STRUCTURAL STEEL DESIGN AND CONSTRUCTION

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GLOSSARY

This glossary defines some expressions that are commonplace to the entire construction industry, with a focus on the steel industry.

Advanced Bill – a preliminary bill of materials prepared using the Engineer of record's contract drawings. From the advanced bill, a purchase order is usually prepared and provided to the steel mill or manufacturer to reserve a time slot (window) in which the steel order will be produced or to reserve a certain quantity of shapes produced by the mill.

AISC – The American Institute of Steel Construction.

AISC Weight – the weight of structural steel as defined by the AISC.

Anchor Bolt – an embedded bolt or threaded connection used to attach column bases and transfer loads to the foundation.

ASTM – The American Society of Testing and Materials and the organization that generally establishes the grades of structural steel.

Beam – a structural element that usually carries its primary loads in bending perpendicular to its axis.

Bearing Area – The part of the Beam, column or structural element that rests on a support.

Blanks – an assembly of identical or nearly identical multiple structural elements or built-ups fabricated prior to engineering or detailing being completed to take advantage of economies of scale in the shop or to gain time on the fabrication schedule.

Brace - a structural element used to stiffen or support a portion of a structure or frame.

Built-up Member – a structural element fabricated from a number of other structural elements connected by welding, bolts or other means.

CAD – **C**omputer **A**ided **D**esign using popular programs such as Autocad® that digitize (computerize) the geometry of the structure.

Calculations – structural analysis tabulations performed and documented by the structural Engineer of record to size all structural elements, braces, and stiffeners in accordance with the Code.

Camber – a curvature built into a Beam, truss or other structural element to offset anticipated deflection so that the element will not bow under dead load.

Chamfer – the result of cutting or grinding (beveling) the edge of a steel member or plate at other than a ninety-degree angle. This often occurs when welding two pieces of steel together.

Code – The Code of Standard Practice for Steel Buildings and Bridges as published by the American Institute of Steel Construction.

Column – a structural element that usually carries its primary loads in compression or tension parallel its axis.

Column Base – usually a thick plate at the bottom of a column through which anchor bolts mechanically connect the column and transfer forces to the foundation.

Composite Beam – a structural element, usually a Beam that is connected to a concrete slab such that the steel and concrete act as one element.

Compression – the state, for example in a column or an element of a truss, whereby a member is being shortened by a force. Compression is an axial load that is the opposite of tension.

Connection – a joint or node of structural elements used to transfer forces between structural elements or members.

Dead Load – the weight of the structural frame (or element) itself plus any equipment permanently attached to it.

Decking – a structural element usually constructed from corrugated bent plate used to form an elevated slab.

Design Forces – the loads that act on the structural system, e.g. dead load, live load, and environmental influences such as wind load, snow load, seismic load, and other dynamic loads.

Detail Drawing – a shop drawing, usually produced by a detailer, that defines the exact shape, dimensions, bolt hole patterns, etc. of a single piece of steel (or more) that may stand alone in the structure or that is one of many pieces in an assembly or shipping piece.

Detailer – a person or entity that is charged with the production of the advanced bill of materials, final bill of materials, and the production of all shop drawings necessary to purchase, fabricate and erect structural steel. The detailer may be an independent contractor or on the staff of a fabrication or erection company.

Detail Piece - a single piece of steel that may stand alone in the structure or that is one of many pieces in an assembly or shipping piece.

Detailing – the production of different types of shop drawings needed to fabricate and erect structural steel.

Engineer of Record – a sole practitioner or member of a firm responsible for the structural engineering of the steel structure and that ultimately seals the drawings and specifications with his or her professional seal.

Erection – the act of assembling the shipping pieces in the field including material handling, safety, plumb and bolt, welding, and placing deck material.

Erection Drawing – a primary shop drawing that illustrates to the raising gang how to assemble the shipping pieces in the field. Ironworkers match piece marks on the actual shipping pieces to the piece marks noted on the erection drawings.

Fabrication – the act of changing steel from the mill or warehouse into the exact configuration needed for assembly into a shipping piece or directly into a structural frame. It includes material handling, template making, cutting, bending, punching, welding, and grinding.

Force – a reaction that develops in a member or structural element, e.g. axial loads, moments, shear and torsion.

Frame – a system of assembled structural elements.

Geometry – the configuration of all the structural elements noted on the engineering and shop drawings that depict the relationship of one structural element to the next. The geometry is controlled by the drawings produced by the Engineer of record from which the detailer uses working points and dimensions to produce erection, detail and other shop drawings. If the "geometry" does not "close" it means that one or more dimensions are wrong.

Girder – a large primary beam used to carry point loads along its length. Girders usually support beams and columns.

Grade – a designation of the ASTM that identifies the chemical composition and strength characteristics of structural steel, e.g. ASTM A50 which identifies the steel as having a yield (or failure) strength of 50,000 pounds per square inch.

Live Load – the loads imposed on a structure that are not permanently attached to the structure such as loads imposed by the weight of people, movable equipment, vehicles and furnishings. It does not include wind load, snow load or seismic load.

Loads – a force or systems of forces carried by the structure or any of its elements.

Loading Combinations – are the systematic application of composite design forces or loading conditions used to determine the maximum stresses in structural members. For example 100% dead load and 80% live load plus 50% wind load from the east plus 75% snow load all occurring in a designated seismic zone. These loads would all be applied to the computer model structure at the same time.

Member – a structural element such as a beam, column, girder or brace.

Mill Order – the actual final purchase order for the mill or manufacturer based on quantities derived from the production of certain steel shop drawings. This order replaces or confirms the advanced bill.

Moment – a force in of steel that is caused by an applied load causing a structural element to want to rotate at a given point causing a moment reaction at that point. The moment, in simple terms, is measured by multiplying the force times the distance that force is applied from the support.

Moment Connection – is a joint that resists and supports a moment such that the joint resists rotation.

Piece Mark – an identification number that distinguishes one piece of steel or assembly from another. Piece marks oftentimes follow a code that can tell the ironworker the exact area, level and location of the piece of steel.

Pin Connection – is a joint that does not resist a moment and in the structural computer model allows the joint to rotate eliminating the moment in a structural member. Pin connections are common in the design of trusses.

Plate Girder – A typically large beam capable of supporting large loads built-up by welding various plates together. Sometimes referred to as a built-up member.

Point Load – is an applied force concentrated in a small area on a structural element. The load is usually measured in pounds. A heavy piece of machinery with a small footprint is an example of a point load.

Reaction – a force or system of forces that occur at a connection or support resulting from the application of loads to the structure. Reactions are needed to design every connection in a structural frame. Reactions are usually categorized as being axial (parallel), bending (perpendicular) and torsion (twisting).

Shear – the deformation force in a structural element, usually a beam, in which parallel planes tend to slide relative to each other.

Shipping Piece – Sometimes a single piece of steel or more typically an assembly of fabricated steel pieces that are transported to the field as a unit and that are erected into the structure as a single assembly.

Splice – a connection between two structural elements to form one structural element.

Standards – a set of engineering calculations that define the procedure submitted by a fabricator for designing certain elements in the structure, e.g. a procedure for designing moment connections, truss connections or simple beam shear connections. The Engineer of Record usually approves of these procedures in advance of the fabricator designing the connections.

Stiffener – a plate or structural element the assists in the distribution of loads to prevent failure of the element at certain points along the element.

Structural Shapes – standard steel configurations produced by steel mills such as wide flanges, channels, angles, pipe, tubes, etc.

Structural Steel – the structural elements that make up the frame that are essential to supporting the design loads, e.g. beams, columns, braces, plate, trusses, and fasteners. It does not include for example cables, ladders, chutes, grating, stairs, catwalks, handrails or ornamental metal.

Stud – a vertical cylindrical bar of steel with a larger cylindrical cap fastened to metal decking used to form a mechanical connection between the metal decking and the poured-in-place concrete slab such that the two form a composite structural element. Studs are also used to produce composite beams.

Submittals – deliverables made by the contractor inclusive of shop drawings, manufacturer cut sheets and material samples.

Templates – forms used by a fabricator to insure the exact fabrication of multiple identical detail pieces. Templates are usually made of a durable cardboard-like material or sheet metal and allow ironworkers in the shop to manufacture detail pieces without taking measurements or referring to detail drawings.

Tension - the state, for example in a column or an element of a truss, whereby a member is being lengthened by a force. Tension is an axial load that is the opposite of compression.

Torsion – the twisting of a structural element about its longitudinal axis by applied equal and opposite forces.

Truss – a structural frame of steel shapes connected into an assembly that can support loads far in excess of beams and girders due in large part to the depth or height of the assembly. A truss is composed of chords (main horizontal members), vertical members and diagonal members.

Uniform Load – is an applied load over a large area on a structural element or over many structural elements. The load is usually measured in pounds per square foot. The force caused by the build up of snow is an example of a uniform load.

Welding – the act of joining steel pieces using heat and filler metal. The welding of structural steel is governed by the American Welding Society (AWS) Structural Welding Code.

Working Point – a reference point on the contract drawings. On drawings depicting steel, the intersections of the centerlines of beams, girders, columns and braces are usually designated as working points.

I. INTRODUCTION TO STEEL DESIGN AND CONSTRUCTION

Steel is a common building material used throughout the construction industry. Its primary purpose is to form a skeleton for the building or structure – essentially the part of the structure that holds everything up and together. Steel has many advantages when compared to other structural building materials such as concrete, timber, plastics and the newer composite materials. Steel is one of the friendliest environmental building materials – steel is 100% recyclable and in fact, according to the American Iron and Steel Institute, steel is the most recycled material in the United States reducing the burden on today's landfills. Steel, unlike wood, does not warp or twist and does not substantially expand and contract with the weather. Unlike concrete, steel does not need time to cure and is immediately at full strength. Steel is versatile, has more strength with less weight, has an attractive appearance, can be erected in most weather conditions, is of uniform quality, has proven durability and has low life cycle costs. These advantages make steel the building material of choice.

Steel as a building material has been studied and tested for many years. It might be said that we understand the behavior of steel better than any other building material. Steel is a predictable material and during the 1990's the industry had implemented new procedures for designing steel structures. Structural design has evolved, mostly due to the necessity caused by earthquakes.

The evolution of steel design brought us from the theory that the stiffer the structure the better. Today, flexibility and ductility is key. Until the 1970's, structures were designed using proven formulas, but the *calculations* were done by hand. Today, using software on your PC, you can literally design a structure in a day, something that could have taken a structural engineer months to do using paper and pencil. The new tools available today solve some old problems and create some new ones. One of the key ingredients of the evolution of steel structure design is *CAD* (Computer Aided Design). The days of drafting are almost gone and digitizing the structure in the computer saves time, ensures quality and usually results in a lower cost. However, like all innovations, technology breeds its own set of new problems.

With us knowing so much about steel one would question why this component of a project is often plagued with problems. The steel industry is well organized. There are *codes* provided by the steel industry, most local and national building *codes* address steel issues, academia is constantly studying steel design and construction, and we are constantly learning from *structural steel* failures. So why is it that *structural steel*, usually a critical path activity on any project, has associated with it so many problems?

The answer lies in the process from design through *erection*, the number and types of parties involved in the process, and the ease and speed at which changes can be accommodated. This chapter will present the basics of structural design, *fabrication* and *erection* and will provide the "non-technical" attorney a better framework from which to understand their client's issues and ask better questions.

