Designers always should remember that
Design = Analysis + Member Design + Connections

98 Tips for Designing Structural Steel

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DESIGNERS OFTEN SPEND most of their time on analysis and member strength design, and an insufficient amount of time on connections and design considerations other than strength. This article provides a compendium of these "other" design considerations, offering guidance to designers so that they may achieve economical designs for steel structures. The suggestions provided are based on our 75 years of combined experience in the design of structural steel. Further suggestions were taken from "Economy in Steel" by Charles J. Carter, S.E., P.E., Ph.D., Thomas M. Murray, P.E., Ph.D., and William A Thornton, P.E., Ph.D., published in *Modern Steel Construction*, April 2000 (available at **www.modernsteel.com/backissues**).

General Considerations

1) **Design for serviceability first, then check strength.** The emphasis for design should be on serviceability, constructability and design details, in addition to strength.

2) **Communicate with fabricators, detailers and erectors.** The EOR should consult with and listen to the fabricators, detailers, and erectors because they all have practical knowledge, gained in the day-to-day experiences of putting together many projects. You, the engineer, should take advantage of this knowledge. Fabricators, detailers, and erectors often have excellent ideas and suggestions that will improve any project. By following their recommendations design costs often can be reduced by focusing your efforts productively, thus increasing your profitability on the project as well as those of the fabricator, detailer, and erector.

3) **Read the AISC *Code of Standard Practice*.** It is important for you to understand the relationships among the parties to the design and construction process for structural steel.

4) **Read ASTM A6.** An understanding of steel mill production tolerances will play a major role in the design and detailing of steel frames and their connections. Designers should be familiar with mill tolerances when selecting members and designing connections. Essential parameters are permissible variations in overall depth, flange tilt, and the position of the web in the wide-flange shape. Recognizing these allowable variations from square and true will guide designers to design connections that are complete and relatively easy to fit up. Allowance for the variations must be included in the connection design. This is usually accomplished with gaps for shims, and oversized and slotted holes.

5) **Keep the design simple.** Simplicity of design avoids field errors. Quoting Fazlur Khan, "Strive for structural simplicity."

6) **Provide understandable plans.** This will avoid detailing and field errors.

7) **Make sure the drawings show all requirements unique to the project.** This will avoid confusion and save you time in the end.

8) **Indicate if camber is required.** Do not specify camber if the required camber is less than ¾ in. Small camber amounts are not practical. Do not round up camber amounts, and use approximately 80% of the calculated simple span camber because the end connections will provide some restraint.

9) **Provide column schedules in the plans.** Column schedules are the best way of presenting your column requirements.

Things You Should Know About

ASTM International. This organization, formerly know as the American Society for Testing and Materials, establishes standards for the manufacture and testing of numerous materials including steel. ASTM A6, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling,* is available for purchase at **www.astm.org**.

Code of Standard Practice for Steel Buildings and Bridges. Also referred to as the *Code* and *COSP*, this document is published by AISC and available as a free download at **www.aisc.org/code**.

OSHA. Created in 1970, the Occupational Safety and Health Administration of the U.S. Department of Labor establishes and enforces workplace standards governing worker health and safety. Regulations and other resources are available at **www.osha.gov**.

RCSC. The Research Council on Structural Connections (**www.boltcouncil.org**) publishes the *Specification for Structural Joints Using ASTM A325 or A490 Bolts*. That document is available as a freeload download at **www.aisc.org/freepubs**.

Specification for Structural Steel Buildings. Also referred to as the *Specification*, this ANSI-approved AISC document is updated every five years and is available as a free download at **www.aisc.org/freepubs**.

Welds and Welding

16) Make sure there is adequate access for welding. Very embarrassing if you don't. See Figures 8-9 and 8-10 in the AISC *Manual* for guidance.

17) Keep fillet weld sizes at or below $\frac{5}{16}$ in. Larger weld sizes generally require multiple passes and may require increased levels of inspection and thus add cost.

18) Use multi-pass fillet welds rather than groove welds. Fillet welds require less preparation than groove welds and thus are less labor intensive. They also may require less weld metal.

