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There's always a solution in steel.

50 Tips For Designing Constructable Steel Buildings

Presented by
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structural STEEL

5

Webinar goal

To review easy ways to enhance the constructability of steel-framed structures.

6

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

7

Constructability defines the ease with which structures can be built.

Constructability = Economy

Four principles of constructability

8

Simplicity = Economy

Least weight *does not always* = Least cost

Fewer pieces = Greater economy

Efficient connection design = Reduced cost

9

Show the reactions

A significant percentage of cost is in the connections.

Excessively conservative connection design requirements do not enhance safety.

Tip #1

10

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

11

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:

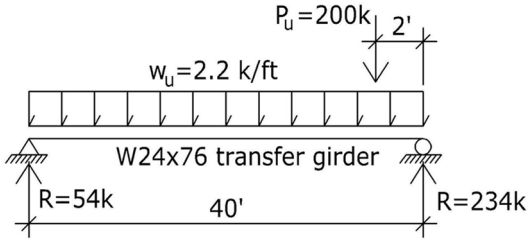
> "Connections shall be designed to support reactions occurring from uniform loads equal to 150% of the uniform load capacity of the beams from Table 3-6 in the AISC Steel Construction Manual."

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

Tip #1

12

Show the reactions



- From Table 3-6, 14th Edition AISC Manual maximum uniform load capacity for W24x76 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 connection strength!

Tip #1

13

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."

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

14

Provide moments & axial forces

Moment connections

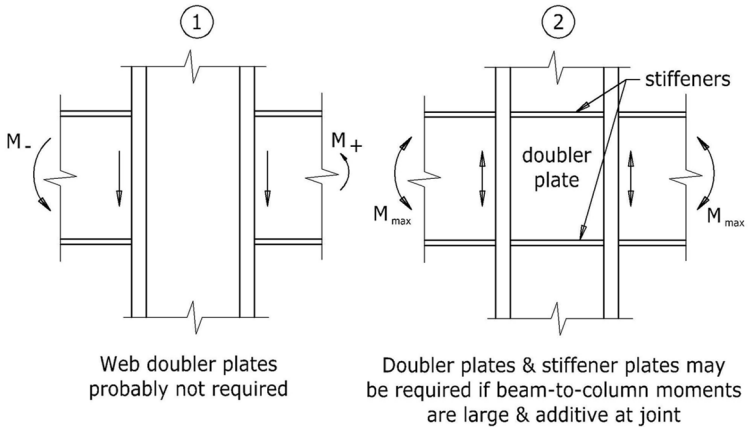
Axial loads in
- Hangers
- Drag struts
- Braced frames
- Truss members

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

Tip #2

15

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

16

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

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

17

Avoid notes such as this on your drawings:

"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

Tip #5

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

18

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

Bearing bolt shear strength values can be used for all of the above when STD or SSL holes are used with loads perpendicular to the slot. (Bolts *may* have to be pre-tensioned.)

Tip #5

19

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

20

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 2.4dtFu.

(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 ply 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

21

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

22

Permit the use of any size & 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 size and type when connection design is delegated to the fabricator.

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

Tip #8

24

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

25

Delegate connection design to the fabricator – *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:

(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 shop and erection drawings;

(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; and,

(e) What substantiating connection information, if any, is to be provided with the shop an erection drawings to the owner's designated representative for design.

Tip #9

26

Delegate connection design to the fabricator

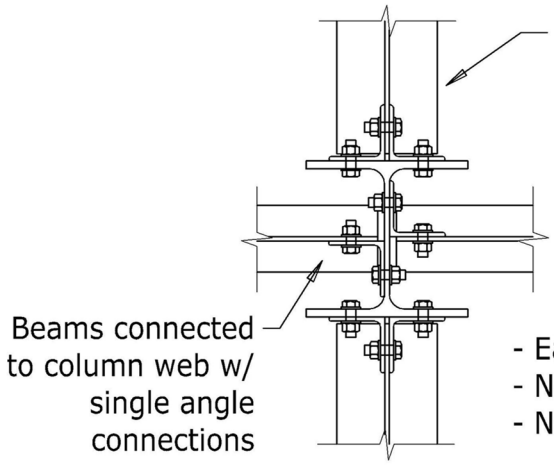
Possible note for delegating connection design when R=3,

"Structural steel connections shall be designed in accordance with the requirements of the building code and with AISC 360-10 using connection design procedures documented in publications such as the AISC *Engineering Journal*, the AISC *Steel Construction Manual*, 14th Edition and the AISC *Steel Construction Manual Design Examples*."