II. THE STEEL PROCESS – FROM DESIGN THROUGH ERECTION

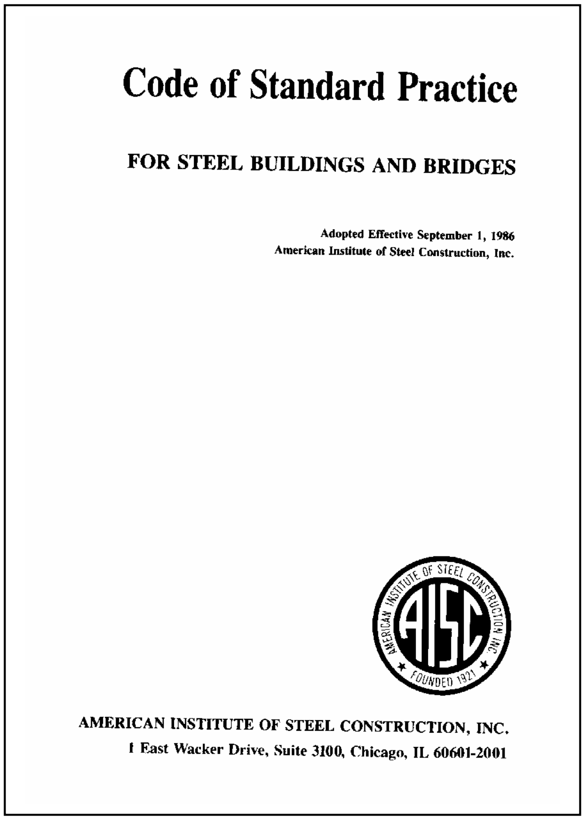
While the size and complexity of the project may drive and in some way change the process, the path of steel structural design and construction is predictable and proven. For the purposes of this chapter we will examine *structural steel* in the context of a building design requiring the services of an architect. However, there are many structures, constructed of steel, that do not require architectural input – these could include *frames* to mount equipment and machinery, offshore platforms, marine terminals, refineries, process plants and other non-aesthetic structures.

The production of conceptual, schematic and design development drawings are essential predecessor activities to finalizing the design of the structural framework. In theory, it is the structural engineer's job to make the vision of the architect come true. While most architects can appreciate the complexity of the structural design of their vision, only the structural engineer can gauge what needs to be done to satisfy the architect's requirements.

After the architecture of the building is determined, the design of the framework – *beams*, *columns*, bracing etc. – proceeds with engineering *calculations*.

A. Engineering

Structural engineering is the application of science and math to design a structure. With reference to the various building *codes*, the recommendations and *codes* of the American Institute of Steel Construction (*AISC*), and the empirical data derived from all the testing done on steel structures, the structural engineer understands and can adequately predict the behavior of steel.



Code of Standard Practice

FOR STEEL BUILDINGS AND BRIDGES

Adopted Effective September 1, 1986
American Institute of Steel Construction, Inc.

AMERICAN INSTITUTE OF STEEL CONSTRUCTION, INC.
1 East Wacker Drive, Suite 3100, Chicago, IL 60601-2001

In the United States and in some other countries, when the term “code” is used in the steel design and construction industry, it is usually in reference to the *Code of Standard Practice for Steel Buildings and Bridges* published by *AISC*. First published in 1924, the Code has been periodically updated to reflect new technology. In the year 2000, the September 1, 1986 version of the Code is still in effect.

The purpose of the Code is clearly stated in Section 1.:

> “The practices defined herein have been adopted by the AISC as the commonly accepted standards of the structural steel fabricating industry. In the absence of other instructions in the contract documents,

> the trade practices defined in this *Code of Standard Practice*, as revised to date, govern the fabrication and erection of structural steel."

The Code provides the structural engineer, *detailer*, fabricator and erector with the framework from which to engineer, detail, fabricate and erect steel. In addition to the *Code of Standard Practice*, the *AISC* publishes a *Commentary on the Code of Standard Practice* that assists the users of the Code in understanding the background, basis and intent of its provisions. It is one of the few construction industry *codes* that has a detailed explanatory commentary.

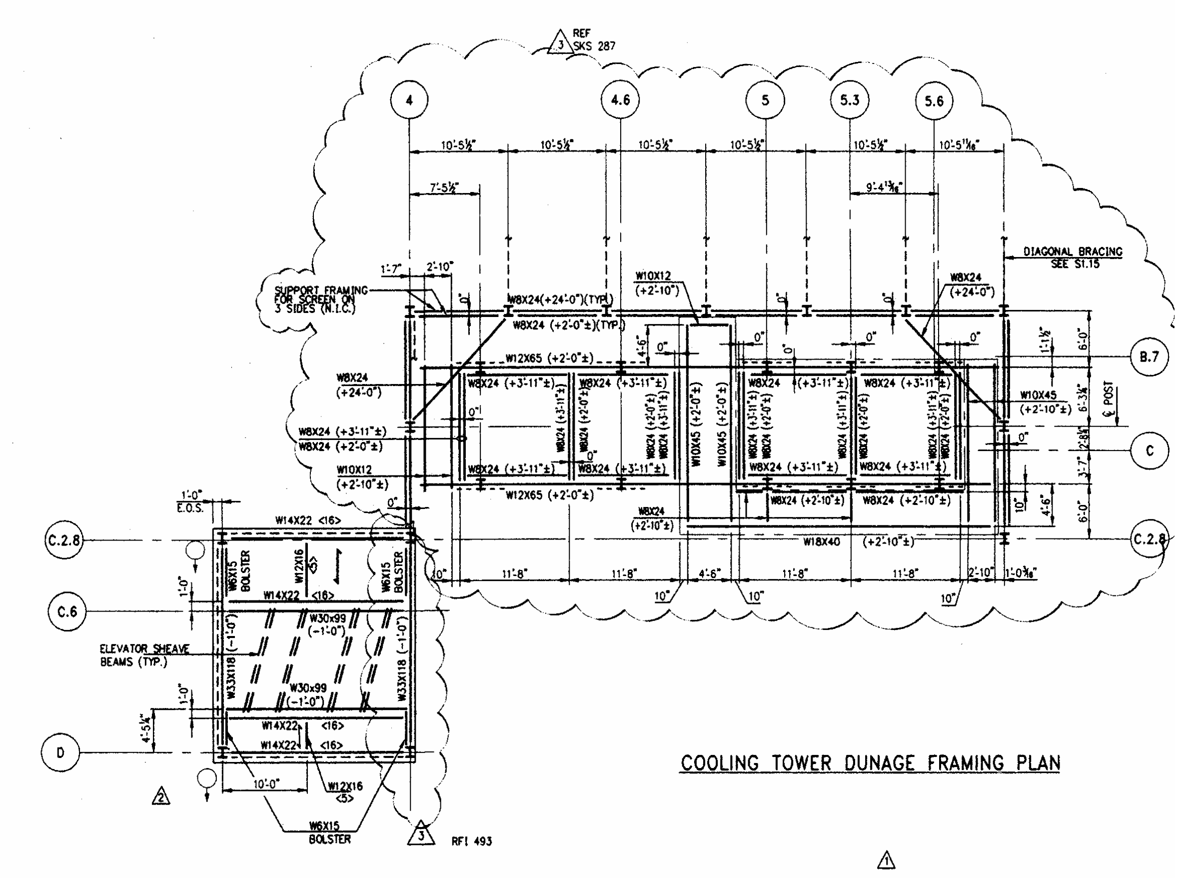
Besides the *Code of Standard Practice*, *AISC* publishes other *codes* that more specifically cover other aspects of steel design and construction. They include the *Specifications for Structural Joints Using ASTM A325 or A490 Bolts* which also includes a commentary section, and the *Manual of Steel Construction* [which allow for two different design approaches to engineering steel – Allowable Stress Design and Load & Resistance Factor Design].

With reference to these *Codes* the structural engineer, using both the computer and hand *calculations*, produces the structural design of the building, bridge or other framework.

For clarity, one can categorize *structural steel* design of frameworks into three areas: main *members*, secondary *members* and *connections*. The structural engineering of main *members* may include *beams*, *columns*, *trusses*, and *girders*. Main members are the skeleton of the framework and are the primary members that carry the loads imparted on the structure. Simply, it is the part of the structure that holds things up. The structural engineering of secondary *members* may include bracing, stairs, and *decking*. Secondary structural elements are designed to carry specific loads. For example, a *brace* is added to provide extra support in the area of a load thereby reducing the size of a member or the *moment* at a *connection*. *Connections* are joints or nodes of structural elements used to transfer *forces* between structural elements or *members*. The structural engineering of *connections* ensures that at the point (node) where the structural *members* meet (connect), sufficient steel area exists to resist the cumulative stresses at that node – axial *loads* (*compression* and *tension*), bending *moments*, and *torsion*al loadings (torque).

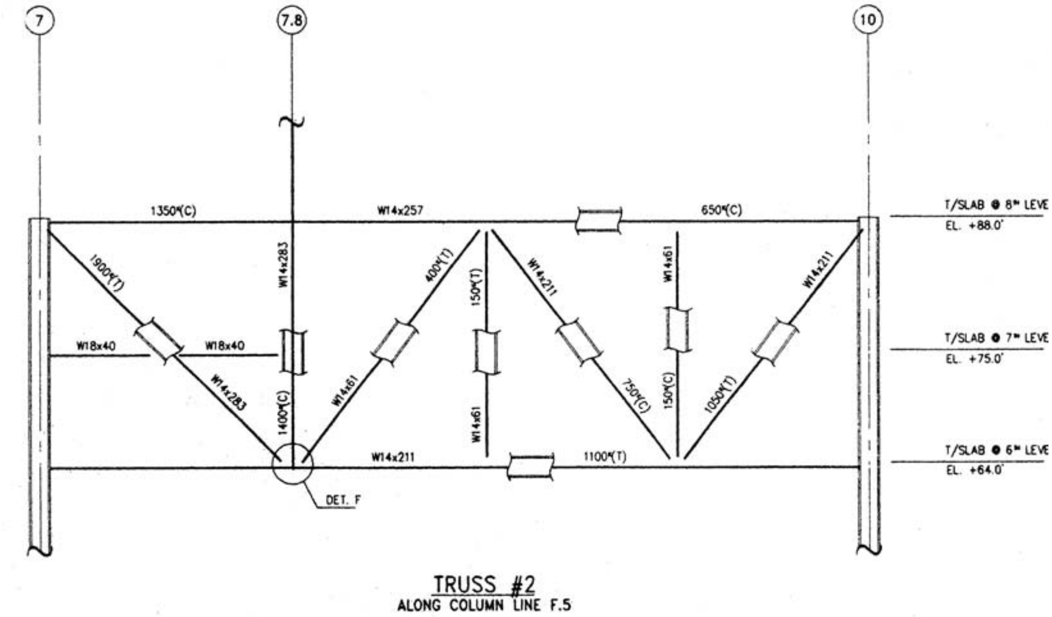
1. Main Member Design

The actual structural engineering *calculations* for the main (primary) *members* takes place after a number of critical factors are determined. To start, the engineer uses the architectural drawings to determine the *column* locations from which the concrete foundation will be designed. The steel *columns* will connect to the concrete foundation through the use of *anchor bolts* embedded in the concrete and connected to *column base* plates with nuts and washers. The location of the *columns* determines the configuration of the framework of *members*.



