50 Tips for Designing Constructable & Economical Steel Buildings

by Clifford Schwinger, PE

THE HARMAN GROUP
structural engineering
parking planning and design
PHILADELPHIA | NEW YORK

January 22, 2020 DVASE Young Members Group Seminar

DVASE | Delaware Valley Association of Structural Engineers
Eastern Chapter of the Structural Engineers Association of Pennsylvania

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Seminar Objectives

To review *easy* ways of enhancing the constructability of steel-framed structures.

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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.

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Constructability

Constructability defines the ease with which structures can be built.

Constructability = Economy

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The lack of constructability usually does not compromise the safety of a building structure…

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…but it could.

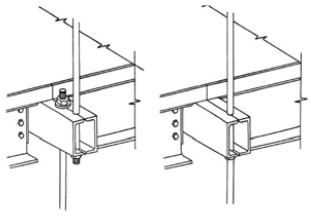

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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Four principles of constructability

Simplicity = Economy

Least weight *does not always* = Least cost

Fewer pieces = Greater economy

Efficient connection design = Reduced cost

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Show the reactions

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

Tip #1

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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,

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

Tip #1

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Show the reactions

- *Do not* reference Table 3-6 for required beam connection strengths.
- *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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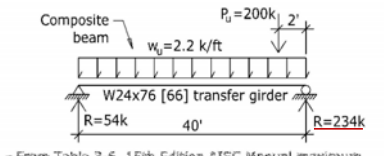
Show the reactions



- From Table 3-6, 15th Edition AISC Manual maximum uniform load capacity for W24x76 (LRFD) is 150k for L=40'
- Connection requirement on contract documents: Design connections for 150% of the reaction from the uniform load capacity of the beams from Table 3-6 (0.75 x 150k = 113k)
- Actual reaction at right end is more than twice as big as specified connection strength!

Tip #1

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Show the reactions

Avoid notes such as this on your drawings:

"Shear connections shall be designed to support 150% of the Total Uniform Loads in Table 3-6 of the AISC Steel Construction Manual. The effects of concentrated loads near an end reaction shall also be considered.

Tip #1

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Provide moments and axial forces

Moments in 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.

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Tip #2

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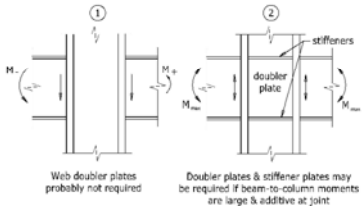
Provide load combinations and directions of reactions, forces and moments



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

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Tip #3

14

Require connections to be designed per the building code, AISC 360-16 & AISC 341-16

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

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Tip #4

15

Allow use of bearing bolt strength values where permitted by the building code

Avoid notes such as this:

"All bolted connections shall be designed as slip-critical connections."

Slip-critical connections are generally only required when over-sized or slotted holes are used with loads parallel to the slots

16

Tip #5

16

Allow use of bearing bolt strength values where permitted by the building code

Avoid notes such as this on your drawings:

"The following connections must be slip-critical:

- Connections within 3 feet of columns
- Connections directly supporting columns
- Hanger connections
- Stair connections
- Cantilever connections
- Bracing connections
- All connections supporting 50k or more
- Connections to plate girders

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Tip #5

17

AISC 360-16, Section J3.1

(a) Bolts are permitted to be installed to the snug-tight condition when used in:

(1) Bearing-type connections, except as stipulated in Section E6

(2) Tension or combined shear and tension applications, for Group A bolts only, where loosening or fatigue due to vibration or load fluctuations are not design considerations

(b) Bolts in the following connections shall be pretensioned:

(1) As required by the RCSC *Specification*

(2) Connections subjected to vibratory loads where bolt loosening is a consideration

(3) End connections of built-up members composed of two shapes either interconnected by bolts, or with at least one open side interconnected by perforated cover plates or lacing with tie plates, as required in Section E6.1

(c) The following connections shall be designed as slip critical:

(1) As required by the RCSC *Specification*

(2) The extended portion of bolted, partial-length cover plates, as required in Section F13.3

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Tip #5

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RCSC Specification for Structural Joints Using High-Strength Bolts

4.1. Snug-Tightened Joints

Except as required in Sections 4.2 and 4.3, *snug-tightened joints* are permitted.