Tip #9

27

Frame girders to column flanges; beams to webs

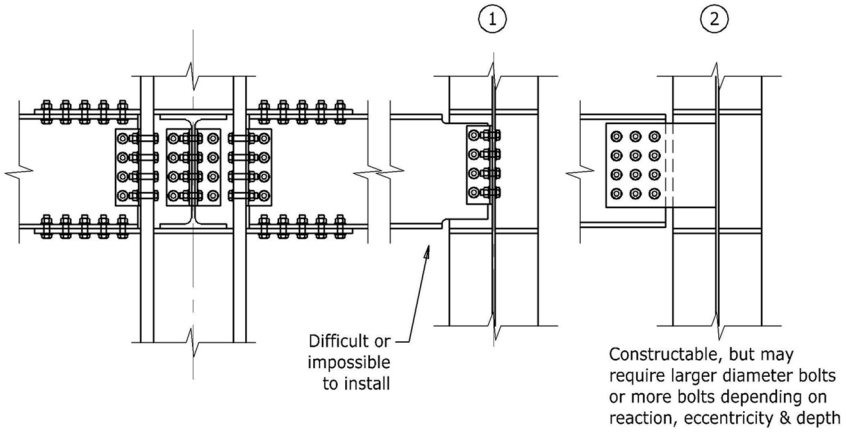


- Easy & safe to erect
- No shared bolts
- No copes

Tip #10

28

Size columns to eliminate need for stiffeners

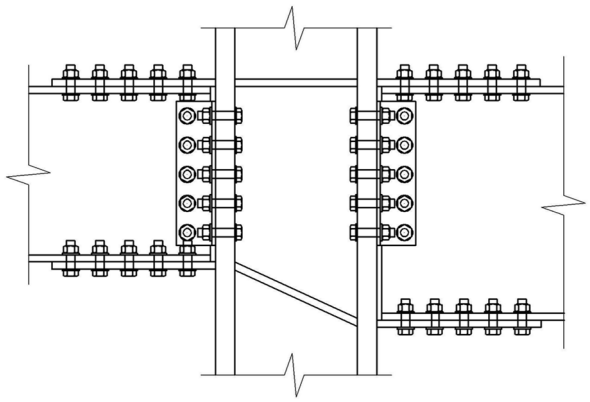


Stiffeners complicate connections

Tip #11

29

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

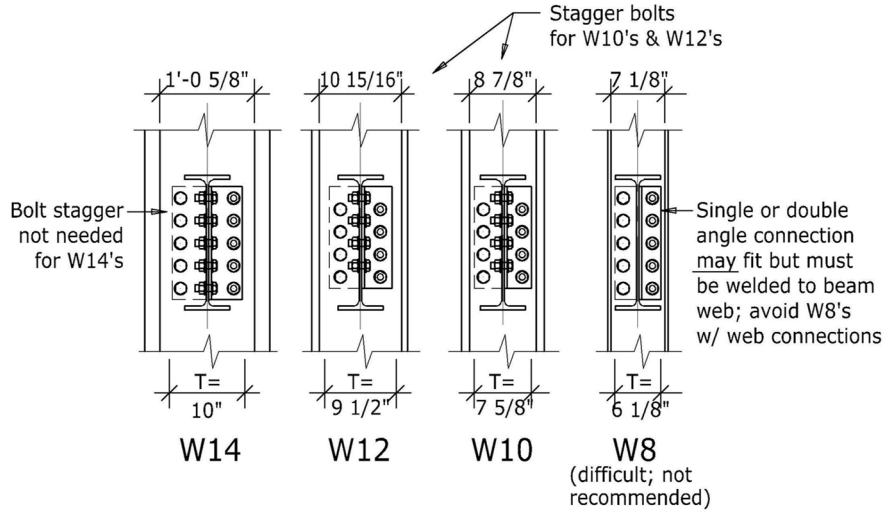


Square stiffeners are less expensive than skewed stiffeners

Tip #12

30

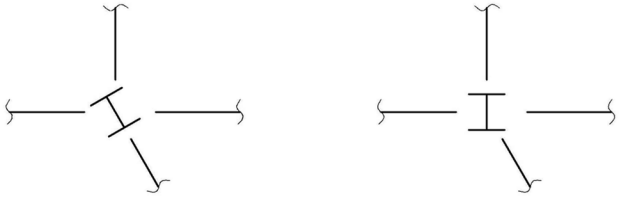
Use deepest practical column; avoid W8 columns with connections to web



Tip #13

31

Orient columns to minimize skewed connections



3 SKEWED CONNECTIONS
1 SQUARE CONNECTION

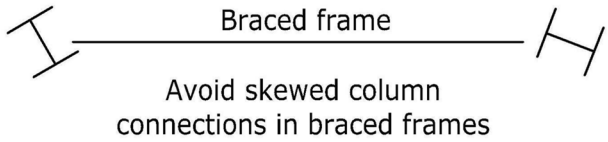
3 SQUARE CONNECTIONS
1 SKEWED CONNECTION

Square connections are less expensive than skewed connections.

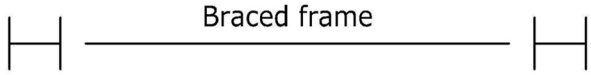
Tip #14

32

Orient columns in braced frames square



Avoid skewed column connections in braced frames

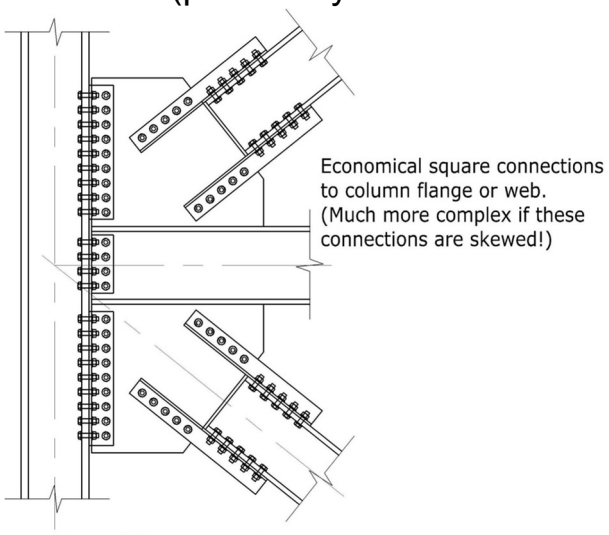


Orient columns to provide square connections in braced frames; preferably to column flanges

Tip #15

33

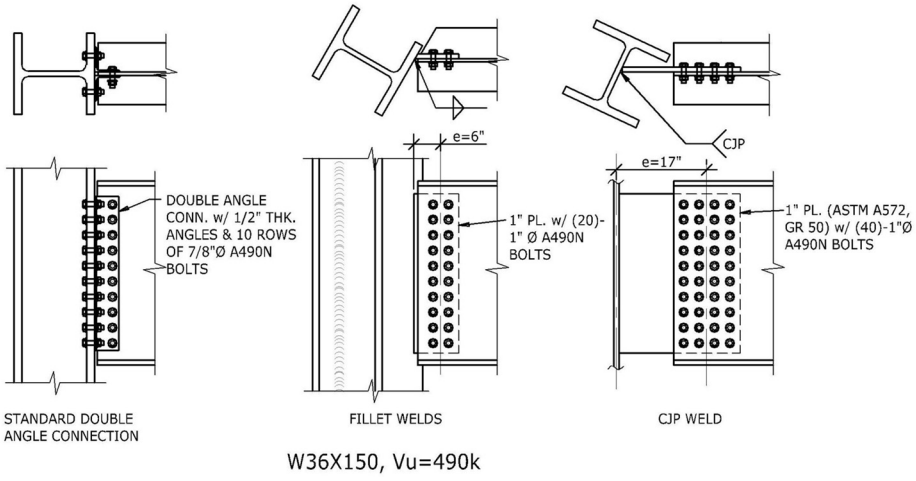
Orient columns in braced frames square to the beams and braces (preferably to the column flanges)