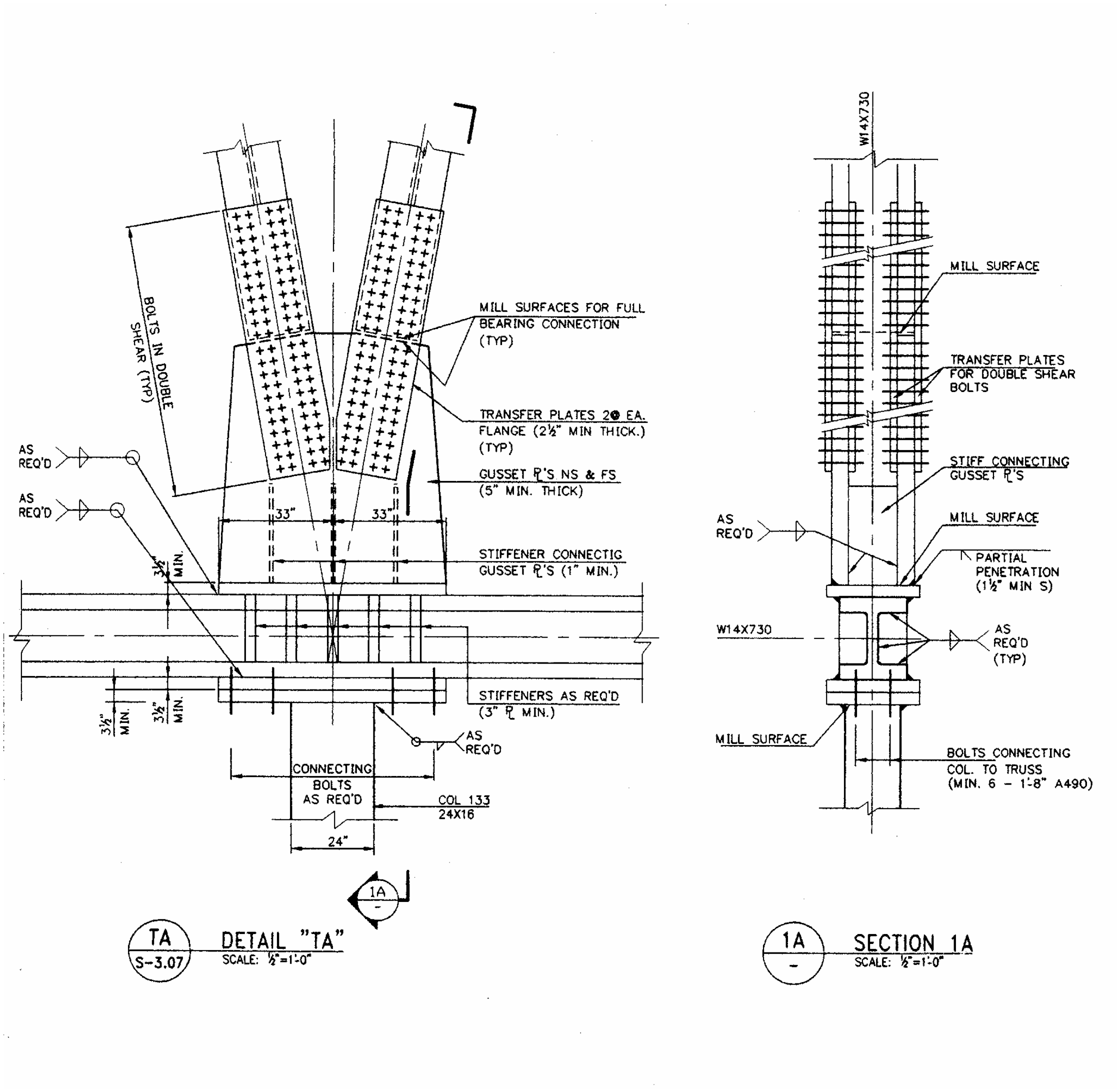
Typical Framing Plan by the Engineer of Record. Note column line locations designated by numerical and alphanumeric designations in circles. Plan views typically show the dimensional spacing between column lines. Column lines are usually located to the centerline of the column, which oftentimes coincides with the centerline of a beam, girder or truss.

Concurrently, the engineer is obtaining other information from the architect on *loads* – *dead load*, *live load*, and special *point loads*. Initially, the structure must hold up its own weight (*dead load*) and must, in addition, hold up *uniform* and *point loads* (*live loads*) that anticipate how the structure will be used during operation. For example, a convention center may be designed for a 400 pound per square foot *live load* on the exhibit floor. By uniformly applying this *live load* to the design, the engineer does not have to calculate the cause and effect of every single piece of equipment that can stress the structure. However, in some cases, certain machinery is placed on the floor that is so heavy that *point loads* must be taken into consideration.



Typical Elevation of a Truss drawn by the Engineer of Record. Elevations describe the relative vertical position of structural elements to one another. Note the top of slab elevations of the various floors. Also note the column line designations and the fact that no dimensions are given for column lines – this information would be contained on a plan drawing. Note that member sizes are being called out and that loads are given for the diagonal members of the truss.

Other *loads* that cause stress on the structure, typically referred to as environmental *loads*, are wind, snow, rain, earthquakes, floods, vibration and *loads* caused by member failure due to fires. These *loads*, plus the *dead* and *live loads,* describe the loading conditions. The art in structural design,



Typical Section and Detail of a Complex Connection drawn by the Engineer of Record. Sections and details are supposed to provide the fabricator with complete instructions on how to fabricate and erect the steel piece or assembly. Note how Section 1A is a slice taken through Detail TA as designated by the circled arrow at the bottom of the detail. Details and sections provide information on dimensions that are not practical to show on large plans and elevations, plate shapes and sizes, welding information and bolt patterns.

for which some of the magic is taken away by the *codes*, is in applying the correct *loading combinations* of loading conditions to the structure to determine the highest stresses in the structural *members* that can reasonably be expected to occur.

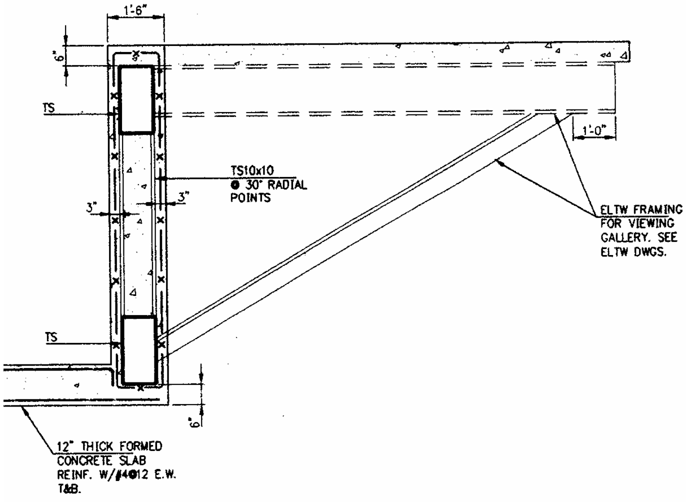
For example, what are the stresses in a *column* when 100% of the *dead load*, 50% of the *live load*, 25% of the snow load, and 75% of the wind load are applied to the structural model? This application of concurrent *loads* is called a loading combination. There can be as few as one loading combination or there can be literally over a hundred. This is one of the problems computer analysis has caused. The ease at which we can program data, and the speed at which results are generated, has resulted in the undermining of the art of being able to determine through experience the critical types and numbers of *loading combinations*. In fact, because of the litigiousness of our industry, engineers too often run every possibility through the computer. Before the advent of PC based software, eight *loading combinations* were often deemed sufficient.

Using the example of the *column* described earlier, each loading combination may result in a different set of stresses and *reactions* on the *column*. The computer or engineer then selects the best sizes and thicknesses of standard *structural shapes* produced by the steel mills. The engineer then evaluates a variety of factors to make sure the *geometry* of the structure works. For example, you would not want a thirty-six inch deep *beam* framing into a fourteen-inch girder. So the engineer makes these determinations and using either *CAD* or draftsmen prepares structural drawings – framing plans, elevation and details. But the important consideration sometimes overlooked by the *Engineer of Record* is what happens at the *connections*.

2. Secondary Member Design

After the main *members* have been located, sized and their *reactions* and *loads* are known, supporting secondary *members* must be designed for the structure. Secondary *members* include *braces*, *stiffeners* and other structural elements that typically support main *members* causing the main *members* to be smaller in size. Other secondary *members* that need to be designed include stairs, catwalks, grating, ladders and other miscellaneous appurtenances.

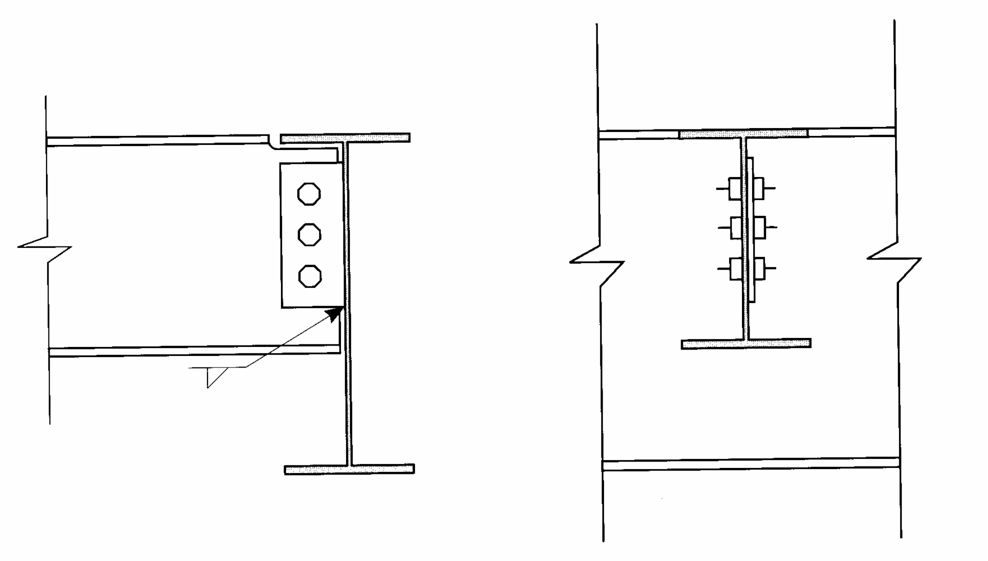
The *dead weight* of the secondary *members* may be significant enough to consider in the design of the main structural *members*. The total weight of secondary *members* can also be significant and must not be overlooked in calculating the weight of the structure.



A typical secondary member of a brace drawn by the Engineer of Record. This drawing is a Section cut vertically through the structure and shows how the brace frames into the horizontal member it is supporting and how it frames into the member to support the load.

3. *Connection Design*

It is often the case that the structural design of the *connections* is delegated contractually by the *Engineer of record* to the fabricator. The rationale is that no entity knows better than the fabricator how best to assemble the *connections*, so why not let the fabricator design them as well. To design the *connections* the fabricator has to have structural engineers on staff or they have to hire a structural engineer as a consultant.

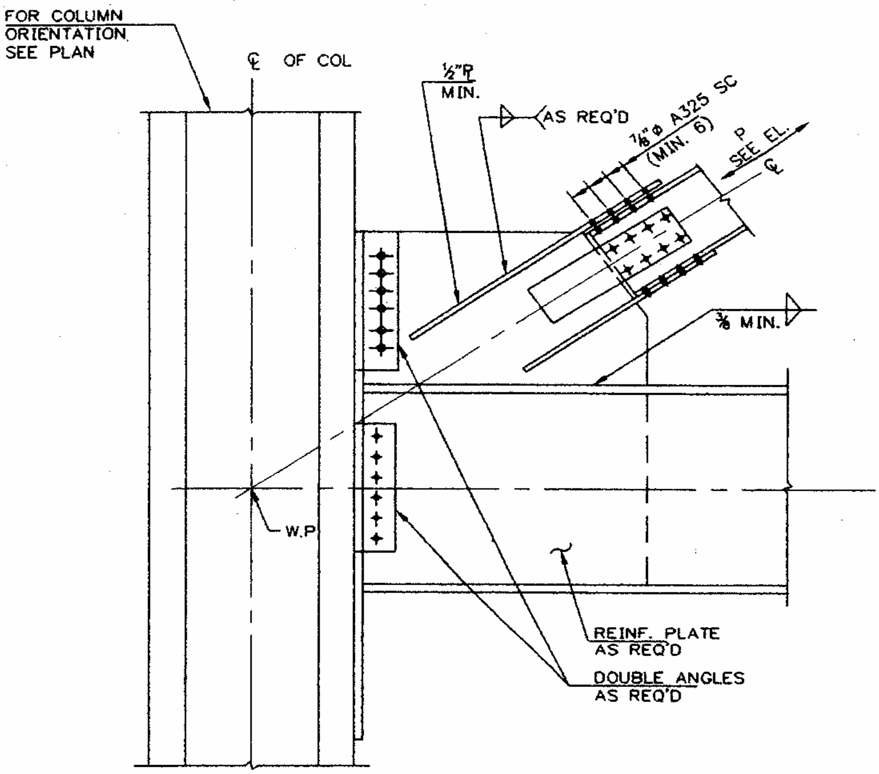


This is an illustration of a simple shear connection. The figure on the left is an elevation and the figure on the right is a section cut right trough the connection. The smaller beam is fabricated with boltholes, while the larger girder is fabricated with a plate welded (note weld symbol) to it with boltholes. In the field the bolt holes on the beam are lined up with the boltholes on the plate and the beams are bolted together.

Either way, by taking this approach, the *Engineer of record* (EOR) in this process delegates to others the responsibility for completing the rest of the design of the structure. Arguably, all the EOR did was size the main and secondary *members*. Yet one can make a case that the complexity in the design of the structural framework lies in the *connections*.