4.2. Pretensioned Joints

Pretensioned joints are required in the following applications:

(1) *Joints* in which fastener pretension is required in the specification or code that invokes this Specification;
(2) *Joints* that are subject to significant load reversal;
(3) *Joints* that are subject to fatigue load with no reversal of the loading direction;
(4) *Joints* with ASTM A325 or F1852 bolts that are subject to tensile fatigue; and,
(5) *Joints* with ASTM A490 or F2280 bolts that are subject to tension or combined shear and tension, with or without fatigue.

4.3. Slip-Critical Joints

Slip-critical joints are required in the following applications involving shear or combined shear and tension:

(1) *Joints* that are subject to fatigue load with reversal of the loading direction;
(2) *Joints* that utilize oversized holes;
(3) *Joints* that utilize slotted holes, except those with applied load approximately normal (within 80 to 100 degrees) to the direction of the long dimension of the slot; and,
(4) *Joints* in which slip at the *faying surfaces* would be detrimental to the performance of the structure

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Tip #5

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AISC 341-16, Section D2.2

For R>3

2. Bolted Joints

Bolted joints shall satisfy the following requirements:

a) **The available shear strength of bolted joints using standard holes or short-slotted holes shall be calculated as that for bearing-type joints** in accordance with Specification Sections J3.6 and J3.10…..

b) Bolts and welds shall not be designed to share force in a joint or the same force component in a connection.

c) Bolt holes shall be standard holes or short-slotted holes perpendicular to the applied load in bolted joints where seismic load effects are transferred by shear in the bolts…..

d) **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.**

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Tip #5

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Snug-tight bolts vs. Pretensioned bolts vs. Slip-critical bolts

Pre-tensioned ≠ Slip-critical

Do not use the terms interchangeably.

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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.)

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Tip #6

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Permit the use of any diameter and type of bolt

Example of what *not* to specify:

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

Allow fabricator to determine the bolt diameter and type when connection design is delegated to the fabricator.

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Tip #7

23

Permit the use of short-slotted holes in shear connections

Example of what *not* to specify:

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

Most fabricators require short-slotted holes 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

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Tip #8

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Read AISC 303-16, Code of Standard Practice for Steel Buildings and Bridges

The roadmap for understanding the EOR's responsibilities when designing structural steel.

Tip #9

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Provide sufficient information on the drawings to minimize uncertainty among bidders

AISC 303-16

3.1.2. Permanent bracing, openings in structural steel for other trades, and other special details, where required, shall be designed by the *owner's designated representative for design* and shown in sufficient detail in the structural *design documents* issued for bidding so that the quantity, detailing and fabrication requirements for these items can be readily understood.

At locations away from *connections*, stiffeners, web doubler plates, bearing stiffeners, and other member reinforcement, where required, shall be designed by the *owner's designated representative for design* and shown in sufficient detail in the structural *design documents* issued for bidding so that the quantity, detailing and fabrication requirements for these items can be readily understood.

(See Tip #10 for member reinforcement at connections…)

Tip #10

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Delegate connection design to the fabricator

Follow AISC 303-16, Code of Standard Practice

. . . 3.1.1. The *owner's designated representative for design* shall indicate one of the following options for each *connection*:

(1) Option 1: the complete *connection* design shall be shown in the structural *design documents*.

(2) Option 2: in the structural *design documents* or *specifications*, the *connection* shall be designated to be selected or completed by an experienced *steel detailer*.

(3) Option 3: in the structural *design documents* or *specifications*, the *connection* shall be designated to be designed by a licensed engineer working for the *fabricator*.

In all of the above options,

(a) The requirements of Section 3.1.2 shall apply.

(b) The approvals process in Section 4.4 shall be followed. . . .

Code of Standard Practice for Steel Buildings and Bridges, June 15, 2016
AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Tip #11

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(3.1.1 continued)

. . . When Option 2 is specified, the experienced *steel detailer* shall utilize information provided in the structural *design documents* in the selection or completion of the *connections*. When such information is not provided, tables in the AISC *Steel Construction Manual*, or other reference information as approved by the *owner's designated representative for design*, shall be used.

When Option 2 or 3 is specified, the *owner's designated representative for design* shall provide the following *connection* design criteria in the structural *design documents* and *specifications*:

(a) Any restrictions on the types of *connections* that are permitted.

(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 *approval documents*.

(c) Whether the data required in (b) is given at the service-load level or the factored-load level.