19) Weld on only one side of a piece if possible. There are many cases where weld is needed on only one side of a piece, for example, column base plates and both transverse and bearing stiffeners.

20) Use intermittent fillet welds when possible. Weld volume can be reduced using intermittent, rather than continuous, filet welds; however, for fatigue situations intermittent welds will have a lower fatigue life than continuous welds.

21) Avoid the weld all around symbol. Welding all around may violate the AISC *Specification*, for example, causing undercut when the weld wraps around a corner. Many times welding all around is not necessary for strength.

22) Avoid welding to galvanized surfaces. The galvanizing must be removed prior to welding and touch up with cold galvanizing compound is generally required. Special ventilation is then required in the shop, and all of these items add cost.

23) Eliminate overhead welding. Overhead welding is difficult. Horizontal and flat positions use the base metal to support the molten weld pool and thus allow easier welding and promote higher quality.

10) Use maximum practical column lengths. There are several splice heights that could be used in the design and erection of steel buildings. The most common and the preferred method is the two-story tier. OSHA permits steel to be erected without netting so long as the distance to the platform below does not exceed 30 ft. Using two-story tiers and decking the upper floor first, the decking crew is protected from falling objects. It also is easier for the erector to stabilize the shorter columns as compared to a three-story tier.

The three floor per tier arrangement is nearly as unfavorable as a four floor per tier arrangement. One exception to this is when the number of floors results in a single-story column at the top of the frame. One often sees a top level column 10 or 11 ft long due to this condition. Depending on the framing arrangement, we often prefer to eliminate this last column splice and elect to use a three-level tier, particularly if the column size is the same or nearly the same. This is with the full recognition that the top level of framing may take a little more work to erect.

There are advantages to starting with a one-story tier at the base of the frame, followed by two-story tiers, in that the efficiency of erection is the same as the two-story tier after the first story is erected. In addition, the first story columns are generally much heavier than the second story columns due to drift control. Weight savings are possible when the base column is a one-story tier.

Four-story tiers should not be used unless absolutely necessary. It is very difficult to stabilize these long columns during erection and it is also difficult to adjust plumbness. Once the lower one or two levels are bolted or welded as the case may be, it will become a real struggle to get upper floor framing to fit. If the floor framing is moment welded at the columns, the weld shrinkage alone may be enough to make it difficult to erect the upper levels of floor framing.

11) Make sure you indicate all of the structural steel work on the structural drawings, limiting reference to Architectural and M-E-P drawings to describe the work. This provides clarity and will provide for the best bids on a project.

12) Minimize changes. Changes cost everyone on a project time and money.

13) Release for mill orders and detailing only when complete. If not complete, inform the architect, contractor and fabricator of the areas that are not yet complete. This saves time and money. If you fast-track the project, plan on revisions and the extra cost of changes. See Section 3.6 of the AISC *Code of Standard Practice* (*COSP*) for further material on this topic.

14) Answer the detailer's questions promptly; this means *really fast*. The EOR's costs, just like those of the fabricator, detailer, and erector, are a function of the time spent on the project. Developing a structural system in which the fabricator, detailer, and erector are "in sync" can save significant coordination time after the release of construction documents. The EOR also can contribute to construction efficiency by reviewing shop drawings and answering questions for the fabricator, detailer, and erector in a timely manner. Remember Benjamin Franklin's observation:"Time is money."

15) Approve shop drawings in a timely manner. This allows the fabricator to schedule the work in the shop most efficiently. The schedule for submittals and approvals should be established early in the project. See Section 4.4 of the *COSP* for further material on this topic.

Steel Construction Manual, also known as the *Manual*. Now in its 13th Edition, it is published by AISC. The *Manual* features property tables for U.S. rolled shapes and includes numerous reference documents, such as the AISC *COSP* and *Specification* and the RCSC *Specification*. It is available for purchase at **www.aisc.org/manual**.

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General Connection Considerations

24) **Time spent on connection design should be consistent with time spent on analysis and member design.** Remember that the majority of shop and field labor is in the connections. Approximately 30% of the cost of structural steel relates to material costs. The rest is highly dependent on connection costs. Spend time thinking through the connections.

