50 Tips For Designing Constructable & Economical Steel Buildings
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Seminar goal
To review easy ways to enhance the constructability of steel-framed structures.

Keep in mind.....
These tips are only suggestions.
There are often several good solutions.
The best solution often depends on local construction practices and contractor preferences.
The best design is one that provides steel fabricators with options and flexibility.

Constructability
Constructability defines the ease with which structures can be built.
Constructability = Economy

Four principles of constructability
Simplicity = Economy
Least weight does not always = Least cost
Fewer pieces = Greater economy
Efficient connection design = Reduced cost

Show the reactions
A significant percentage of cost is in the connections.
Excessively conservative connection design requirements do not enhance safety.

Tip #1
Excessively conservative connection design requirements do not enhance safety.

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Show the reactions

*Do not* require connections to be designed for full shear strength of the member.

*Avoid* notes such as this on your drawings:

“Connections shall be designed to support the full shear strength of the member.”

Tip #1

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Show the reactions

*Do not* require connection strength to be based on the Table 3-6 maximum uniform load values.

*Avoid* notes such as this on your drawings:

“Connections shall be designed to support reactions occurring from uniform loads equal to 150% of the uniform load capacity of the beams from Table 3-6 in the AISC Steel Construction Manual.”

(This note is usually excessively conservative, but sometimes can result in connections with insufficient strength.)

Tip #1

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Show the reactions

*Avoid* notes such as this on your drawings:

“Connections shall be designed to support reactions occurring from uniform loads equal to 150% of the uniform load capacity of the beams from Table 3-6 in the AISC Steel Construction Manual.”

The only way fabricators can “consider” the effects of concentrated loads is to submit an RFI asking for the reactions – so save yourself time and put the reactions on drawings before they are issued for bid.

Tip #1

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Provide moments & axial forces

Moment connections

Axial loads in
- Hangers
- Drag struts
- Braced frames
- Truss members

*Do not* require connections to develop the full capacity of the section unless required by analysis or by the building code.

Tip #2

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Provide load combinations & directions of reactions, forces and moments

*Do not* require shears and moments to be considered in all directions unless they really might occur in all directions.

Tip #3
Require connections to be designed per the requirements of the building code, AISC 360-10 & AISC 341-10

*Do not* mandate connection design requirements beyond what is required by the building code.

Tip #4

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**AISC 360-10, Section J1.10**

Limitations on Bolted and Welded Connections

Joints with *pretensioned bolts* or welds shall be used for the following connections:

1. Columns splices in all multi-story structures over 125 ft in height
2. Connections of all beams and girder to columns and any other beams and girders on which the bracing of the columns is dependent in structures over 125 ft in height.
3. In all structures carrying cranes over 5-ton capacity; roof truss splices and connections of trusses to columns; column splices; column bracing; knee braces; and crane supports.
4. Connection for the support of machinery and other live loads that produce impact or reversal of load.

**Pre-tensioned ≠ Slip-critical**

Do not use the terms interchangeably.

Tip #5

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**AISC 341-10, Section D2.2**

2. Bolted Joints

Bolted joints shall satisfy the following requirements:

1. The available shear strength of bolted joints using standard holes shall be calculated as that for bearing-type joints in accordance with Specification Sections J3.6 and J3.10. The nominal bearing strength at bolt holes shall not be taken greater than 2.44f_u.
2. Bolts and welds shall not be designed to share force in a joint or the same force component in a connection.
3. Bolt holes shall be standard holes or short-slotted holes perpendicular to the applied load.
   
   **Exception:** For diagonal braces specified in Sections F1, F2, F3 and F4, oversized holes are permitted in one connection only when the connection is designed as a slip-critical joint for the required brace connection strength in Sections F1, F2, F3 and F4.
4. All bolts shall be installed as pretensioned high-strength bolts. Faying surfaces shall satisfy the requirements for slip-critical connections in accordance with Specification Section J3.8 with a faying surface with a Class A slip coefficient or higher.

Even when designing an R>3 Seismic Load Resisting System, bearing bolt strength values may be used (versus slip-critical) when the holes are STD or SSL with loads applied perpendicular to the slot.