(d) Whether LRFD or ASD is to be used in the selection, completion, or design of *connection* details.

(e) What *substantiating connection information*, if any, is to be provided with the *approval documents* to the *owner's designated representative for design*. . . .

Tip #11

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(3.1.2 continued)

. . . (2) When Option 3 in Section 3.1.1 is specified for a *connection*, two subsidiary options are available to the *owner's designated representative for design*; either:

(a) Option 3A: member reinforcement at *connections* shall be designed by the *owner's designated representative for design* and shown in the structural *design documents* issued for bidding so that the quantity, detailing and fabrication requirements for member reinforcement at *connections* can be readily understood, or;

(b) Option 3B: the *owner's designated representative for design* shall provide a bidding quantity of items required for member reinforcement at *connections* with corresponding project-specific details that show the conceptual configuration of reinforcement appropriate for the order of magnitude of forces to be transferred. These quantities and project-specific conceptual configurations will be relied upon for bidding purposes. If no quantities or conceptual configurations are shown, member reinforcement at *connections* will not be included in the bid.

Subsequently, member reinforcement at *connections*, where required, shall be designed in its final configuration by the licensed engineer in responsible charge of the *connection* design. . . .

Tip #11

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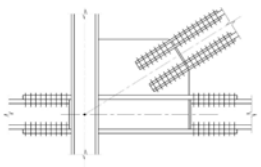
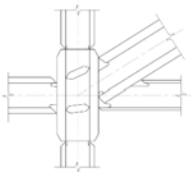
Never stop thinking about the connections

Never stop thinking about connection constructability and connection designability.



Detail on contract documents (EOR did not consider designability)



Detail required

Tip #12

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Look for "kinked connections"

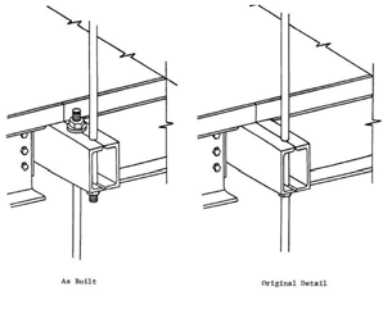

Figure 10.2 Comparison of interrupted and continuous hanger rod details.

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Tip #13

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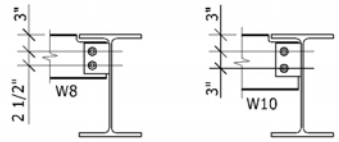
Think twice before using W8 beams



- Non-standard bolt spacing is required for two-bolt shear connections in W8's. (Use W10x12's instead of W8x10's.)
- Also, W8's framing to heavy shapes (with wide flanges) may require web reinforcing. Better to use a deeper beam (W10 or W12) that will not require web reinforcing.

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Tip #14

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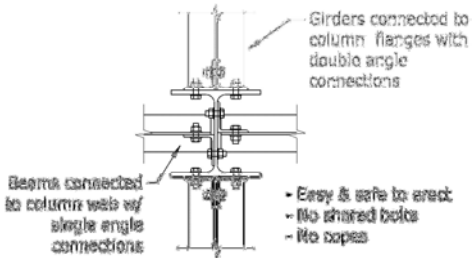
Frame girders to column flanges; beams to webs



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Tip #15

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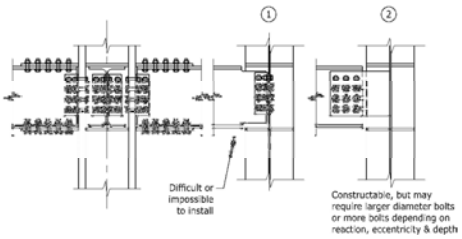
Size columns to eliminate need for stiffeners



Stiffeners complicate connections and increase cost.

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Tip #16

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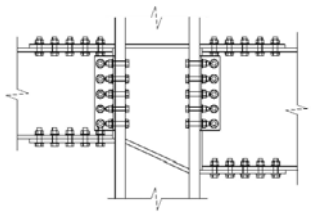
Where column stiffeners can't be avoided, make opposing beams the same depth



Square stiffeners are less expensive than skewed stiffeners

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Tip #17

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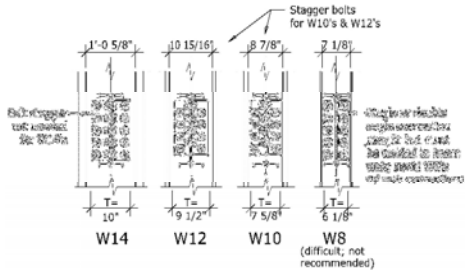
Use deepest practical column; avoid W8 columns with connections to web



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Tip #18

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Orient columns to minimize skewed connections

3 SKEWED CONNECTIONS
1 SQUARE CONNECTION

3 SQUARE CONNECTIONS
1 SKEWED CONNECTION

Square connections are less expensive than skewed connections.