Tip #15

34

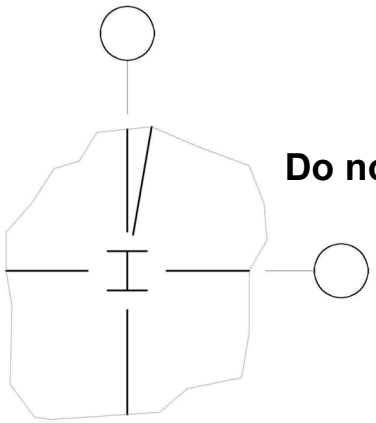
Frame members with very large reactions square to columns - preferably to the flanges.



Tip #16

35

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

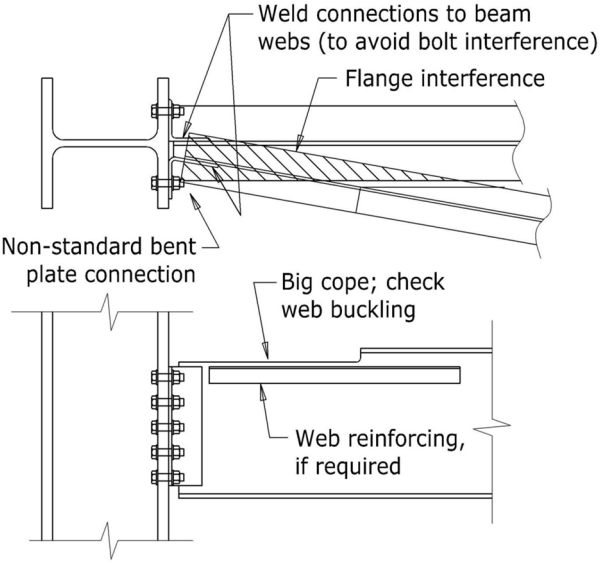


Do not do this!

Tip #17

36

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

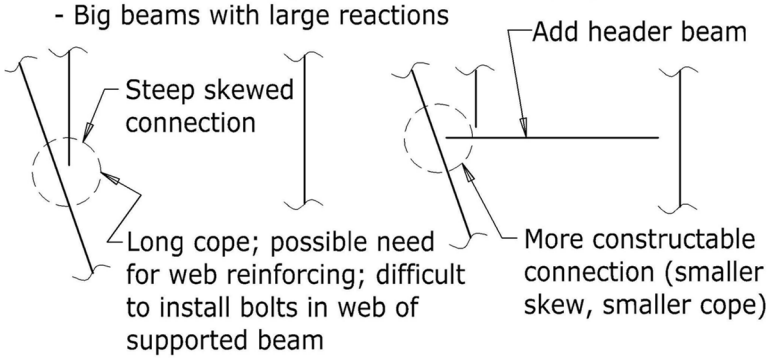


Tip #17

37

Head off steeply skewed connections

Steep skewed connections can be a problem with,
- Small beams (long copes realtive to depth)
- Big beams with large reactions

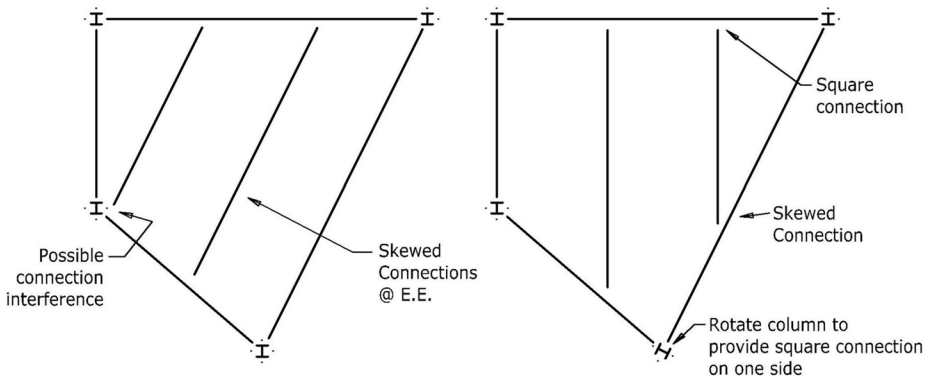


PROBLEM SOLUTION

Tip #18

38

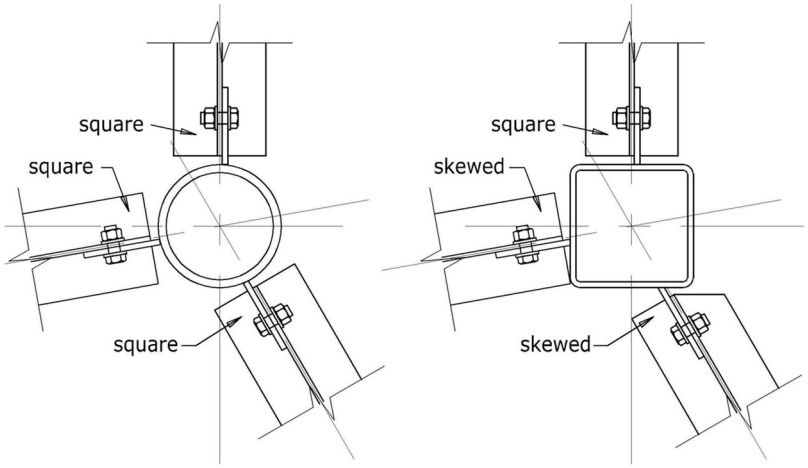
Configure framing to minimize skewed connections



Configure skewed framing to provide square connections at one end.
Square connections are less expensive than skewed connections.