Connections cannot be designed without the input of the EOR. The connection designers need to obtain geometrical data from the structural drawings. This establishes the location and the sizes of *members* connecting at a node. Next the *connection* designers require knowledge of design intent, e.g. how did the EOR mean for this *connection* to act – did they want it to react like a *moment connection* or should it be designed as a *pin connection*. Without getting into the dynamics of structural theory, what is important is that the fixity of a *connection* must match what the EOR modeled when the main and secondary member sizes were determined in the computer analysis. The type of *connection* used in the structural computer model or hand calculation can easily be illustrated on the structural drawings for the *connection* designer's use.

Next, the *connection* designers need to know the *forces* or *reactions* for each of the *members* connecting at the node. The *connection* designer is looking for *reactions* such as axial *forces*, bending *moments*, *shear* and *torsion*. The difficulty is that every member of the framework has



DETAIL "B"

Detail of Connection with Stiffener Plates drawn by the Engineer of Record. Notice how the centerline of the diagonal member crosses the centerlines of the two main members at a work point designated W.P. Note that this section does not provide enough detail information to fabricate the necessary pieces to make the connection. This is the purpose of detail and erection drawings drawn by the detailer. This section describes the need for reinforcement plates, but does not describe the thickness and size of the plates. This will be determined by the connection designer.

different *reactions* for each loading combination selected. The manner in which the EOR selects one set of *reactions* to supply to the *connection* designer is a complex issue and one that will be addressed below.

On the assumption that the *connection* designer has been given all the necessary criteria, the *connections* are designed using computer programs or hand *calculations*. These *calculations* must be prepared and stamped by a licensed professional engineer and are subject to the approval of the EOR. But, in some cases, there are thousands of *connections*. To alleviate the EOR's burden of approving every *connection* design, *standards* or template designs are produced.

For example, a typical design procedure will be prepared for a cantilever *beam* whose *connection* is a *moment* type. Once the procedure is approved by the EOR, the *connection* designer follows this design procedure for every *connection* design meeting this criterion. At the end of the project, the *connection* designer certifies that it has followed the approved procedure, but it is good practice for the EOR to spot check for compliance.

Connections may be the most complex part of the structural engineering of a project. Besides figuring out how to physically weld or bolt the various *members* together, the engineers have to consider the need for various stiffening plates and bracing. The design of *connections* is not cookbook. However, once the true *reactions* are known at the *connection*, which is the real design challenge, the application of the structural formulas is routine.

At the completion of the structural engineering of the entire framework – main and secondary *members* and *connections* – a book of engineering *calculations* is prepared.

4. Engineering Calculations

Somewhat analogous to as-built drawings, the EOR should prepare a record of the final *calculations* used for determining the size and type of all *members* and their *connection* configuration. Later, this record can be used for many purposes, including to re-analyze the design after a failure or to check the structural integrity of the framework for new *loads* due to changes in the physical configuration of the structure such as a new floor or an addition.

Unfortunately, large and complex jobs rarely have the final structural *calculations* in order. Oftentimes, preliminary designs and the iterative design of structural elements are mixed up with final *calculations*.

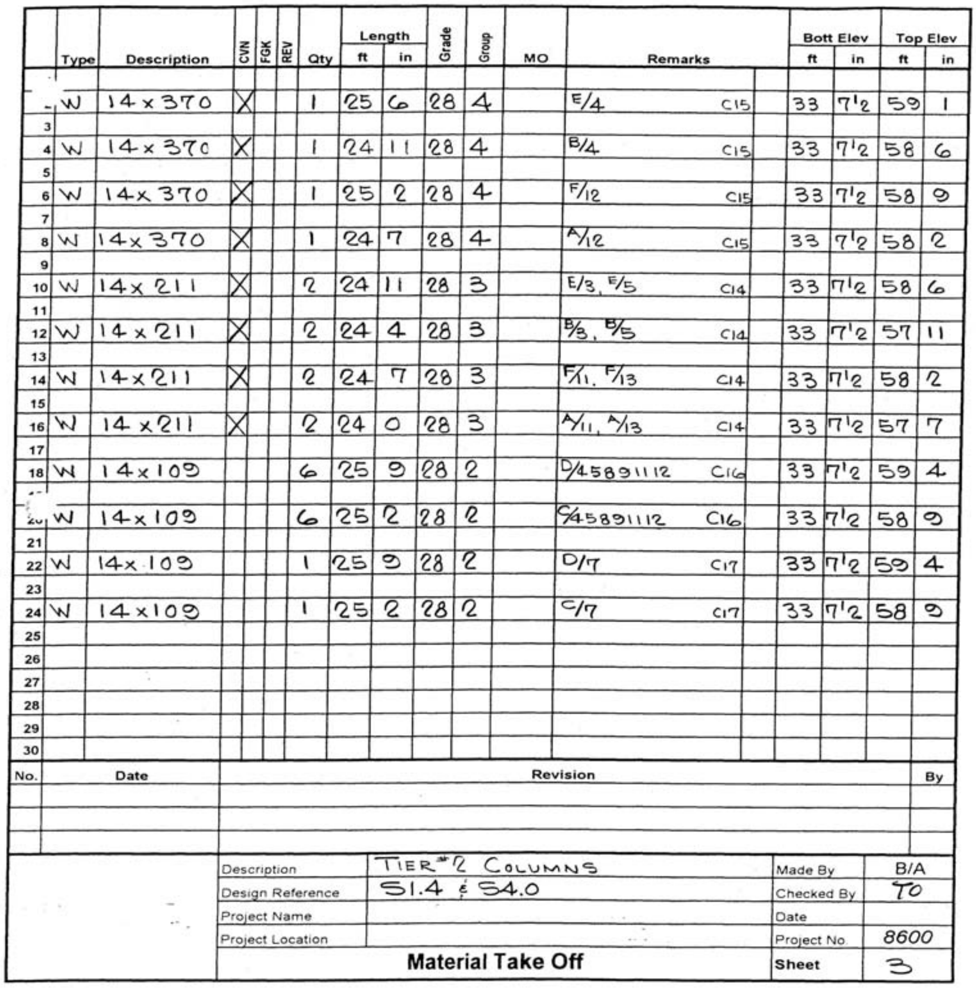
Lastly, it is important that the results of the final design *calculations* match what was fabricated and erected in the field.

B. Detailing

Detailing is the process of converting the structural design drawings to shop drawings. These shop drawings are used by the fabricator to identify the size, shape, and material *grade* of every single piece of *structural steel* in the framework. On huge projects, those with over 40,000 tons of steel, it would not be unusual for the framework and *connections* to be comprised of literally 300,000 individual pieces of steel. Keep in mind however that to facilitate *erection* economy many of these *detail* pieces are fabricated into assemblies before being shipped to the field. On a huge project, as described above, it would not be unusual for a project of this magnitude to have more than 45,000 assemblies or *shipping pieces*.

Detailing is a step by step, arduous process, although technological advancements such as *CAD* and electronic mail have made the job of the steel *detailer* easier. *Detailers* have the responsibility to interpret the structural design drawings for the purpose of determining what steel needs to be purchased and how it will all fit together.

1. Advanced Bill of Material



	Type	Description	CVN	FGK	REV	Qty	Length		Grade	Group	MO	Remarks	Bott Elev		Top Elev	
							ft	in					ft	in	ft	in
	W	14 x 370	X			1	25	6	28	4		E/4 C15	33	7½	59	1
3																
4	W	14 x 370	X			1	24	11	28	4		B/4 C15	33	7½	58	6
5																
6	W	14x 370	X			1	25	2	28	4		F/12 C15	33	7½	58	9
7																
8	W	14x 370	X			1	24	7	28	4		A/12 C15	33	7½	58	2
9																
10	W	14x 211	X			2	24	11	28	3		E/3, E/5 C14	33	7½	58	6
11																
12	W	14 x 211	X			2	24	4	28	3		B/3, B/5 C14	33	7½	57	11
13																
14	W	14x211	X			2	24	7	28	3		F/11, F/13 C14	33	7½	58	2
15																
16	W	14 x211	X			2	24	0	28	3		A/11, A/13 C14	33	7½	57	7
17																
18	W	14x109				6	25	9	28	2		D/45891112 C16	33	7½	59	4
	W	14x109				6	25	2	28	2		C/45891112 C16	33	7½	58	9
21																
22	W	14x 109				1	25	9	28	2		D/7 C17	33	7½	59	4
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24	W	14x109				1	25	2	28	2		C/7 C17	33	7½	58	9
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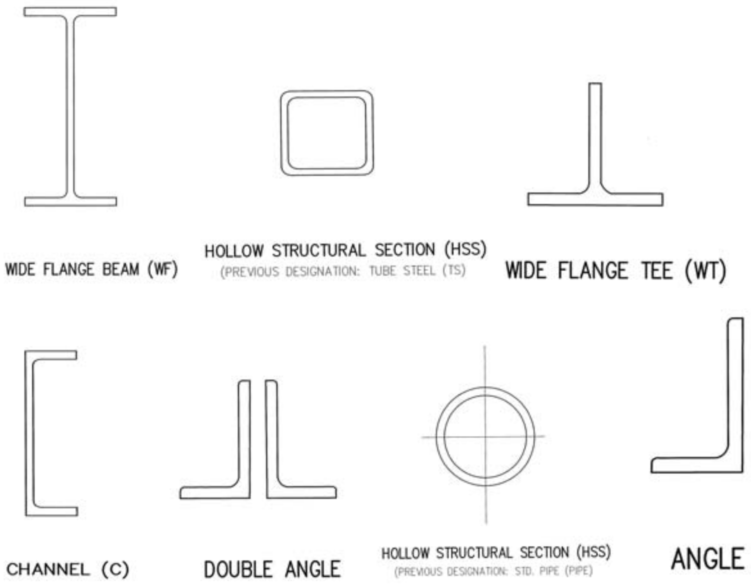
No.	Date	Revision	By

Description	TIER #2 COLUMNS	Made By	B/A
Design Reference	S1.4 & S4.0	Checked By	TO
Project Name		Date	
Project Location		Project No.	8600
Material Take Off		**Sheet**	3

Typical Bill of Material prepared by the detailer to send to the mill. As an example, line 6 lists the type of member as a ‘W’ or wide-flange shape 14 inches tall weighing 370 pound per foot being 25 feet 2 inches long made of Grade 28 steel.

Whether the fabricator hires an outside person or firm to provide the *detailing* or utilizes in-house personnel, one of their first tasks is to produce the *advanced bill* of materials. Taken directly from the structural plans produced by the EOR, *detailers* prepare the steel orders (bill of material) to purchase steel from the mill. Steel is usually purchased in a series of phases or all at once. Steel purchased from a mill in a huge lot insures material availability, quality and a volume discount. Material not purchased from a mill, for example from a warehouse, is more costly and there is no guarantee that the sizes and *grades* will be available. Steel can be purchased domestically or abroad. U.S. manufacturers face stiff competition from countries such as Japan, Germany and England.

Steel mills in general do not produce all the various types of steel required on a project. Some mills only produce plate and some mills only produce shapes such as wide flanges, channels and angles, for example. Some mills produce all shapes, but they restrict the sizes of the shapes they manufacture. For example some mills are tooled to only



Common Steel Shapes

produce very large shapes such as heavy wide-flange *beams* and some mills may not produce wide-flanges shapes at all.