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Tip #19

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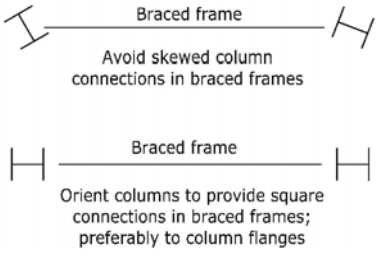
Orient columns in braced frames square



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Tip #20

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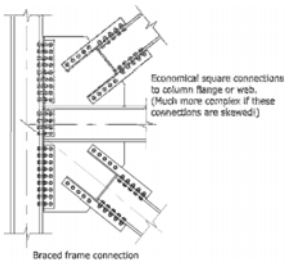
Orient columns in braced frames square to the beams and braces (preferably to the column flanges)



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Tip #21

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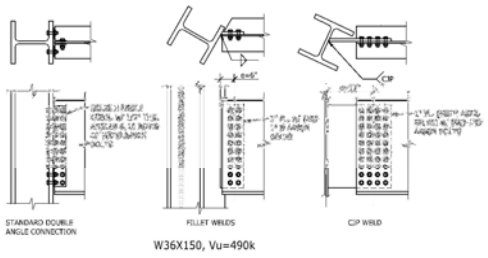
Frame members with very large reactions square to columns – preferably to the flanges



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Tip #22

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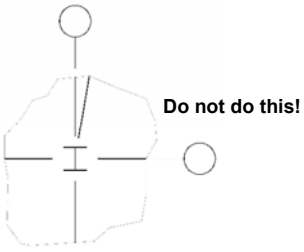
Configure framing so that no more than one beam frames to any one side of a column



Do not do this!

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Tip #23

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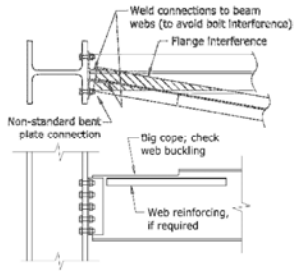
Configure framing so that no more than one beam frames to any one side of a column



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Tip #23

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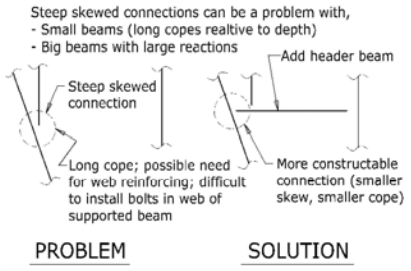
Head off steeply skewed connections



Tip #24

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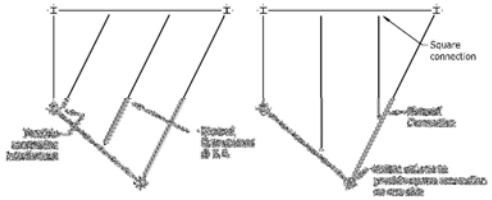
Configure framing to minimize skewed connections



Configure skewed framing to provide square connections at one end.

Square connections are less expensive than skewed connections.

Tip #25

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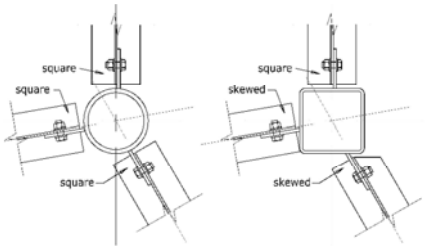
Favor pipe columns over square/rectangular HSS when there are skewed connections



All connections to pipe columns are square

Tip #26

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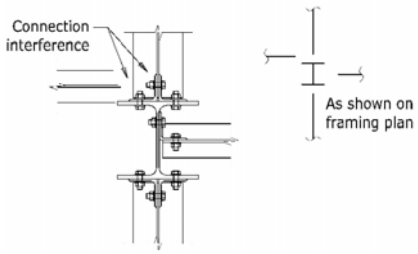
Watch out for connection interference where beams are slightly offset from columns