Tip #19

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

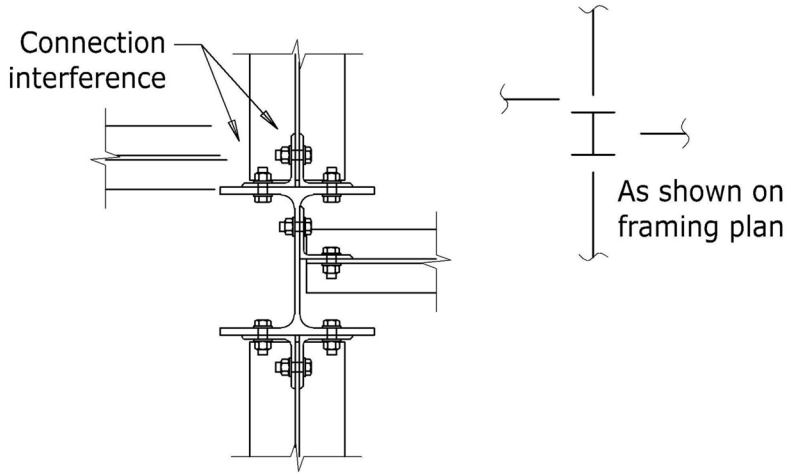


All connections to pipe columns are square

Tip #20

40

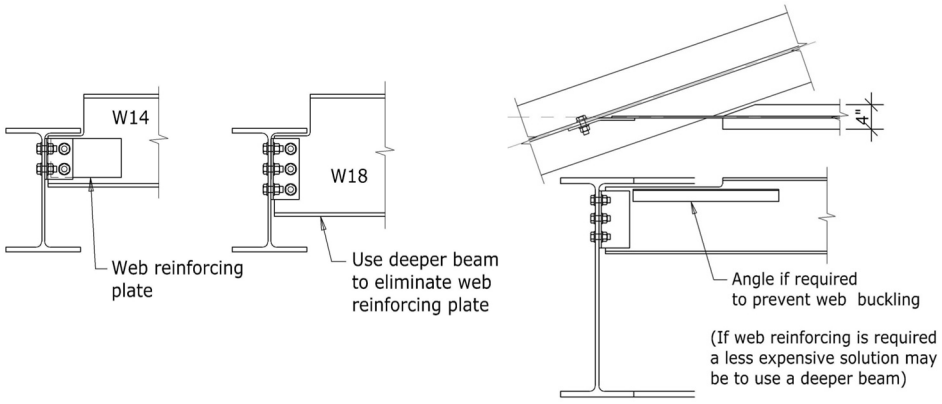
Watch out for connection interference where beams are slightly offset from columns



Tip #21

41

Increase beam depth to avoid web reinforcement



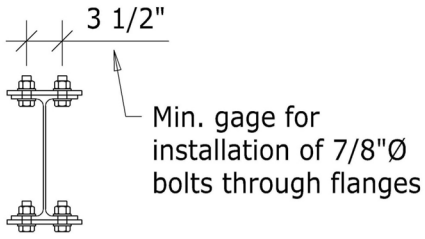
Possible situations requiring web reinforcing:

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

Tip #22

42

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 #23

43

Size members to have sufficient strength at the net section

Rule-of-thumb:

$$\text{Max. recommended stress ratio at gross section} = \frac{\text{Required strength}}{\text{Usable strength}} = 0.75 \text{ (max.)}$$

Tip #24

44

Questions?

45

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…")*

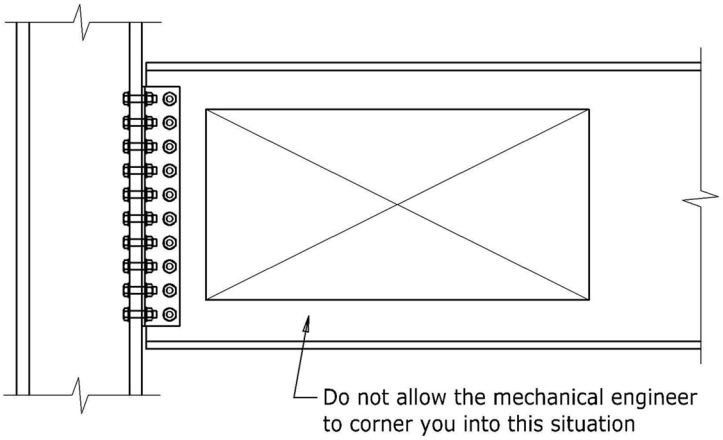
Ask your client in writing for the information that you need and give dates for when that information is needed.

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

Tip #25

46

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

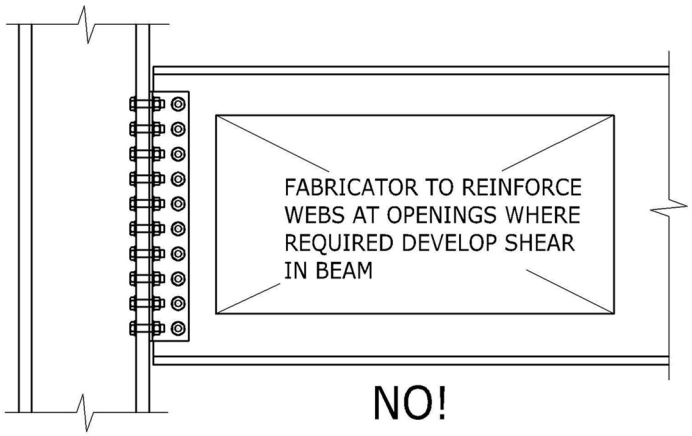


Coordinate locations and routing of MEP systems early to develop cost effective solutions to coordination issues.