25) **Make framing decisions along with connection decisions.** For optimum connections the framing members must be compatible. You cannot select members and connections independently of one another.

26) **Use field-bolted moment connections.** This reduces cost, because bolting is less affected by weather than welding.

27) **If you are not designing the connections, show all reactions on the drawings: axial, shear, moment, and transfer forces for the full set of forces in each load combination provided.** This is a requirement of the *COSP* and will save time on the project. This topic is discusse in detail in Part 2 of the *Manual*.

28) **Design connections for the actual forces.** Designing for the actual forces can greatly reduce the cost of connections and reduce the number of RFIs. Designing to develop member strength should be limited to those conditions required by the building code or the design.

29) **Do not specify a percentage of the tabulated Maximum Total Uniform Load.** When beams are selected for serviceability considerations, minimum depth or shape repetition, the uniform load tables will often result in far heavier connections than would be required by the actual design loads. This is an unfavorable condition that can result in uneconomic structures. The uniform load tables also are inappropriate for relatively short spans. Short spans have very high load capacities that often result in connections in excess of what would be required by the actual design loads. In short beams where the uniform design load (UDL) method is specified, it is frequently necessary to extend webs and cope bottom flanges so that there is sufficient connection depth. All of this is inappropriate if one considers the actual design loads. Using the UDL method for girders is also a concern. Non-uniform loading may result in an end reaction greater than that of 50% of the total uniform load taken from the Maximum Total Uniform Load Table from Part 3 of the AISC *Manual*. Likewise in composite beams, specifying either the end reaction using the Maximum Total Uniform Load Table or perhaps a percentage greater than 50% at each end may be inaccurate in some cases. Using UDL is a shortcut that may result in girder and composite beam connections that are undersized with respect to the actual required loads.

30) **Avoid "one size fits all" connection tables for a nominal beam depth.** Connection designs can be provided using connection tables; however, avoid the "one size fits all" approach. It is not appropriate to say that all W14 beams should have a particular connection. The size range of W14 beams is significant, as is the case for many other nominal beam depths.

31) **Avoid multiple linked tables.** Tables should be referenced back to the plan, where beam reactions are shown, so that the correct connections get matched to the right locations. Take care to avoid presentation of the connection requirements in multiple linked tables as this is simply an invitation to make an error. The presentation of these connection designs or connection requirements should be as straightforward as possible so that the detailing process can move forward in an orderly way. The documents must be presented in a clear fashion to minimize or eliminate errors.

32) **Group connection requirements by strength, not nominal beam depth.** Connections always should be grouped by strength and not by nominal beam depth. The tabulated connections should be matched to framing by comparing the tabulated connection strength to the connection reactions shown in the framing plans. For instance, a three-row double angle connection with ¾-in.-diameter bolts might correspond to some heavy W12 beams, but also to some light W18 beams.

33) **Show beam reactions on the plans.** This will result in optimum connection design, as described above.

34) **Use AISC standard details: Use of standard connections reduces costs and confusion.** Typical connections are double-angle (bolted/bolted or bolted/welded), single-angle (for beam to beam), single-plate (for beam to beam, both square and skewed), and shear end-plate (heavy skewed connections). Refer to Section 10 of the AISC *Manual*.

35) **Be aware of OSHA Subpart *R* rules for steel erection.** OSHA 1926.756(c)(1) prohibits double connections at columns and/or at beam webs over a column where all the bolts are common to both connections, unless means is provided to secure the first beam erected from falling away when the second beam is erected. Figures 2-13 through 2-17 in AISC *Detailing for Steel Construction*, Third Edition, provide common solutions that conform to the rule. If staggered connections are used, check that the T-dimension can accommodate the extra row of bolts. Other OSHA Subpart *R* rules are cited in this article and the complete list is available at **www.osha.gov**.

36) **Show special connections.** This reduces connection costs, RFIs and provides clear requirements for the bidders.

37) **Provide "moment envelopes" for moment connection design.** This reduces connection costs, RFIs, and provides clear requirements for the bidders.