Tip #27

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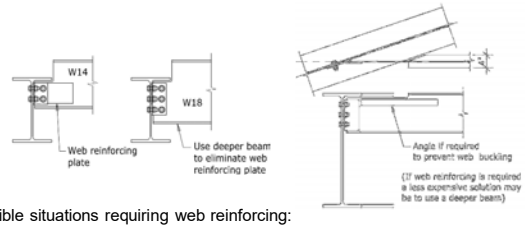
Increase beam depth to avoid web reinforcement



Possible situations requiring web reinforcing:

- Large copes with heavy reactions
- High beams framing to low girders
- Skewed beams with long copes

Tip #28

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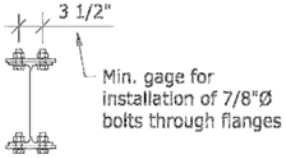
Beams with flange-bolted moment connections must have sufficiently wide flanges to install bolts



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

Tip #29

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Size members to have sufficient strength at the net section

Rule-of-thumb: Limit tension yield strength ratio to .075

$$\frac{\text{Required strength}}{\text{Usable strength}} = 0.75 \text{ (max.)}$$

Tip #30

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Communicate and coordinate

- Talk to the architect if their design is creating structural inefficiencies (i.e., adding cost).
- 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 #31

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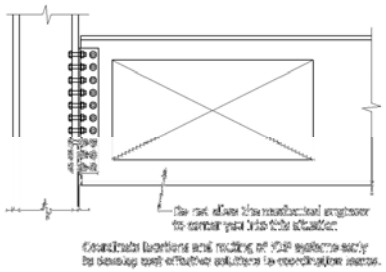
Here's what can happen when you don't anticipate, coordinate and communicate



Tip #32

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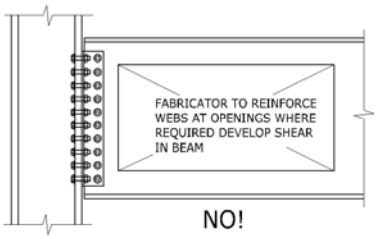
Do not delegate design of reinforcing around beam web openings



Tip #33

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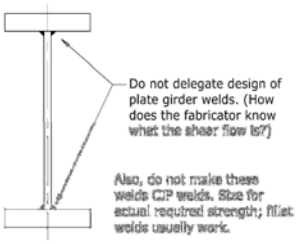
Do not delegate design of plate girder welds



Use fillet welds sized for required strength

Tips #34 & 35

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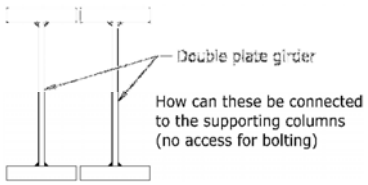
Think about how the connections will be designed & detailed even when delegating connection design



EOR's delegating connection design per AISC 303-16, Section 3.1 Option 3 are required to do this for all connections.

Tip #36

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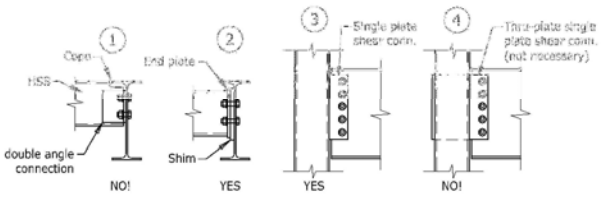
Configure HSS framing to simplify connections



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Tip #37

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Some welding tips to enhance constructability

- Strive for downhand or vertical welds
- Don't specify "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

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Tip #38

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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)

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Tip #39

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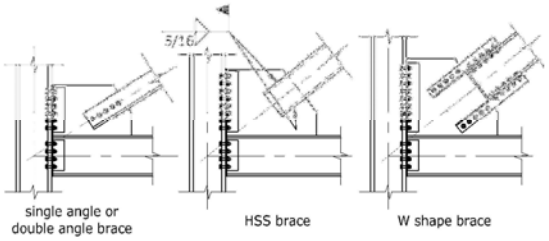
57