Tip #5

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**Permit the use of one-sided connections**

*(single angle and single-plate connections)*

Example of what *not* to specify:

"Avoid one-sided connections if possible and do not use for beams deeper than 18". If it is necessary to use a one-sided connection, this connection shall be designed in accordance with the AISC Manual."

(See AISC Steel Construction Manual for limitations and procedures regarding design of single-plate and single angle connections.)

Tip #6
Permit the use of short-slotted holes in shear connections

Example of what \textbf{not} to specify:

"All bolts shall be ¾" diameter. All holes shall be 13/16" diameter."

Most fabricators require short-slotted holes in shear connections to accommodate tolerances and facilitate steel erection. (SSL holes are needed when beams are cambered.)

AISC connection design procedures permit the use of SSL holes with snug-tightened bolts for most types of shear connections.

Tip #8

Delegate connection design to the fabricator

From AISC 303-10:

3.1.2. The owner’s designated representative for design shall indicate one of the following options for each connection:

(1) The complete connection design shall be shown in the structural design drawings;
(2) In the structural design drawings or specifications, the connection shall be designated to be selected or completed by an experienced steel detailer; or,
(3) In the structural design drawings or specifications, the connection shall be designated to be designed by a licensed professional engineer working for the fabricator.

Tip #9

Delegate connection design to the fabricator – \textbf{but do so properly}

When option (2) or (3) above is specified, the owner’s designated representative for design shall provide the following information in the structural design drawings and specifications:

\begin{itemize}
\item[(a)] Any restrictions on the types of connections that are permitted;
\item[(b)] Data concerning the loads, including shears, moments, axial forces and transfer forces, that are to be resisted by the individual members and their connections, sufficient to allow the selection, completion, or design of the connection details while preparing the shop and erection drawings;
\item[(c)] Whether the data required in (b) is given at the service-load level or the factored-load level;
\item[(d)] Whether LRFD or ASD is to be used in the selection, completion, or design of connection details; and,
\item[(e)] What substantiating connection information, if any, is to be provided with the shop and erection drawings to the owner’s designated representative for design.
\end{itemize}

Tip #9

Frame girders to column flanges; beams to webs

Girders connected to column flanges with double angle connections
Beams connected to column web w/ single angle connections
- Easy & safe to erect
- No shared bolts
- No copes

Tip #10
Size columns to eliminate need for stiffeners

Where column stiffeners can't be avoided, make opposing beams the same depth

Stiffeners complicate connections

Square stiffeners are less expensive than skewed stiffeners

Tip #11

Tip #12

Use deepest practical column; avoid W8 columns with connections to web

Orient columns to minimize skewed connections

Square connections are less expensive than skewed connections.

Tip #13

Tip #14

Orient columns in braced frames square

Orient columns in braced frames square to the beams and braces (preferably to the column flanges)

Tip #15

Tip #15
Frame members with very large reactions square to columns - preferably to the flanges.

Configure framing so that no more than one beam frames to any one side of a column

Configure framing so that no more than one beam frames to any one side of a column

Configure framing to minimize skewed connections

Head off steeply skewed connections

Favor pipe columns over square/rectangular HSS when there are skewed connections
Watch out for connection interference where beams are slightly offset from columns

As shown on framing plan

Tip #21

Increase beam depth to avoid web reinforcement

Possible situations requiring web reinforcing:
- Large copes w/ heavy reactions
- High beams framing to low girders
- Skewed beams with long copes

Tip #22

Beams with flange-bolted moment connections must have sufficiently wide flanges to install bolts

Min. gage for installation of 7/8"Ø bolts through flanges

Min. recommended flange width to install bolts through flange = 6” (Don’t forget to check net section.)

Tip #23

Size members to have sufficient strength at the net section

Required strength
Usable strength

= 0.75 (max.)

Rule-of-thumb:

Max. recommended stress ratio at gross section

Tip #24

Communicate and coordinate

Talk to the architect if their design is creating structural inefficiencies.

Failure to proactively communicate & coordinate early can box you into a corner. (“You should have told us this would be a problem two months ago...”)

Ask your client in writing for the information that you need and give dates for when that information is needed.

Anticipate what other consultants will be doing in order to avoid coordination problems and interferences during construction.

Tip #25

Here’s what can happen when you don’t anticipate, coordinate and communicate...