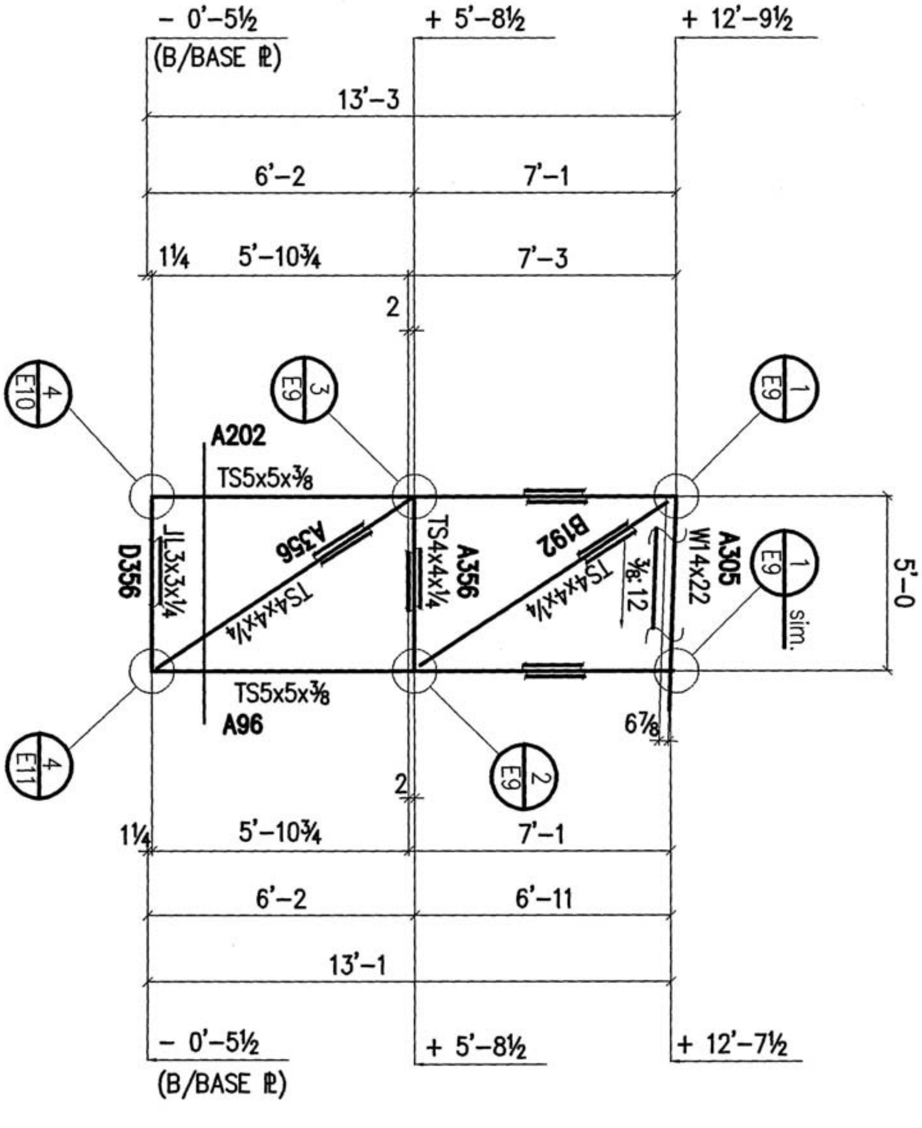
In fact, some mills only produce certain shapes at various times of the year. Therefore it is critical to know what shapes and sizes your project is going to utilize as early as possible. This will insure availability and a predictable schedule for delivery. If you miss a mill's "window" for producing certain types of steel and the mill has already contracted for this year's annual production, you will be forced to find another source.

The *advanced bill* of material is no more than a detailed quantity takeoff of the steel in the job. Besides ordering standard shapes, the *detailers* determine the quantities, sizes and thicknesses of flat plate that are required. These plates will be cut up to fabricate various assemblies including *plate girders* and *stiffeners*.

The next step after the *advanced bill* is produced is to prepare the *erection drawings*.

2. Erection Drawings

Erection drawings provide the field *erection* crew (raising gang) with the roadmap of how to *erect* (put together) the steel assemblies after they are delivered to the field. Essentially, they are a set of instructions on how to put the puzzle pieces together. The *erection drawings* look very similar to the structural drawings produced by the EOR with a few major distinctions. First, every assembly shipped to the field is given a *shipping piece* number to identify it. This number is noted on the drawing and is also stenciled onto the actual assembly of steel. Second, on the *erection drawings*, every assembly of steel is shown, no matter how insignificant or small. The *erection* crew must know where each assembly fits into the structural framework. Also, unlike the structural drawings, the *erection* drawing illustrates how the *connections* will be fabricated in the field. In fact, because the *erection drawings* are produced first (before the *detail drawings*), the *erection drawings* need to exactly illustrate the

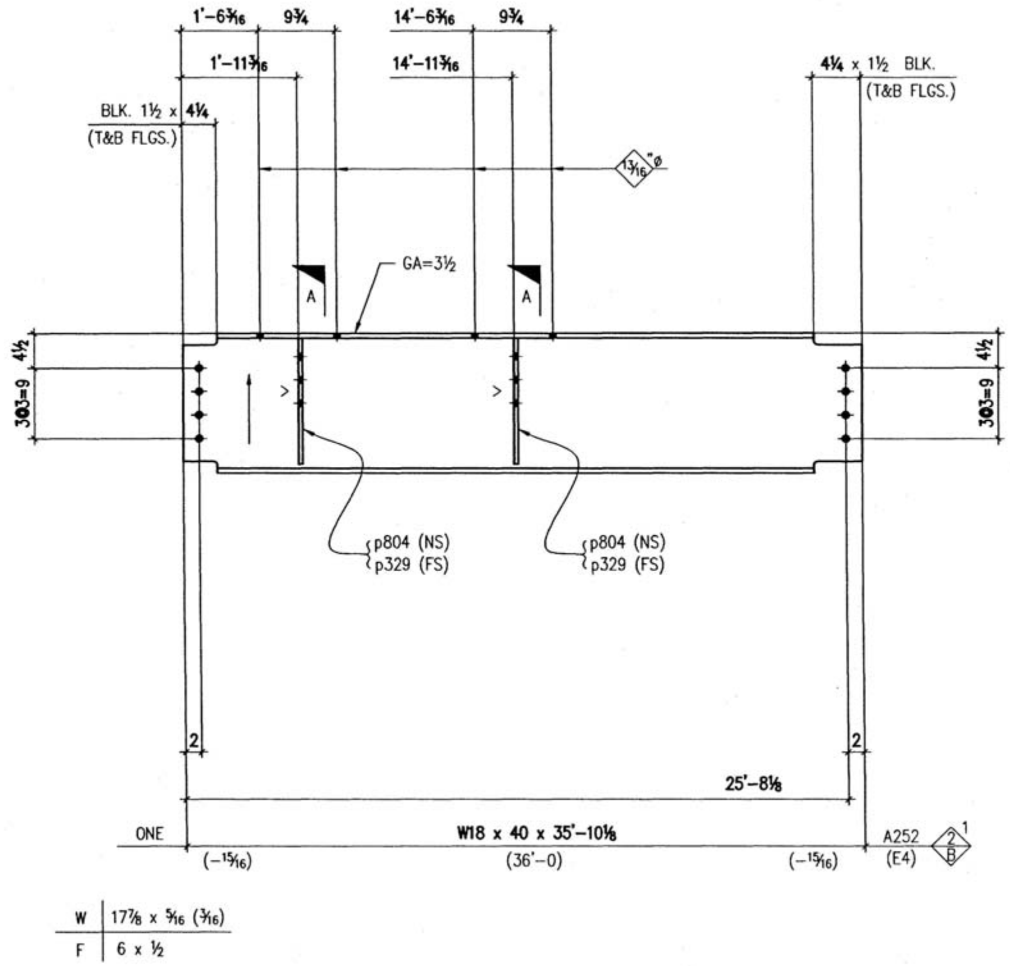


Section from erection drawing indicating shipping piece numbers; for example as D336, A202, and B192. Notice that every connection has an associated detail where the erector can find the instructions on how to weld and/or bolt the connection in the field. Every dimension for locating each member is given to the centerline of the member.

location of the *members* so that the *geometry* of the *connections* can be designed and *detail drawings* can be completed. For every assembly a *detail* drawing is produced illustrating the parts (elements) of the assembly.

3. *Detail drawings*

Detail drawings are what most people in the construction industry would categorize as the official shop



Beam section from a detail drawing providing precise cutting instructions to the fabricator. Section illustrates location of bolt holes and stiffener plates. The beam is designated as piece number A252 and the nearside stiffener plates have piece number p804 and the far side plates number p329.

drawings. *Detail drawings* depict the components of each assembly; remember those 300,000 individual pieces of steel. On these drawings, the *detailers* give the fabricator step by step instructions on how to *fabricate* each piece. *Fabrication* involves material handling, cutting, burning, drilling, grinding, *welding*, punching, bending, *shearing*, and sawing the components of the assembly. Each detail piece is given a distinct number so that the fitters in the shop know how to put the assembly of *detail pieces* together into *shipping pieces*.

Detail drawings usually depict a final bill of material for the steel shown on a particular drawing. Any additional pieces not contained in the *advanced bill* of material are either added to the original purchase order(s) or are bought from sources other than the mill.

On the huge project described earlier it would not be unusual to have more than 15,000 *detail drawings* and approximately 2,000 *erection drawings*. Administratively, it is a nightmare for the fabricator, *detailer*, EOR, architect and erector to track changes. To assure the EOR that the *detailer* and fabricator have followed their instructions as to design and design intent, the fabricator is required to submit its *erection* and *detail drawings* for approval, like any typical shop drawing. The only difference here is the substantial quantity of steel *detail drawings*.

4. Submittals and Approvals

The only way the EOR will know what is being fabricated and erected is to review the drawings produced by the *detailer*. Periodically, it is important for the EOR to make site inspections of the *fabrication* plant to assure adherence to the requirements set forth in the structural design. Fortunately, many details on how to bolt, weld, *camber* and *chamfer* steel are controlled by the *AISC* in its *Code of Standard Practice for Steel Building and Bridges*.

To reduce the thousands of shop drawings needing review by the EOR, certain *standard* drawings are produced. These drawings depict how typical assemblies will be put together and include details on bolting, shop and field *welding*, and configuration.

Like any shop drawing, the EOR reviews the details of these drawings for conformance to the *standards* and its design intent, e.g. to verify that a *connection* intended to be a *moment connection* will function as one if the steel is assembled in conformance with the detail drawing.

> Soon after some of the steel has arrived at the fabricator and some of the *detail drawings* are complete, *fabrication* begins. The phasing and coordination of the *advanced bill* of materials and the *detail drawings* is critical to the success of the project.

Detailing also involves the production of a number of other specialty drawings. These include *anchor bolts* plans, bolt placement drawings, *column* schedules, stair and handrail drawings, and specialty *connection* drawings.

C. Fabrication

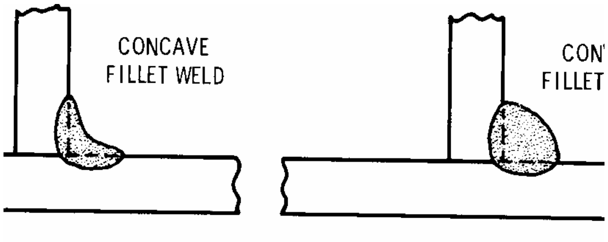
Fabrication is the process of cutting, burning, *welding*, drilling, grinding, punching, bending and generally producing the steel *detail pieces* shown on the *detail drawings*. The process of *fabrication* is systematic.

The process starts with coordinating the first steel to be fabricated with the steel inventory. Separate material handling laborers make sure that the fitters have the correct steel at various fitting stations when the steel is needed. Concurrently, template makers are producing disposable cardboard-like *templates* used for cutting steel. These *templates* take the guesswork out of the shop worker’s hands. They just fabricate the steel to match the template and, in theory, a perfect detail piece is produced.

With the right steel at their location and *templates* in hand, the fitters begin the process of producing the *detail pieces*.

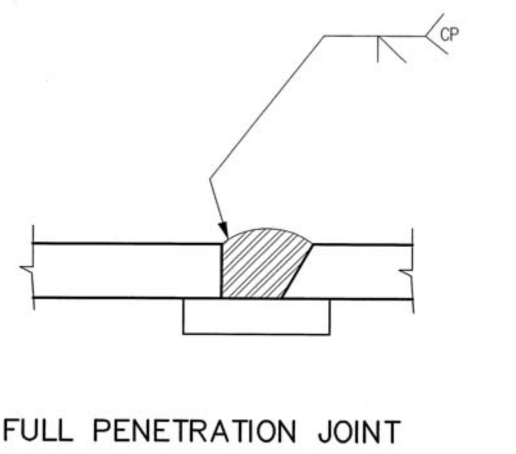
Later in the process, fitters or a separate *welding* crew will attach a series of *detail pieces* together to form the assemblies or *shipping pieces*. There are many techniques used in *welding* metal together.