Select efficient diagonal braces



58

Tip #39

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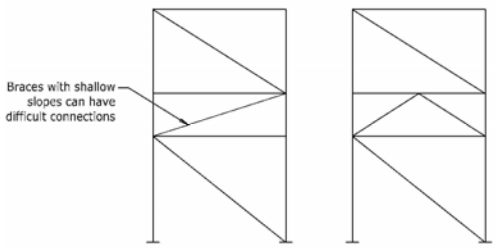
Configure slopes of diagonal braces at 35 to 55 degrees



59

Tip #40

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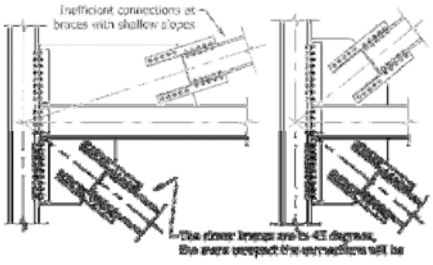
Configure slopes of diagonal braces at 35 to 55 degrees



60

Tip #40

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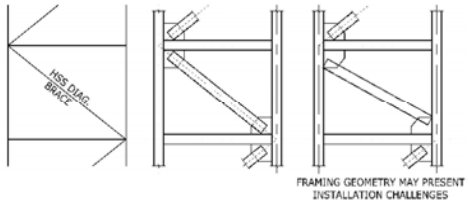
Verify that framing can be installed



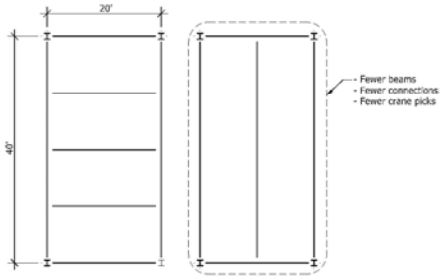
Braced frame shown. Similar conditions can occur in floor framing and trusses.

61

Tip #41

61

Configure framing to minimize the number beams

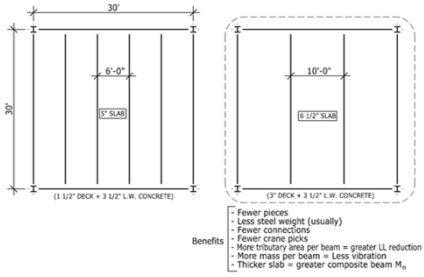


62

Tip #42

62

Maximize slab span to minimize the number of beams



63

Tip #43

63

For seismic design use R=3 when possible

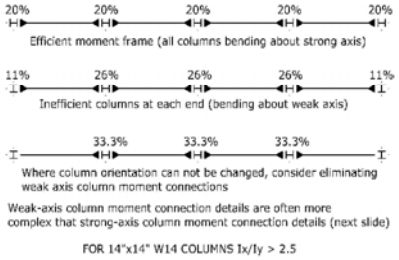
- There are significant connection and member design requirements imposed when the seismic response modification coefficient, "R" is > 3.
- *Ordinary* Steel Concentrically Braced Frames (R=3.25) and *Ordinary* Steel Moment Frames (R=3.5) are not so "ordinary"!

64

Tip #44

64

Orient columns in moment frames for strong axis bending

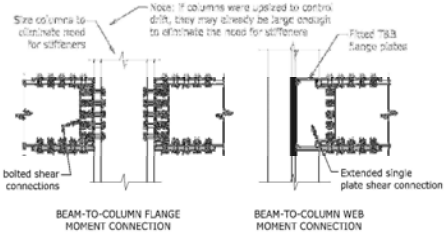


65

Tip #45

65

Orient columns in moment frames for strong axis bending



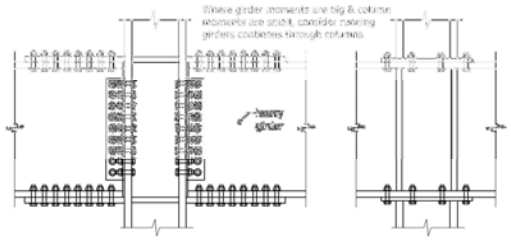
Strong axis beam-to-column moment connections are usually less complex than weak axis beam-to-moment connections