Coordinate locations and naming of MEP systems early to develop cost effective solutions to coordination issues.
Do not delegate design of reinforcing around beam web openings

Tip #27

Provide sufficient information on the drawings to minimize uncertainty among bidders

AISC 303-10 Section 3.1.1,
Permanent bracing, column stiffeners, column web doubler plates, bearing stiffeners in beams and girders, web reinforcement, openings for other trades and other special details, where required, shall be shown in sufficient detail in the structural design drawings so that the quantity, detailing and fabrication requirements for these items can be readily understood.

Tip #28

Do not delegate design of plate girder welds

Tip #29 & 30

Use fillet welds sized for required strength

Think about how the connections will be detailed even when connection design is delegated to the fabricator

Double plate girder
How can these be connected to the supporting columns (no access for bolting)

Tip #31

Configure HSS framing to simplify connections

Tip #32

Some welding tips to enhance constructability

Strive for downhand or vertical welds
Avoid specifying "all around" welds unless they are needed to achieve the required strength
Avoid specifying arbitrary CJP welded moment connections
Favor fillet welds over groove welds

Tip #33
Select efficient diagonal braces

Single angles: Good for small loads (tension only)
Double angles: Efficient connections (double shear bolts)
HSS’s: Highest brace strength per pound of steel (field welding required for installation)
W shapes: Good for high axial loads (but connections can be more intricate than with the other brace types)

Configure slopes of diagonal braces at 35 to 55 degrees

Braces with shallow slopes can have difficult connections

Verify that framing can be installed

Braced frame shown. Similar conditions can occur in floor framing and trusses.

Configure framing to minimize the number beams

Tip #34
Tip #34
Tip #35
Tip #35
Tip #36
Tip #37
Maximize slab span to minimize the number of beams

For seismic design use $R=3$ when possible

There are significant connection and member design requirements imposed when the seismic response modification coefficient, "R" is > 3.

Ordinary Steel Concentrically Braced Frames ($R=3.25$) and Ordinary Steel Moment Frames ($R=3.5$) are not so "ordinary"!

Orient columns in moment frames for strong axis bending

Tip #39

Strong axis beam-to-column moment connections are generally less complex than weak axis beam-to-column moment connections

Tip #40

Tip #41

Run heavy moment-connected girders through columns to simplify flow of moment through the columns

Tip #42

Run cantilevered roof beam over tops of columns

Tip #43
Minimize the "gingerbread"

"Gingerbread" = little pieces of steel.
- Brace angles
- Relieving angles
- Bent plates
- Stiffeners
- Web doubler plates
- Little beams

Selectively turn slab spans to reduce "gingerbread"

Avoid skewed beam-to-column moment connections
Difficult to detail

Avoid full depth stiffeners where possible

Simplify base plates and anchor rod details

Some constructability tips for hangers

Tip #44

Tip #45

Tip #46

Tip #47
Understand fabricator preferences regarding preferred connection details

- Shear connections
- Moment connections
- Braced frame connections
- Truss connections

Tip #48

Avoid torsion in W shape beams

W shapes are inefficient in resisting torsion.

Solutions:
- Brace W shapes to take out torsion
- Use HSS sections

Tip #49

Camber intelligently

- Do not camber beams in moment frames & braced frames
- Do not camber short beams (< 25' long)
- Do not camber light beams (< 19 plf)
- Do not over-camber (camber for 75% of slab + steel weight)
- Specify additional concrete be poured to achieve level floor
- Include ponded concrete load in design
- Do not specify camber < 3/4"
- Do not specify that camber be measured after erection.
- Compare camber cost to material cost

For more information, go to presentation on AISC website, “Specifying Camber: Rules-of-Thumb for Designers” www.aisc.org/elearning found under “Boxed Lunch” presentations

Tip #50

Summary

To enhance constructability,
- Think about the connections
- Show the reactions, moments & axial forces
- Do not impose arbitrary constraints on connection design
- Delegate connection design
- Strive to keep connections square
- Use R=3 for seismic design (when permitted).
- Understand fabricator preferences
- Permit alternative connection details
- Minimize the number of structural framing members
- Minimize the “gingerbread”
- Communicate & coordinate

Tip #51

Thank you!
Questions?

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