The two most common *welding* processes in the construction industry fall under the categories of gas *welding* and arc *welding*. Gas *welding* is a process in which heat is produced with an electric arc formed between a metal electrode and the metal being welded. An inert gas, usually helium or argon shields the arc from contamination. Common gas techniques are MIG (metal-inert-gas) and TIG (tungsten-inert-gas) *welding*.



Typical Fillet Weld Details

Carbon arc *welding* is a puddling process in which the heat from an electric arc creates a small pool of molten metal that can be added to using metal from a filler rod. This is sometimes referred to as stick

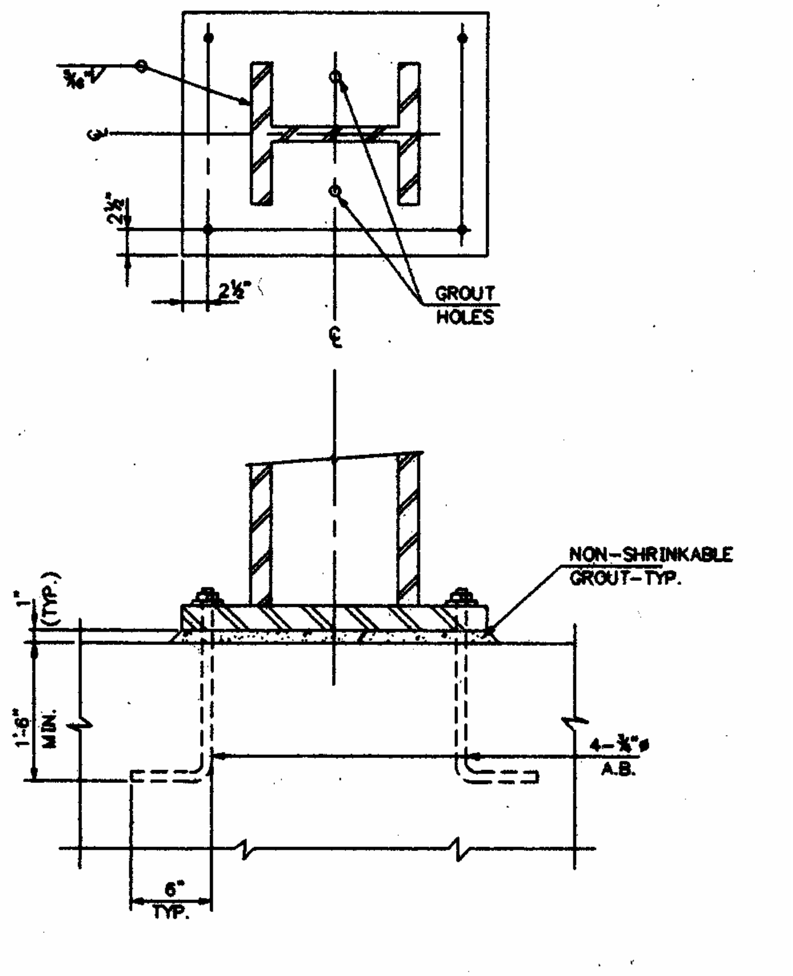


Note: Chamfered Edges, Welding Symbol and Backer Plate *welding*. *Welding* techniques for shop *fabrication* or field *erection* of steel are similar.

After the fabricated assembly is transported to the field, the only work remaining is unloading, sorting (shakeout), temporary storage and *erection*.

D. Erection

Erection is the process of erecting or connecting together the *shipping pieces* in the field at the project site. Generally *columns* get



Wide flange column welded to steel base plate and connected to foundation via anchors bolts embedded into concrete foundation. Non-shrinkable grout is used as a base and to level the column base plate.

erected first, then *trusses* and major *girders*, then *beams*, bracing, stairs and other miscellaneous steel.

The success of *erection* is dependent on a few important factors. The first and most critical element is the *erection* of the *columns*. *Column base* plates are connected to the foundation using *anchor bolts* placed in the concrete by the foundation contractor. The location of the *anchor bolts* (usually four or more) for a single *column* in the foundation must match exactly the pattern of bolt holes in the base plate of a single *column*.

Moreover, because it is more economical to erect *frames* comprised of multiple *columns* held together with *beams* and *braces*, rather than individual columns, the spacing between *anchor bolt* groupings must line-up exactly with the location of the *columns*. In the real world bolt hole patterns in base plates often do not match the *anchor bolt* locations. Also, the centerlines of *columns* often do not line up with the centerline of the *anchor bolt* grouping. To prevent these errors, fabricators usually insist on a survey of the *anchor bolt* locations prior to fabricating base plates and *frames*. Another method of mitigating the tight tolerances is for the foundation contractor and the fabricator to use *templates* to insure an exact match.

Another critical element of *erection* is crane access and movement. Steel is erected using one or more cranes, usually more than one. Typically a few different types of cranes are used for steel *erection* – tower cranes, crawler cranes and hydraulic cranes. Tower cranes are those large T-shaped, counterbalanced configurations used to erect multi-story structures and capable of heavy lifts. These cranes rotate about a single point and are capable of lifting steel anywhere within the radius of the tower arm. Crawler cranes are mobile and move around the site to make the necessary steel "picks." Hydraulic cranes tend to be smaller, more mobile, and are used for lighter *loads*.

Crane movement is an important consideration in the constructibility review of a project. Erectors usually divide the job into phases based on the anticipated movements of the cranes. For the sake of efficiency the fabricator usually fabricates the job in these same phases so that the erector has the necessary steel for a single phase (or area)[1]. One or more of these cranes may be designated for unloading steel when it shows up at the jobsite.

On most projects, the *erection* process starts with unloading the *shipping pieces* using one of several cranes usually on the site. Sometimes *shipping pieces* are erected into the framework directly from the truck; othertimes pieces must be placed first in a staging area for later *erection*.

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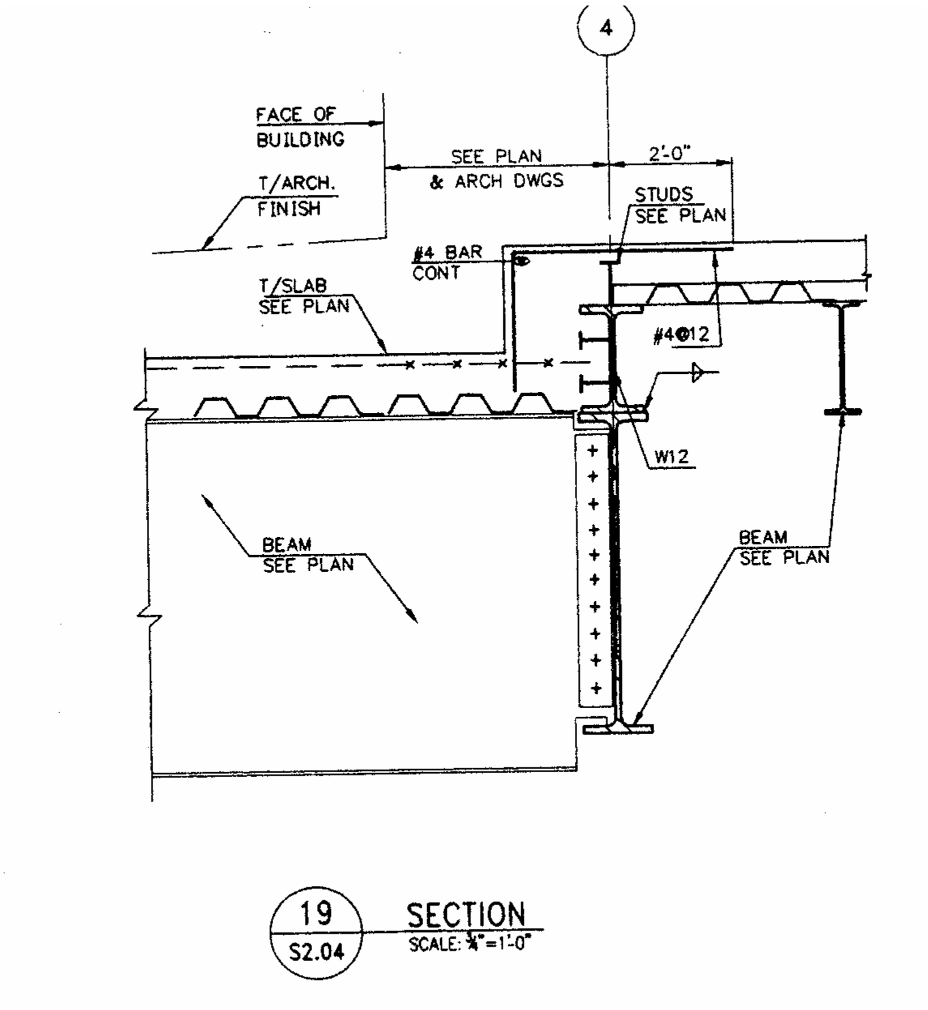
[1] When preparing an as-built schedule for steel activities, one can usually ascertain the actual dates for the erection of steel by analyzing crane movement – a description of which should be detailed on a daily construction report or log.

Other *erection* activities include plumb and bolt, safety, *welding*, *decking*, and buttoning-up. Plumb and bolt is the process of placing the steel assemblies in their proper location, aligning them and temporarily bolting them in place (bolts are not typically torqued to their final state until a majority of the area or *frame* has been erected). Safety is an activity performed by a separate crew that installs cable handrails and other safety devices in an area before the ironworkers begin to work. This allows the ironworkers to move freely from one area to another without interruption. A *welding* crew or multiple *welding* crews are then responsible for final *welding* of all the assemblies in accordance with the *erection drawings*. A bolting crew may also be utilized.

Decking is the process of placing corrugated bent plate on the structural *frame* to later accept cast-in-place concrete to form a slab. *Decking* is a structural element formed by bending plate into a corrugated shape. The height or deepness of the corrugations and the length and frequency of the corrugations determine the *decking's* strength. Oftentimes the erector will contract with a second tier contractor to design, detail, fabricate and erect the deck. Included in the *decking erection* activity is the installation of *studs* that weld to the deck for the purpose of mechanically fastening the poured-in-place concrete to the deck forming a monolithic (composite) structural element.

The final torquing of bolts, *welding* of deck, installation of stairs, and installation of *studs* is an activity commonly referred to as buttoning-up. Buttoning-up the structure is one of the final structural *erection* activities.



Section of two-level slab illustrating main steel beams, decking and studs. The corrugations of the decking run perpendicular to the beams. Notice how this structural section is referencing architectural drawings for dimensional information. Details regarding beam sizes, connections, stud locations, rebar placement, etc. are contained on other drawings.

Erection is a process that is dependent on the accuracy of the *erection drawings* and the accuracy of the fabricated steel. If steel is not fabricated according to the *detail drawings* or if the *detail drawings* are in error, *erection* is disrupted. Field engineers, working for the erector, are responsible for the design of the fix. The field engineers produce field work, commonly referred to as FW drawings, to indicate the fix. Either these drawings are sent back to the fabricator to produce the steel or the *fabrication* is done in the field. Either way the process takes time.

Another aspect of *erection* that is error prone involves steel stairs. No matter what precautions are taken by the EOR, the erector seems to always discover two common errors: 1) the stairs do not fit as intended and/or 2) some sort of interference is discovered. Stair problems are usually corrected in the field without input from the EOR, *detailer*, or fabricator.

III. THE IMPACT OF ERRORS, OMISSIONS AND CHANGES ON THE PROCESS OF DESIGNING AND CONSTRUCTING STRUCTURAL STEEL

Problems in the design and construction of *structural steel* are, for the most part, caused by change. The change can result from an error, omission, or just the desire by one of the parties to change an element of the work, which then affects the structural design and *geometry*. As discussed earlier, the entire process involves four primary events – engineering, *detailing*, *fabrication* and *erection*. As a general rule the earlier in this four phase process the change is identified and modifications implemented, the less the impact on the project.

A. Engineering

The best time to discover an error or omission or enact a change is usually during the structural engineering phase of steel design and construction. By way of example changes might include the placement of new steel not anticipated, the changing of steel already in the model, or the deletion of steel. Any one of these changes may impact engineering. They may cause the EOR to rework *calculations*, perform additional structural *calculations*, or even rerun the analysis performed by the computer. Fortunately, the impact is usually small in terms of time and cost because the change is known and implemented long before any steel is fabricated.