Bolted Connections

47) **Make sure that there is adequate access for bolting.** Very embarrassing if you don't. See the AISC *Manual* Tables 7-16 and 7-17 for entering and tightening clearances.

48) **Limit bolt diameters to 1⅛ in.** Diameters of ¾ in. or ⅞ in. are generally preferred. Diameters greater than 1⅛ in. require specialized equipment. Note that bolts larger than 1 in. require increased edge distances and increased spacing between bolts.

49) **Limit bolt grades and sizes.** Fewer bolt sizes increases shop efficiency in drilling and punching. Also, quality assurance is simplified with fewer bolt sizes and grades on a given project.

50) **Use ASTM A325 bolts if possible.** A325 bolts provide the best fastener value, because they are the most common.

51) **Use snug-tightened joints when possible.** Do not specify slip critical joints unless they are required. Remember that slip critical joints are "perform" tasks and require continuous in-process inspection.

38) Provide forces for braced frame and truss connection design. This will result in optimum connection design.

39) Maximize work requiring intermittent rather than continuous inspection. As codes and standards have evolved, the amount of third party inspection has increased. These inspections are in addition to the quality control work of the contractors and can impose a significant burden on the project. The types of connections used will affect the amount of third party inspection work that has to be performed in the field and the associated costs.

Inspection is covered in Chapter 17 of the *International Building Code* and in Chapter N of the 2010 AISC *Specification for Structural Steel Buildings*. For a discussion of inspection terminology and requirements, see "Quality Time," *Modern Steel Construction*, March 2010 (available at **www.modernsteel.com/backissues**).

40) Minimize work requiring continuous inspection. The opposite of the above.

41) Watch out for W6 and W8 columns. The relatively small inter-flange distance can cause connection problems.

42) Don't require bolting and welding to the same member. Fabricators prefer designs that will allow the material to flow continuously through the shop. That means your design should not require welding to a column or a beam if the design also requires drilling or punching holes in the same member. Drill and punch lines are different lines than the welding lines and it costs money to transfer a column or beam from one line to another. The material will not flow smoothly through the shop if such transfers must be made.

43) Show all forces for a complete load path and try to provide an equilibrium condition at each joint. If you are not designing the connections, this will reduce confusion for the connection designer, because it permits a check for static equilibrium at a joint.

44) Transfer forces should include all drag strut forces and diaphragm connection details. These are of course necessary for a complete design of connections.

45) Consider modifying work points for extreme connection geometry. This can greatly reduce connection costs. Extra column or beam steel may be required but overall a cost savings is generally recognized. Examples of this are moving truss end connection work points to the face of the supporting columns and spreading truss web member end work points for ease of assembly.

46) Avoid through plates on HSS columns. Single plate shear connections can be welded directly to the HSS face thus making it unnecessary to slot the HSS and insert a plate. See AISC *Steel Design Guide 24*, available at **www.aisc.org/epubs** as a free download for AISC members and for purchase by others.

52) Minimize slip-critical connections. Limit slip critical connections to cases where they are required by AISC/RCSC, which include oversize holes or slotted holes not perpendicular to the load. See RCSC *Specification*, Section 4.3.

53) Use N type bolts rather than X bolts. This saves detailing time and inspection costs. However if X bolts are used, note that because the threaded length is constant for each diameter (RCSC *Specification* Table C-2.1), a quick check will determine the minimum ply thicknesses for the use of X bolts.

Member Design

54) Minimize the number of anchor rods per column (the OSHA minimum is four) and use simple arrangements. Increasing the number of anchor rods in a base connection increases the odds that there will be problems with the alignment of the rods and the base plate holes. If possible use doubly symmetric arrangements.

55) Check that beams do not have to be severely coped, especially with both top and bottom copes. This occurs when deep members frame into shallow members.

56) Use materials that are readily available. If materials are not available long lead times are required. Consult with your local fabricator and the AISC website (**www.asic.org**) as to material availability.

57) Check for camber differences on adjacent members, especially when adjacent parallel member ends are staggered. This can cause severe deck installation problems.