Tip #26

47

Do not delegate design of reinforcing around beam web openings



Tip #27

48

Provide sufficient information on the drawings to minimize uncertainty among bidders

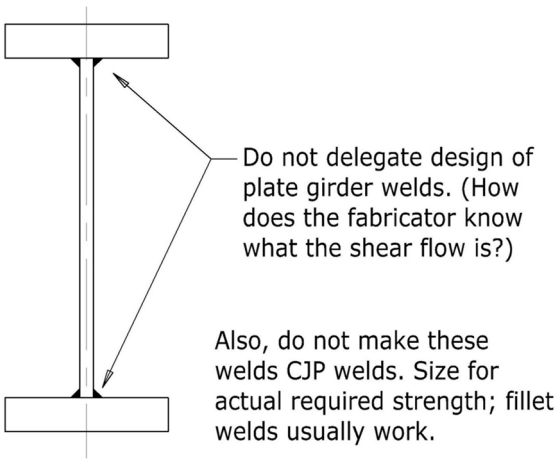
AISC 303-10 Section 3.1.1,

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

49

Do not delegate design of plate girder welds

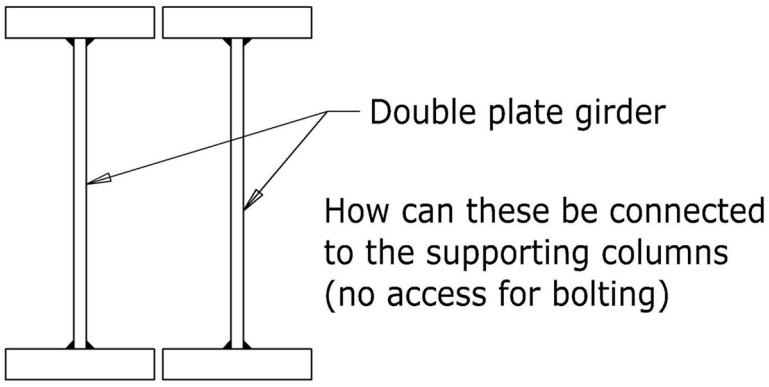


Use fillet welds sized for required strength

Tips #29 & 30

50

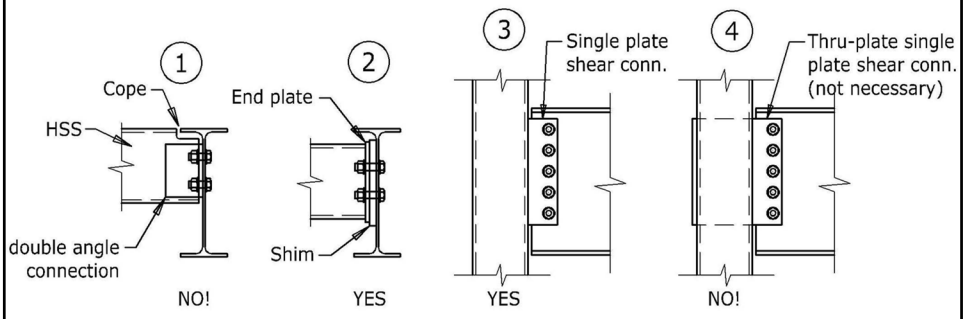
Think about how the connections will be detailed even when connection design is delegated to the fabricator



Tip #31

Configure HSS framing to simplify connections

51



Tip #32

Some welding tips to enhance constructability

52

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

53

Select efficient diagonal braces

Single angles: Good for small loads (tension only)

Double angles: Efficient connections (double shear bolts)

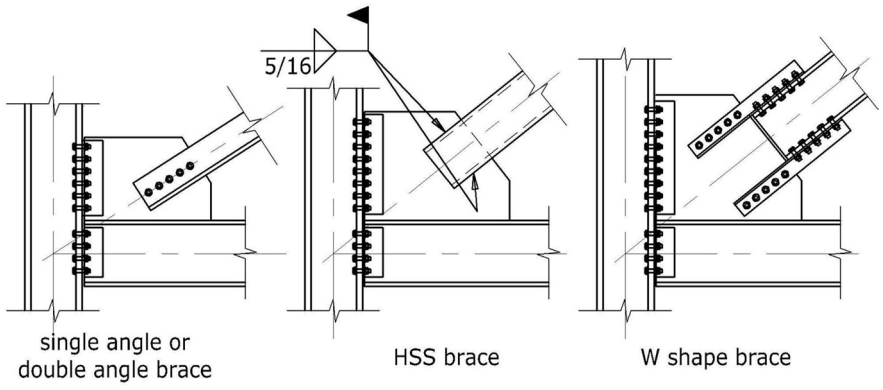
HSS's: Highest brace strength per pound of steel (field welding required for installation)

W shapes: Good for high axial loads (but connections can be more intricate than with the other brace types)

