historical shape designations that may be encountered on a set of old drawing documents are correlated under the current designation reference shown in Table 2.

Loading Up

Once the building framing layout, member sizes, connection types, and material strengths are known, it becomes a matter of analyzing the system for the anticipated loads for which the structure is required to be designed. The question often arises whether an existing structure must be checked per codes and specifications of the era during which it was constructed, or by current codes and specifications.

The load side of the design equation is stipulated in the local building code. The capacity-resistance side of the design equation is given in the material specification standard, such as the AISC specification.

A building structure is usually grandfathered in as to the design loads it is intended to support for certain occupancy; as long as the occupancy does not change, the structure is not modified to any great extent unless there is reason to believe it is unsafe. The IBC's *Model Building Code* requires that if a structural modification or occupancy change results in a force increase of greater than 5 percent, the structure must be brought up to current code requirements.

In contrast, the specification standard to which a building was originally designed is not the standard by which it should be judged. The steel is not "smart" enough to know the standard to which it was designed. If the physical layout, dimensions, section properties, and material strengths are known, design checks by current standards are appropriate. However, it is often advantageous to use the specifications to which the structure may have been originally designed as a guide in checking the validity of any assumptions used in the investigation or analysis. For example, if you have a good idea of the design era of the construction, plan layout, member sizes, spacing, or existing dead loads, and an analysis shows the structural components grossly over-stressed or under-stressed according to the original design specification, it may be wise to verify the gathered information or assumptions used in the investigation process. In other words, double-check your numbers!

Appendix 5 of the 2005 AISC *Specification for Structural Steel Buildings* (a free download at **www.aisc.org/2005spec**) covers evaluation of existing structures. This appendix applies to the evaluation of the strength and stiffness under static vertical (gravity) loads of existing structures by structural analysis, load tests, or a combination of both.

The Right Foot

Working with existing structures may often seem like a daunting task at the outset. However, if engineers are cognizant of the historical nature of the construction materials and techniques used in the original structure, and are able to take advantage of the tools available in evaluating the structure, they can gain some confidence knowing that they've started off on the right foot. MSC

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Table 2
Rolled Shapes

W Shape (Wide Flange) CB (Carnegie Beam) WF (Wide Flange)
M Shape LB (Light Beam) JrB (Junior Beam)
S Shape (Standard Beam) I (I-beam)
HP Shape (Pile)
C Shape (Channel)
MC Shape (Miscellaneous Channel)
Angle (Angle)
WT Shape (Tee cut from W Shape)
MT Shape (Tee cut from MT Shape)
ST Shape (Tee cut from S Shape)
Rectangular HSS (Rectangular Tube)
Square HSS (Square Tube)
Round HSS (Round Tube)
Pipe