B. Detailing

Even minor changes during the *detailing* phase may have a large impact on the project, depending upon the nature of the change. Conversely, the change might be significant, but have little impact. It depends on the type and timing of the change. Their impact is best understood by dividing the *detailing* activities into four distinct tasks –

advanced bill of materials, *erection drawings*, *detail drawings* and *submittals*/approvals.

Since the information needed to prepare the *advanced bill* is derived from the EOR's structural drawings, changes at this stage will not affect the detail or *erection drawings*. If the change occurs early enough it can be accounted for in the *advanced bill*. If the change occurs after the mill purchase order is prepared, two impacts occur.

First, the new or replaced steel caused by the change is not contained in the purchase order and sometimes the mill cannot accommodate changes to the order. Therefore, the changed steel will need to be purchased separately, which is more work, and for which a premium cost may be paid. Second, if the change replaced steel, the originally ordered steel specified in the *advanced bill* will not be needed on the project. The impact to the fabricator is that steel bought and paid for will now be put into the fabricator's inventory. This is costly – material handling and storage is a huge labor expense for fabricators, the fabricator is out of pocket real dollars, and if the *mill order* was for odd lengths, the fabricator may only be able to sell the unnecessary steel for scrap value (about 4 to 10% of its original cost). If the change occurs during or after the shop drawings are produced another set of issues emerge.

Detailers coordinate the sequence of drawings produced with the fabricator and erector. The steel process, on most projects, is a "fast-track" process, meaning that *fabrication* and *erection* are taking place on elements of the structure for which the design is complete while the design of the other elements of the structure are still in process. The *detailing* of the entire structure need not be complete to get a jump-start on *fabrication*, and likewise on *erection*. In a perfect world an assembly can be detailed, fabricated, shipped and erected in as little as two to three days at a minimum, but the maximum time can take weeks, if not months depending on the complexity of the assembly.

Once a drawing sequence is determined (this matches the *fabrication* and *erection* sequence), any change will impact the production of drawings. For example, if a change occurred before a *detailer* began drawing an assembly, the impact will be minimal depending on the actual change. Some changes only require a change in dimensions, but some changes involve the addition of more *detail pieces* or even new assemblies. The later changes may cause more drawings to be necessary. It would not be unthinkable for a series of late changes on the huge job described earlier to cause the number of shop drawings to escalate from an anticipated 12,000 (all drawing types) to as many as 18,000.

If the *detailer* has completed a detail drawing, and it has already been transmitted to the fabricator's shop office, a change may require that the work be put on hold and may affect a recall of the shop drawings. This event will now disrupt the *detailer* because they now have to re-detail a drawing they had thought was done. Likewise, *fabrication* is also disrupted. The resulting extra demands on steel handling, coordination, project management to track changes, and quality control is costly and difficult. Once a drawing has been released to the shop for *fabrication* more serious impacts occur.

C. Fabrication

The *detailer* sends the shop drawings to the fabricator's shop office for processing. This processing includes: checking the drawing to insure all pieces are detailed, making *templates*, deciding which pieces will be fabricated first, deciding on gaining economies of scale by fabricating like pieces simultaneously, and checking the shop drawings against the latest set of structural drawing prepared and issued by the EOR.

If a change comes in during *fabrication* it will inherently impact both *detailing* and *fabrication*. The impacts are huge when an assembly is fifty per cent complete and a change is issued revising a structural element. This disruption may cause a partially completed assembly to be discarded in its entirety or set-aside on hold. Both cause more work and create inefficiencies.

If a change is sent to the fabricator after the assembly is completely fabricated the impact is similar. But if the assembly has already been shipped to the field and the *erection* crew has already installed it, the impacts are very expensive and may have a significant time impact on the project.

D. Erection

Changes that occur during *erection* are the most costly and disruptive. First, after so many months of engineering and *detailing*, fabricators and erectors get frustrated that all the bugs haven't been worked out sooner, and that frustration often impedes the level of communication and coordination that is necessary and timely to implement a change with minimal impact to project cost and schedule. Second, any changes that occur after steel is erected will reversibly impact *erection*, *fabrication*, *detailing* and engineering.

Assemblies already erected must either be dismantled or additional engineering will be required to make what is erected work (with new steel) according to the design. *Erection* proceeds in a logical sequence. Changes made after *erection* of the assembly is complete invariably impact *erection* equipment, primarily cranes, safety and manlifts. They may require the moving of some big cranes and may require the moving or additional rental of equipment. Disruptions caused by these changes require ironworkers to remobilize in an area already completed. In short, changes cause the erector more work, which takes more time and drives up costs.

Changes can occur during *detailing*, *fabrication* or *erection*. Complicated field changes discovered during *erection* are usually sent back to the *detailer* to implement and then get transmitted to the shop for *fabrication*. In the field, the erector's field engineer can sometimes detail (work out the *geometry* and design) simple changes. *Fabrication* of this changed or new piece or assembly can take place back in the shop or the ironworkers in the field can fabricate the new work.

V. SPECIAL CONSIDERATIONS IN STRUCTURAL STEEL DESIGN AND CONSTRUCTION

Problems in the steel industry share many of the same characteristics as sister industries: HVAC, plumbing, electrical, concrete, instrumentation, life safety and more. But, steel has some unique characteristics of its own which give rise to special considerations in its design and construction.

A. Weight

Steel is heavy and people associate weight with money and that is true. But the real cost of the steel framework is in the design of the *connections*. For example, depending on the project, steel could be bought for about $400 per ton, fabricated for about $450 per ton and erected for $550 per ton. Adding these components up brings the cost of installed steel to approximately $1,400 per ton. The equivalent cost of *connections* could cost anywhere from $2,000 to as much as $6,000 per ton or more. Efficiently designed *connections* translate into cost savings during *fabrication* and *erection*.

Many people in the construction industry think that the way to reduce the cost of the structural contract is by reducing the weight of the main *members*. While this does reduce the structure's weight, it causes the *connections* to become heavier and more complex. *Connections* must contain enough steel material to resist axial *forces*, bi-directional bending *moments*, *torsion*, and *shear*. Reducing member sizes reduces the amount of steel at the *connection* without changing the *loads*. The only place this can be made up is by the addition of various gusset and stiffening plates to add to the steel area at the node.

A simple example is that a wide flange shape *beam* that is eighteen inches tall and weighs one hundred and thirty pounds per foot (W18 x 130) has similar structural characteristics as a W27 x 84. The latter weighs forty-six pounds per foot less, and thus its use will lighten the main member weight. However, the cost impact on *fabrication* and *erection* at the *connections* could totally offset any cost savings associated with the use of the lighter *beam*. Weight savings do not always translate into cost savings.

B. *Connections*

As discussed earlier, the *connection* designer needs full information on *loads* and design intent from the EOR in order to design efficient and constructable *connections*. Unfortunately, given the increasingly litigious nature of the industry, structural engineers are reluctant to give out this information. Their reluctance stems from a concern that their structural modeling and analysis may not accurately have calculated the correct *loads*. As a consequence, engineers have reverted to a design procedure that falls somewhere in the middle of the spectrum between good and bad design practice.

Rather than supplying the “real” *loads*, the EOR requires *connection* designers to design *connections* based on the member’s (primary or secondary) ultimate strength. That means that the *connection* designer must design for the largest load possible in the member just before the member collapses or fails. Because these large *loads* have an inherently large safety factor, the resultant *connection* will be severely over-designed, very heavy, complex to fabricate and costly.

The impact of this will be an increase in *detailing*, *fabrication* and *erection* costs. But which party is going to pay for this extra work? Is it the fabricator providing *connection* designs or is it the EOR? Has the fabricator provided a lump-sum price or a GMP? Is this a predictable and reasonable risk for the fabricator to take? These are some of the key issues plaguing the steel construction industry today. Does the EOR have the right to reduce member weight at the expense of more complex *connections* without the input from the *connection* designer and fabricator? Industry participants regularly grapple with these troubling questions.

C. Quality

If one thing can be said about the steel construction industry it is that we can detect the differences between good steel and bad, and good workmanship and bad. Fabricators get s to verify the chemistry and metallurgical characteristics of every piece of steel manufactured and delivered; quality control and assurance in the *fabrication* shop is easily seen visually and is easily tested using a number of different destructive and non-destructive tests. Essentially, we can microscopically determine if the steel is good, whether the welds and bolts are good, and if the characteristics of the steel have changed. Macroscopically we can visually inspect the steel, inspect the bolts and inspect the welds and we can visually examine the steel for abnormalities. In fact, fabricators and erectors have some of the best quality controls programs in the construction industry.

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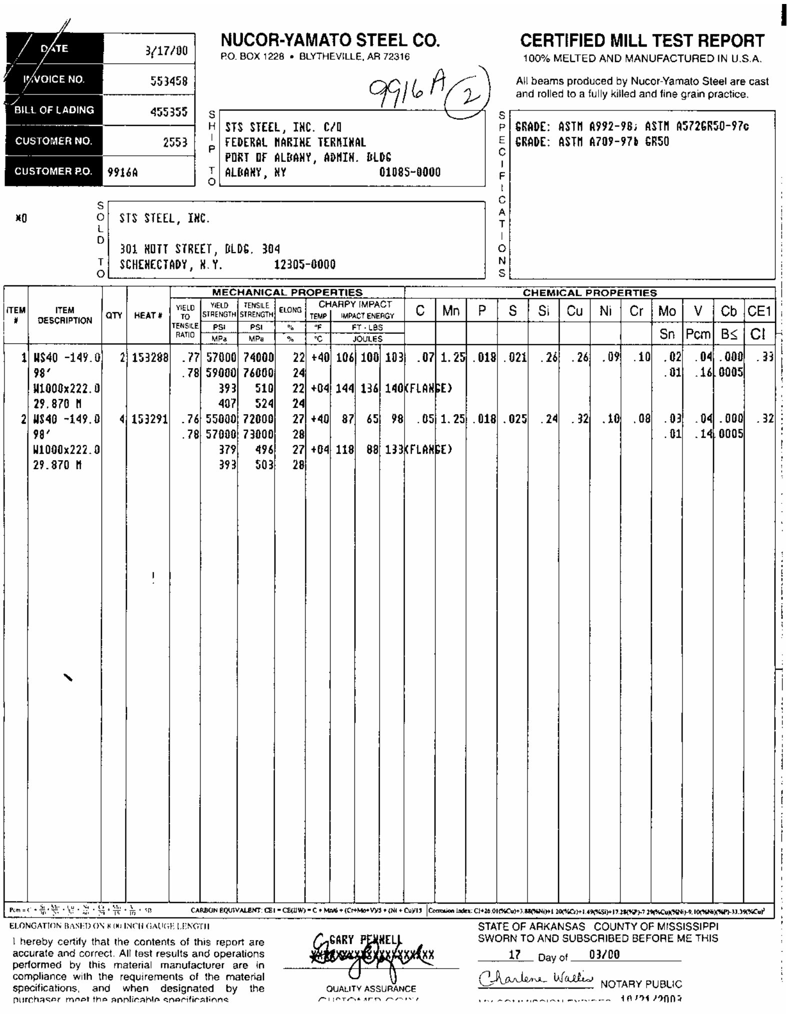

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	98′			.78	57000	73000	28													.01	.14	.0005	
	W1000x222.0				379	496	27	+04	118	88	133(FLANGE)												
	29.870 M				393	503	28																

Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + 5B   CARBON EQUIVALENT: CE1 = CE(IIW) = C + Mn/6 + (Cr+Mo+V)/5 + (Ni + Cu)/15   Corrosion Index: CI=26.01(%Cu)+3.88(%Ni)+1.20(%Cr)+1.49(%Si)+17.28(%P)-7.29(%Cu)(%Ni)-9.10(%Ni)(%P)-33.39(%Cu)²

ELONGATION BASED ON 8.00 INCH GAUGE LENGTH

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by this material manufacturer are in compliance with the requirements of the material specifications, and when designated by the purchaser meet the applicable specifications.