58) Make sure members have sufficient width for elements bearing on them. Very embarrassing if you don't. Joists should be aligned, not staggered at common supports so the deck layout is easier.

59) Run cantilevered roof beams over column tops whenever possible. This is a safety issue for erection. However, flange squareness on the beam is a concern that must be addressed.

60) Have steel deck span all in the same direction if possible. This reduces deck layout costs.

61) Avoid moment connections into the weak axis of columns. Moment connections into the weak axis of columns can cause a multitude of field problems. The ratio of I_x to I_y makes rigid frames with weak axis columns very inefficient.

62) Use W12 minimum depth beams for floor framing. Use W14 sections if the supporting girder requires a large cope on the beam. This is recommended so the standard connections will fit on the T-dimension of the web.

63) Shop weld short cantilevers when possible. Cantilevers can be an erection safety issue because the cantilever is not fully supported until the moment connection is completed. OSHA 1926.756(a)(2) requires that the minimum bolts for a cantilever be evaluated by a competent person. Field welded cantilevers typically require shoring or some other type of support until the flange welds are made. Either bolted moment connections or continuous beam construction is preferred for erection. Design of bolted moment connections is more efficient when actual design loads are used instead of the default design requirement of full M_p of the section. Short cantilevers can be welded directly to the column, completely eliminating the need for any field connection work. The only concern is whether or not the pieces can be readily stacked and shipped. Of particular concern is that these pieces are not symmetrical and not balanced about the column centerline. Thus, the stability of these pieces during the erection of the frame must be addressed by the erector.

64) Avoid beams with 4-in. flanges at:

–Spandrel beams with adjustable edge form.
–Beams requiring bolted flange connections.
–Locations where joists frame from each side.

65) When using composite beams:

–Use section stiffness to limit deflection and avoid large cambers.
–Use actual required percent of composite to limit studs.
–Avoid studs on infill beams parallel to deck ribs.

66) Design considerations for connections:

–End plates may be limited by bolts or column flange bending capacity, but are effective for frame stability during erection.

–CJP welds are a "no brainer" but generally more expensive.

–Top and bottom bolted flange plates are an option if less than M_p is required, but column flange squareness and permissible variations in beam must be addressed in the details.

67) Size columns to avoid reinforcement. This reduces fabrication costs. Use the AISC "Clean Columns" program available as a free download at www.steeltools.org.

68) Use HSS when appropriate for tall columns. This will reduce costs particularly in one- and two-story structures.

69) Eliminate web penetrations if possible; if unavoidable, design and locate them in the construction documents. Unreinforced penetrations are preferred. Avoiding or standardizing unreinforced web penetrations will reduce costs.

70) Repeat column base plate details, and minimize thicknesses. This will reduce detailing, fabrication and erection costs.

71) Minimize the number of column splices. This will reduce costs. It is estimated that one bearing splice requires roughly 500 lb of steel, and that one moment splice requires about 2,000 lb of steel. See previous discussion on two-story vs. four-story tiers.

72) Reduce beam and joist spacing in snow drift areas. This is less expensive than changing the deck thickness.

73) Use beams rather than joists when many concentrated loads are present or when concentrated load locations are not known. Beams provide the best solution when concentrated load locations are not precisely known, or when concentrated loads are likely to be relocated. KCS-joists also may be effective, however, additional webs may be needed.

74) Repeat plate thicknesses rather than using different thicknesses. This will simplify detailing and fabrication.

75) Repeat member sizes whenever possible. Least weight is not least cost. This saves both detailing and fabrication time. In addition, a larger order of the same size members may have a reduced cost.

76) Consider making beams continuous and stacking columns when long cantilevers are required. This will result in simpler connections and will be fast and safe to erect. However, flange squareness on the beam is a concern that must be addressed.

77) Maximize prefabrication and shop work. This reduces costs.

78) Minimize field work. This reduces costs.

79) Select members with favorable (constructible) geometry. This accommodates connection design, fit up and bearing requirements.