Tip #34

54

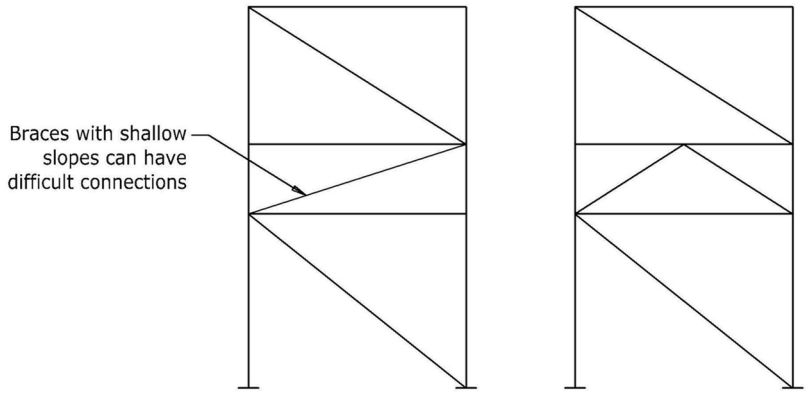
Select efficient diagonal braces



Tip #34

55

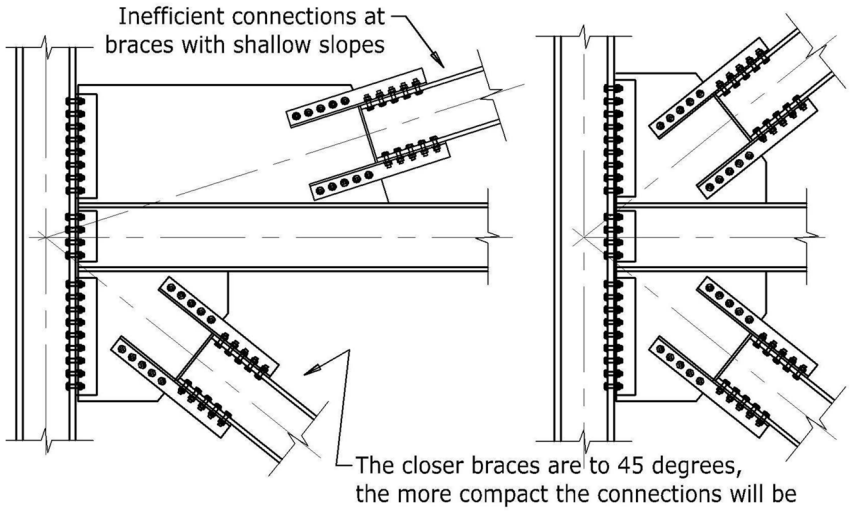
Configure slopes of diagonal braces at 35 to 55 degrees



Tip #35

56

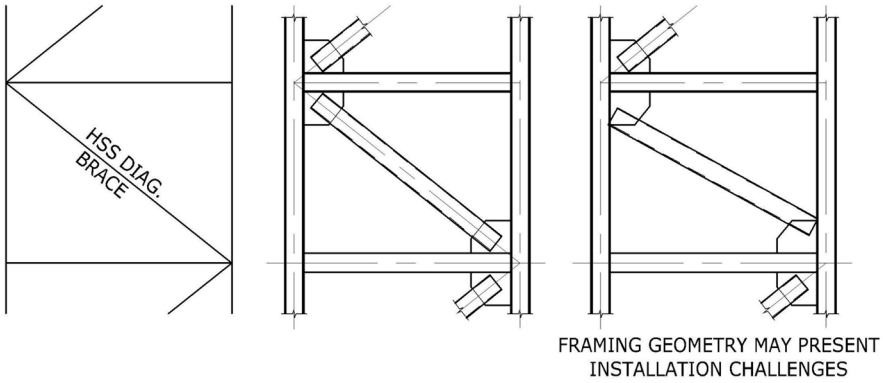
Configure slopes of diagonal braces at 35 to 55 degrees



Tip #35

Verify that framing can be installed

57

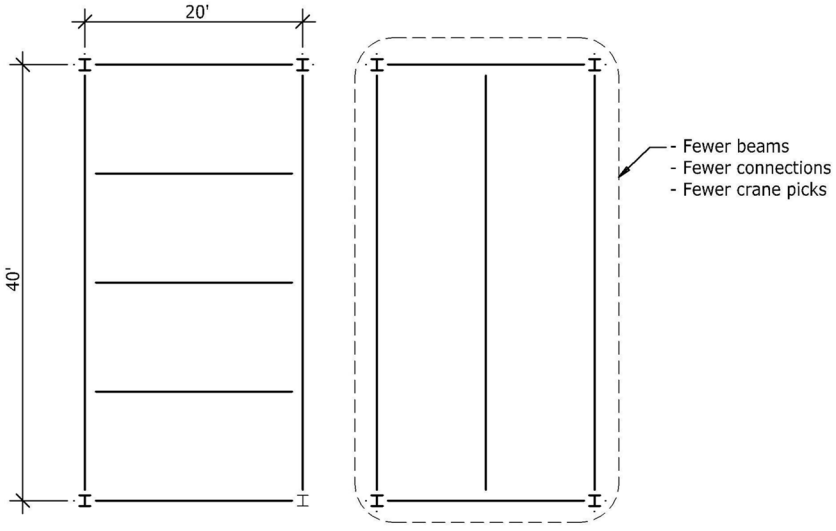


Braced frame shown. Similar conditions can occur in floor framing and trusses.

Tip #36

Configure framing to minimize the number beams

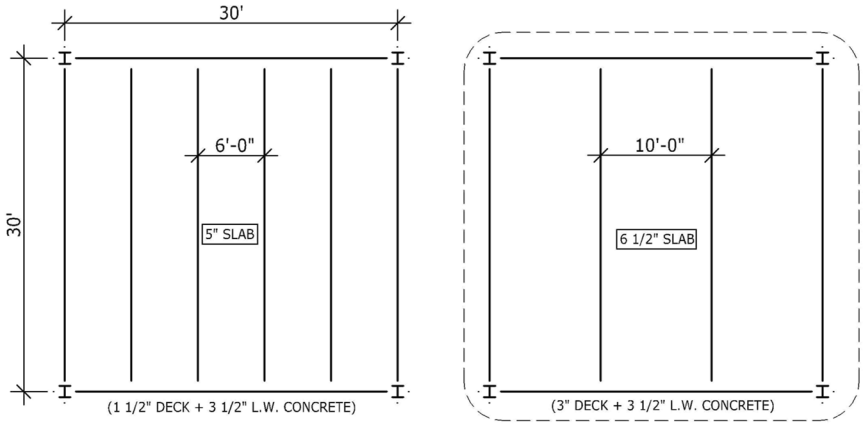
58



Tip #37

59

Maximize slab span to minimize the number of beams



Benefits
- Fewer pieces
- Less steel weight (usually)
- Fewer connections
- Fewer crane picks
- More tributary area per beam = greater LL reduction
- More mass per beam = Less vibration
- Thicker slab = greater composite beam M_n

Tip #38

60

For seismic design use R=3 when possible

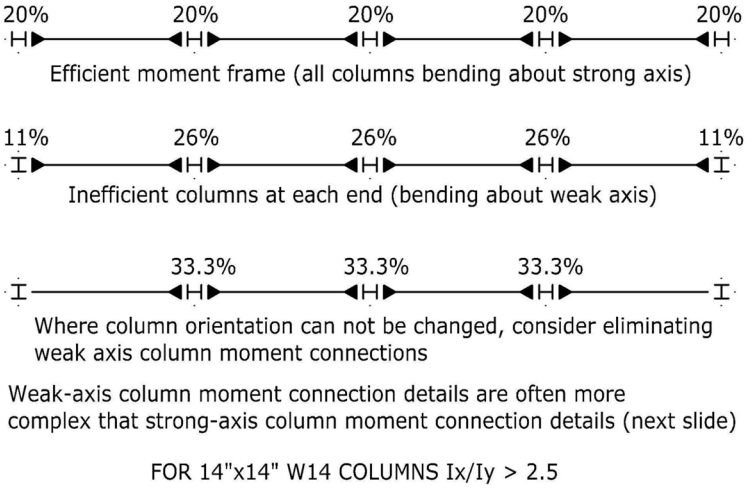
There are significant connection and member design requirements imposed when the seismic response modification coefficient, “R” is > 3.