GARY PENNELL
QUALITY ASSURANCE

STATE OF ARKANSAS COUNTY OF MISSISSIPPI
SWORN TO AND SUBSCRIBED BEFORE ME THIS
17 Day of 03/00
Charlene Wallis NOTARY PUBLIC
10/21/2003

Sample Mill Report certifying the mechanical properties of the steel, including yield and tensile strength, used to manufacture the shape. Also included are the chemical properties of the steel, based on the customary chemical composition of steel, including carbon, manganese, phosphorus, sulfur, silicon, copper, nickel, chromium, molybdenum, and vanadium.

el design and construction is a systematic process. From engineering through *erection* all the steps are purposeful and necessary. Shortcuts are not tolerated, and when taken predictably result in unintended consequences.

Since the steel activities are usually on the critical path of the project schedule, any disruption can have an impact on the project finish date. Because of the assembly line nature of steel – in *detailing*, *fabrication* and *erection* – little float is available to absorb disruptions that cause delays. A key concept in steel design and construction is to always work one piece of steel or assembly one time. Once a piece is engineered, it gets detailed, then fabricated and then erected. There is usually no allowance for rework in any schedule.

E. Changes

As discussed earlier, changes generated for whatever reason are the *structural steel* industry's nemesis. *The AISC Code of Standard Practice for Steel Buildings and Bridges* deals effectively with this issue. From SECTION ¶4.1 of the *Commentary* it states:

> On phased construction projects, to insure the orderly flow of material procurement, detailing, fabrication and erection activities, it is essential that designs are not continuously revised after progressive releases for construction are made. In essence, once a portion of a design is released for construction, the essential elements of that design should be “frozen” to assure

> adherence to the construction schedule or all parties should reach an understanding on the effects of future changes [change orders and claims] as they affect scheduled deliveries and added costs, if any.

In defense of the EOR, their work is dependent on getting the programmatic requirements from the architect and owner. If they do not have timely information, or if the information is changing, the steel contract will surely be negatively impacted.

F. Cost Estimates

We know so much about the design and construction of steel structures that cost estimates are reliable and accurate. *Detailers*, fabricators and erectors prepare cost estimates that meticulously reflect the work required during engineering, *detailing*, *fabrication* and *erection*. Engineering estimates during design development may be the most difficult to perform because little is known about the structure. Based on having "*released for construction*" structural drawings, *detailing* hours and the number of drawings can be accurately predicted. Knowing the major and secondary steel-framing *members* provides the fabric for estimating material and *fabrication*. Since *connection* design is not completed, nor are miscellaneous parts of the structure, the fabricator must put an allowance in its bid to cover that work. The cost of *connection* *fabrication* and *erection* is usually estimated using allowances as low as 10% or as high as 20% of a structure's weight. *Connections* are oftentimes estimated by making assumptions as to the number of anticipated *shear*, *moment* and complex *connections* assigning a unit cost and weight to each type. Lastly, *erection* may be the easiest to estimate accurately. Erectors understand and know how many tons of steel and *shipping pieces* a raising gang can erect in a day. They know the rate at which bolts are installed, *welding* is performed and *decking* is applied.

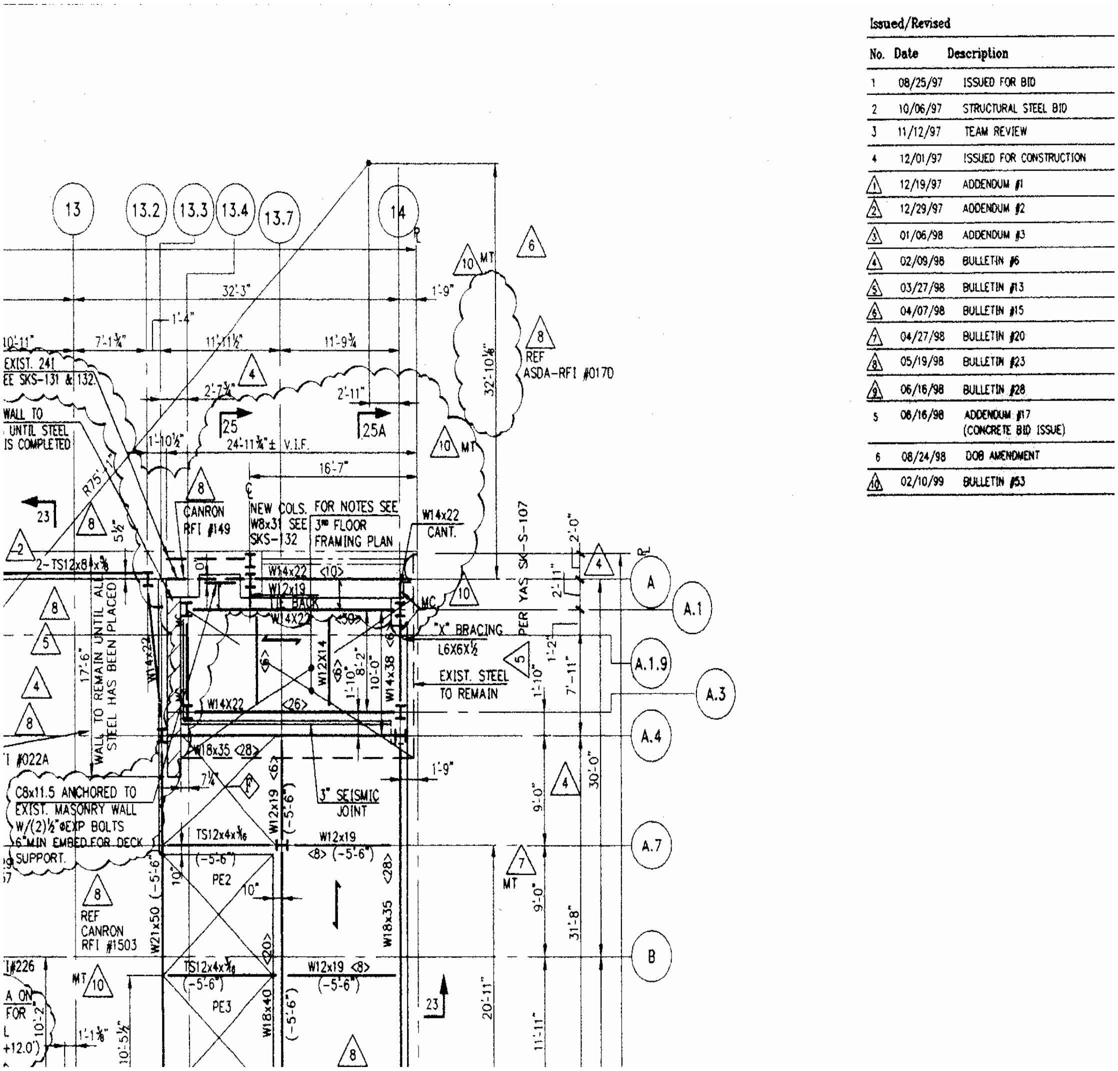
The more the engineer, *detailer*, fabricator and erector know about the design, the better and more competitive the estimates. Some fabricators and erectors are asked to give lump-sum prices based on allowances. While commonplace, agreeing to this places a substantial risk on the fabricator and erector. As an extreme example, two structures with an allowance of 10,000 tons can have either 40,000 small pieces of steel to be fabricated and welded or, as an extreme, the 10,000 tons can be comprised of two large pieces of steel. Clearly, the associated costs of engineering, *detailing*, *fabrication* and *erection* will differ dramatically. This admittedly extreme example highlights the problem with basing cost estimates on weight. Estimates should be based on the labor, material and equipment associated with *detail pieces*, *shipping pieces* and special requirements.

G. Other Disciplines

The *AISC Code* requires that all data needed for the *fabrication* and *erection* of steel be located on the structural drawings. However, often times it is not. The EOR often records details and dimensions on architectural, electrical and mechanical drawings. The fabricator has to literally search for the information and must review every iteration of every drawing of every discipline to assure itself that changes to steel have not been made. Although most steel contracts clearly state that the fabricator has the obligation to review the drawings of other disciplines, this is ineffective and constitutes an erosion of good engineering practice and a waste of time. A *detailer* should not be forced to wade through scores of architectural drawings to find the top of steel elevation of a horizontal *beam*, or find out the size of a *beam* penetration by reviewing an electrical or mechanical drawing. While accepted, this is clearly in conflict with the AISC C*ode* and good engineering practice. The AISC C*ode* indicates that other disciplines drawings are to be used to supplement the structural drawings, not replace them.

H. Structural Drawings

In any discipline there is a convention for preparing plans. The protocol for steel is well known, agreed to, and it works. A



Issued/Revised

No.	Date	Description
1	08/25/97	ISSUED FOR BID
2	10/06/97	STRUCTURAL STEEL BID
3	11/12/97	TEAM REVIEW
4	12/01/97	ISSUED FOR CONSTRUCTION
△1	12/19/97	ADDENDUM #1
△2	12/29/97	ADDENDUM #2
△3	01/06/98	ADDENDUM #3
△4	02/09/98	BULLETIN #6
△5	03/27/98	BULLETIN #13
△6	04/07/98	BULLETIN #15
△7	04/27/98	BULLETIN #20
△8	05/19/98	BULLETIN #23
△9	06/16/98	BULLETIN #28
5	06/16/98	ADDENDUM #17 (CONCRETE BID ISSUE)
6	08/24/98	DOB AMENDMENT
△10	02/10/99	BULLETIN #53

Partial plan with drawing revision block. Revision block indicates that Issue No. 4 was issued for Construction and since that issue this drawing had been re-issued twelve times. The drawing illustrates changes, with clouds around the affected area, with the appropriate revision number noted. Drawings are clouded to show the latest changes and are removed on subsequent re-issues – the revision marks in the triangles always remain on the drawing.

convention in preparing steel plans is to note a change[2] on a drawing by drawing a cloud around the change and to note the revision number. Unfortunately too often the EOR neglects to follow this convention. The result is that changes may not be clearly communicated to the *detailer*/fabricator.

On large, complex, troubled projects, line checking is the answer. *Detailers* review the latest structural drawing with the revision previously issued – line by line, dimension by dimension, note by note. In fact, at the end of a line checking exercise, the drawing being checked looks like a rainbow – yellow denoting areas that have not changed, green denoting steel that has been deleted, and red indicating new steel. If the EOR always clouded the changes, the labor of line checking, which is very expensive, would not be necessary.

I. Failure

Even though so much is known about steel and structures are designed with conservative safety factors, structural failures occur. Structural failures can be forensically studied to determine their cause. Failures may result from bad design, poor assumptions,

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[2] Changes can be issued by the EOR one at a time using a sketch (usually sent to the detailer by Fax) or in Bulletins, which is a re-issuing of a structural drawing.

unanticipated loadings or combinations, bad material, poor workmanship, or microscopic anomalies. Material science is such today that with more than reasonable certainty we are able to determine the cause of any particular failure. With this information, the *AISC* collects and analyzes this information and periodically updates the *Code*.

J. Economies of Scale

Steel *detailers* strive to draw similar *detail pieces* and assemblies on single shop drawings to save time and money. Consider a project that has thirty-nine built-up *columns* (four plates welded together to form a box), all having the same end conditions and differing only in their length. Typically, the *detailer* might elect to show one illustration of the *column* on one shop drawing and use a *column* schedule to depict the lengths of each *column* giving each a shipping piece number. Thirty-nine shop drawings are clearly not needed and *detailers*, when putting together their proposals, count on such economies of scale.

Likewise, fabricators count on this same economy of scale during the *fabrication* of *detail pieces* and the preparation of assemblies. Using the example above, a fabricator might elect to fabricate thirty-nine identical *columns* or "*blanks*" and cut them to final dimensions when the exact lengths are known. Because much of the plate cutting in large shops is computerized, fabricators can save substantial time and cost by pre-fabricating assemblies.

Whether in the *detailer's* office or in the *fabrication* plant, changes disrupt planned-for economies of scale. If for example a change submitted by the architect alters the length of one of the *beams*, the blank might be too short and may need to be scrapped. Most fabricators count on economies of scale in their bid and count on the time and cost savings. If a change disrupts the fabricator's plan, the fabricator clearly loses the benefit.

If designed with *fabrication* in mind, structures can be configured to have repetitious *members* in type, size, material and end conditions. Even if that means that some *beams* may be heavier than required, the labor hours saved in *fabrication* may easily pay for the added cost of material.

The Author would like to acknowledge the contributions of the American Institute of Steel Construction and Brawley & Associates, a Detailer in Sutter Creek, California, for providing some of the illustrations in this chapter.

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