66

Tip #46

66

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

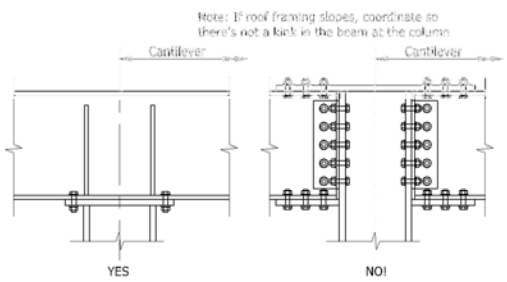


67

Tip #47

67

Run cantilevered roof beam over tops of columns



68

Tip #48

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Consider using ASTM A913 shapes for axial loaded members w/ large loads

- 65 ksi and 70 ksi shapes can reduce cost and simplify connections (versus ASTM A992)
- Available only for heavier shapes (consult producers for availability).
- 15th Edition AISC Manual has column compression capacity tables for both 65 ksi and 70 ksi (Tables 4-1b & 4-1c)
- Common uses: columns and trusses

69

Tip #49

69

Minimize the "gingerbread"

"Gingerbread" = little pieces of steel

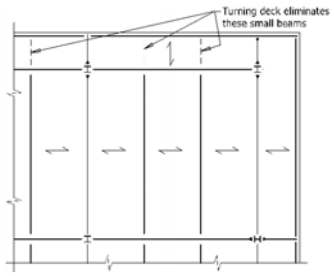
- Brace angles
- Relieving angles
- Bent plates
- Stiffeners
- Web doubler plates
- Little beams

70

Tip #50

70

Selectively turn slab spans to reduce "gingerbread"



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Tip #50

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Bonus constructability tips!

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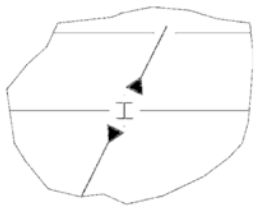
72

Avoid skewed beam-to-column moment connections



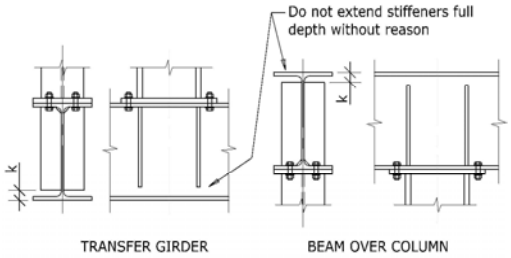
Difficult to detail

73

Tip #51

73

Avoid full depth stiffeners where possible



74

Tip #52

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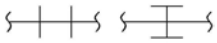
Orient columns on transfer girders w/ column webs parallel to girder webs



Yes No!

(80% of column area is in the flange.)

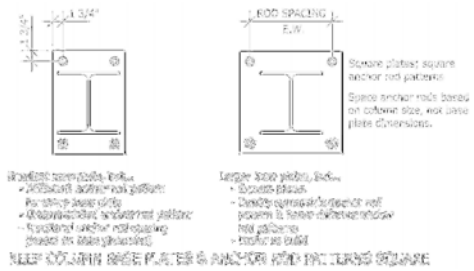
Same suggestion when girders w/ large reactions frame over columns.

75

Tip #53

75

Simplify base plates and anchor rod details



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Tip #54

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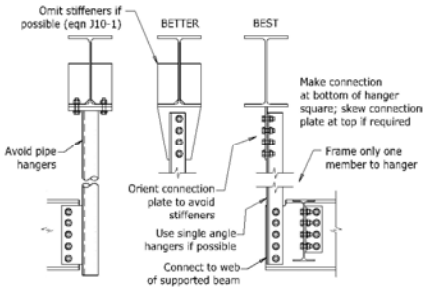
Some constructability tips for hangers



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Tip #55

77

Understand fabricator preferences regarding preferred connection details

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

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Tip #56

78

Avoid torsion in W shape beams

W shapes are inefficient in torsion.

Solutions:

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

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Tip #57

79

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 < ¾"
- Do not specify that camber be measured after erection.
- Compare camber cost to material cost

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Tip #58

80

Camber intelligently

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

81

Tip #58

81

Summary

To enhance constructability:

- Always be thinking about the connections (always be looking for kinked connections)
- Show the reactions, moments and axial forces
- Do not impose arbitrary constraints on connection design
- Delegate connection design
- Strive to keep connections square

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Summary

To enhance constructability:

- 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 and coordinate

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Thank you!

Questions?

Clifford Schwinger, PE
cschwinger@harmangroup.com

THE HARMAN GROUP
structural engineering
parking planning and design
PHILADELPHIA | NEW YORK

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