80) Limit galvanized members to 40 ft maximum. Most galvanizing tanks have a maximum length of 40 ft. One can double dip but the overlap may be objectionable.

81) Minimize the need for stiffeners and doubler plates. (See also "clean columns," above.) This greatly reduces costs (see table).

Estimated Steel Requirements for Stiffeners	
1 pair of fillet welded stiffeners	300 lb
2 pair of fillet welded stiffeners (at top and bottom girder flanges)	600 lb
1 pair of groove welded stiffeners	1,000 lb
2 pair of groove welded stiffeners (at top and bottom girder flanges)	2,000 lb
1 doubler plate	350 lb

82) Avoid members meeting at acute angles. When they do, it causes detailing and connection design nightmares. Use a header at an obtuse angle or skew the framing.

Erection Considerations

83) Provide permanent bracing that can be used as temporary bracing when possible. Saves the erector time and cost.

84) Provide straightforward connections that can be erected without added temporary provisions. Saves the erector time and cost.

85) Make sure that all beams can be brought into place without interference. Saves time and cost, and is a safety issue.

86) Make sure that all beams can be brought into place without having to spread columns apart. Saves time and cost, and is a safety issue.

87) Provide for construction tolerances in your design. Allow for mill and fabrication tolerances by using shims and oversize or slotted holes where required.

88) Check cumulative tolerances. Accumulation of tolerance variations can cause fit-up problems.

89) Check to see that the tolerances specified match your expectations of the final product. Know the tolerances for all of the materials that connect to or abut the structural steel.

90) Minimize the amount of loose material for details. This will save time and cost.

Specification Issues

91) **Have realistic specifications that match your actual intent and design requirements.** Over-specifying requirements needlessly adds cost to the project.

92) **Follow the specification requirements as set forth in the AISC *COSP*.** The *COSP* contains recommendations and requirements for the contents of construction documents, i.e., the plans and specifications, with regard to completeness and what is required in those documents.

93) **Use recognized specification formats**. Avoid problem specifications by using common national templates, such as AIA's MasterSpec or the MasterFormat developed by the Construction Specifications Institute. Remember that these template specifications *must* be adapted to your project. Make sure drawing notes agree with the specifications.

94) **Be sure the specified primer is compatible with the top coat and specify the correct surface preparation.** Coordinate with the architect to establish that the primer is compatible with the finish coat. Give close attention to various finish coating systems and the required shop work that is related to them. See AISC *Specification* Section M3 and its Commentary for more information on this topic.

95) **Do not specify painting when not required.** The guidance from AISC is that painting be restricted to those conditions when it is absolutely necessary for either corrosion protection or final appearance. If those two conditions do not exist, and if members are kept dry, there is no need to paint structural steel. Remember that the shop coat is not a permanent paint system and has limited protective qualities. With regard to fireproofing systems, they usually adhere better to unpainted steel. Refer to the AISC *COSP* and its Commentary on the subject of surface preparation and shop painting for more information on this topic.

96) **Indicate Architecturally Exposed Structural Steel (AESS) judiciously.** Just because structural steel can be seen in the final design doesn't mean that it must be fabricated and erected using the stricter standards associated with AESS. Specifying AESS adds cost to the project; therefore, a cost-benefit analysis should be made to ensure that there is reasonable benefit to the project before doing so. It may be that when the structural steel is exposed to view, conventional fabrication can achieve the desired effect. Fabricators are encouraged to allow the inspection of AESS only from the actual distance that it will be viewed in the completed structure.

97) **Clearly state quality assurance inspection requirements in your specifications.** Scope and type of inspection should be indicated. Only specify inspections if necessary for the situation. If shop inspections are necessary so indicate so that shop interruption is minimized. See Chapter N of the 2010 AISC *Specification*.

98) **Avoid specifying single brand names.** Avoid specifying single brand names if possible, if possible indicate other "equals." By all means make sure the products you specify are available.

While presenting this many design tips may seem exhaustive and comprehensive, the authors hope that all are useful to designers and contractors. However, there are probably just as many more useful tips out there somewhere. Pass them on to your colleagues so that they, too, can achieve more efficient steel structures. MSC