Ordinary Steel Concentrically Braced Frames (R=3.25) and *Ordinary* Steel Moment Frames (R=3.5) are not so “ordinary”!

Tip #39

Orient columns in moment frames for strong axis bending

61



Weak-axis column moment connection details are often more complex that strong-axis column moment connection details (next slide)

FOR 14"x14" W14 COLUMNS Ix/Iy > 2.5

Tip #40

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

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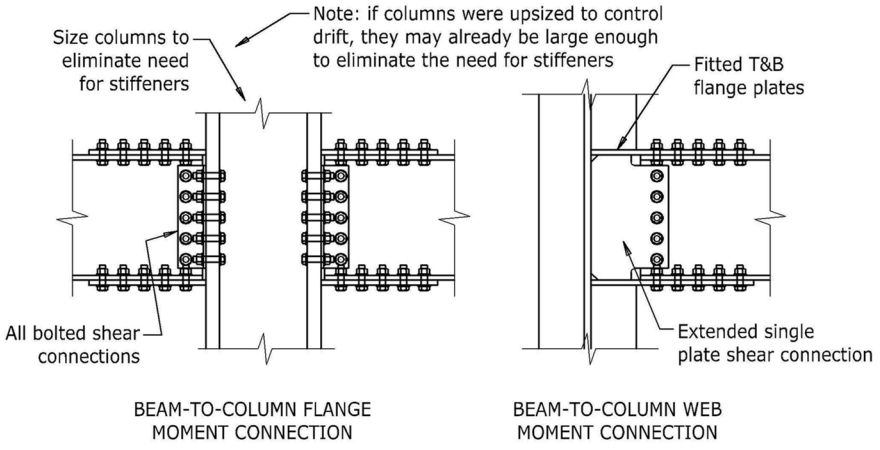

Tip #41

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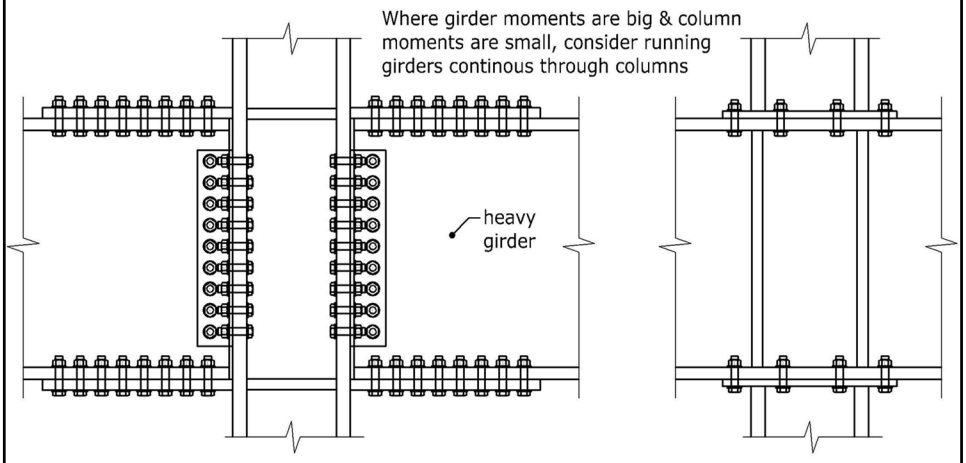
Run heavy moment-connected girders through columns to simplify flow of moment through the columns



Tip #42

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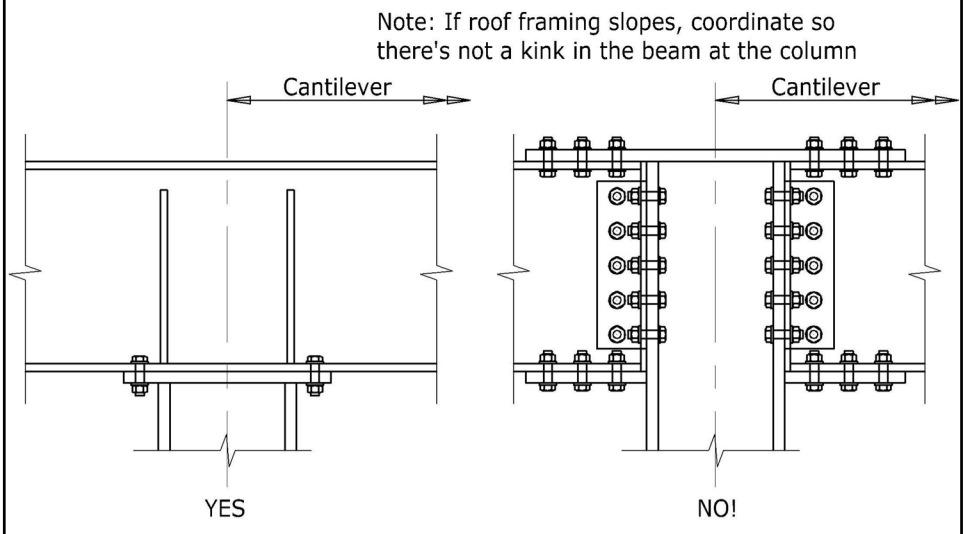
Run cantilevered roof beam over tops of columns



Tip #43

65

Minimize the “gingerbread”

“Gingerbread” = little pieces of steel.

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

Tip #44

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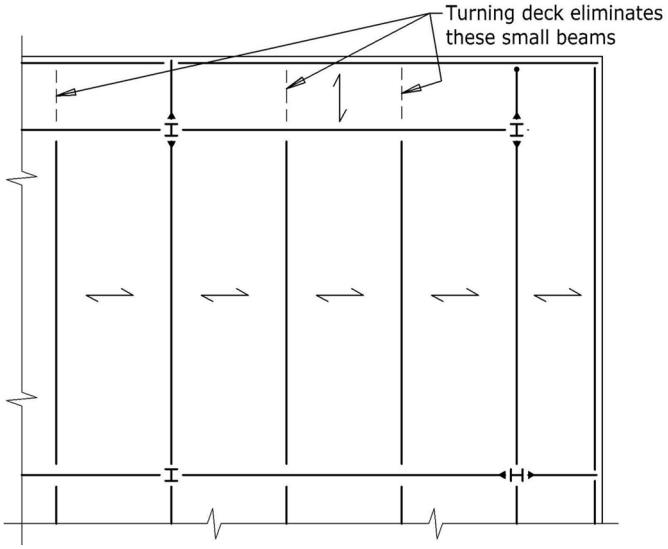
Selectively turn slab spans to reduce “gingerbread”



Tip #44

Avoid skewed beam-to-column moment connections

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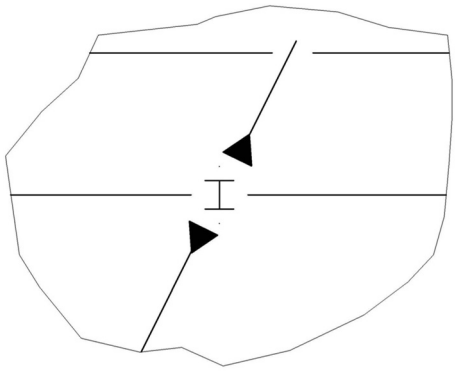

Difficult to detail

Tip #45

Avoid full depth stiffeners where possible

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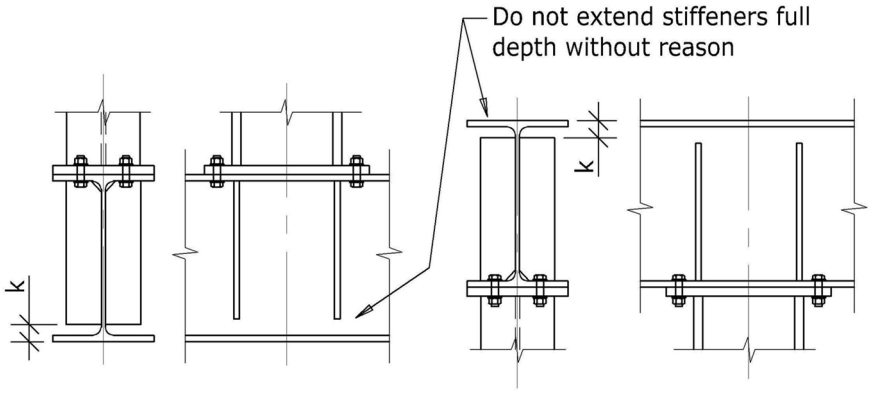
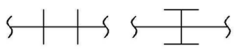


Also, orient columns with webs parallel to beam webs at these locations…



Tip #46

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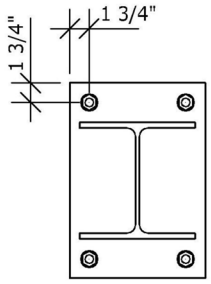
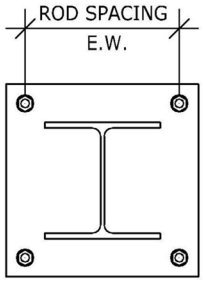
Simplify base plates and anchor rod details





Square plates; square anchor rod patterns

Space anchor rods based on column size, not base plate dimensions.

Smallest base plate, but...
- Diffferent anchor rod pattern for every base plate
- Unsymmetrical anchor rod pattern
- Fractional anchor rod spacing (based on base plate size)

Larger base plates, but...
- Square plates
- Doubly symmetric anchor rod pattern & fewer different anchor rod patterns
- Easier to build

KEEP COLUMN BASE PLATES & ANCHOR ROD PATTERNS SQUARE

Tip #47

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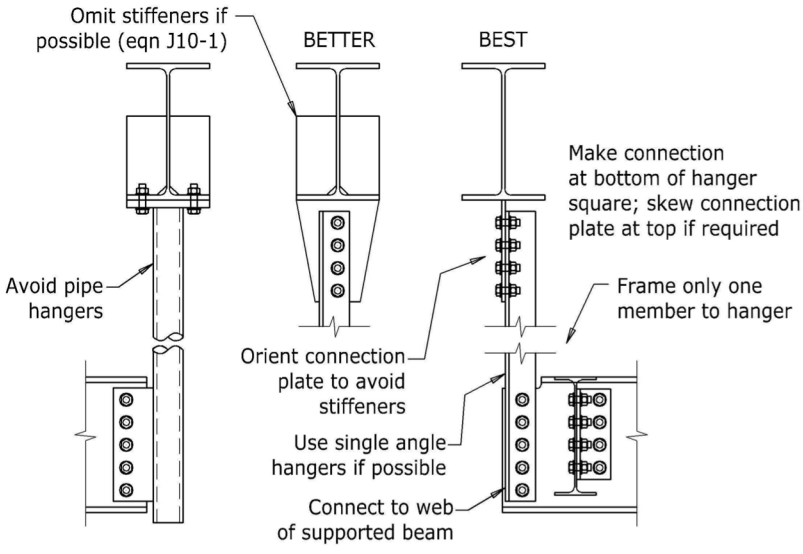
Some constructability tips for hangers



Tip #47

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Understand fabricator preferences regarding preferred connection details

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

Tip #48

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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

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- 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

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

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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

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Thank you!
Questions?

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Phone: 610-337-3360

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