50 Tips For Designing Constructable Steel Buildings

by Cliff Schwinger, P.E.

cschwinger@harmangroup.com

Seminar goal

To review easy ways to improve 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 is not always = Least cost

Fewer pieces = Greater economy

Efficient connection design = Reduced cost

Show the reactions… the *actual* reactions.

A significant percentage of cost is in the connections.

Excessively conservative connection design requirements are waste of money and do not enhance safety.

1

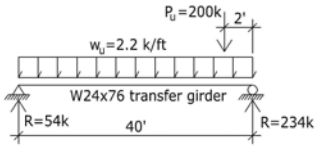
Show the reactions… the *actual* reactions.

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

Do not specify required connection strength based on the Table 3-6 maximum uniform load values. (Usually excessively conservative, but sometimes will result in insufficient connection strength.)

1

Show the reactions… the *actual* reactions.



- From Table 3-6, 13th 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!

1

Show the reactions… the *actual* reactions.

Example of what ***not*** to specify:

> "Shear connections shall be designed to support 150% of the Total Uniform Loads in Table 3-6 of the 13th Edition AISC Steel Construction Manual. The effects of concentrated loads near an end reaction shall also be considered."

1

Provide *actual* connection design moments and member forces

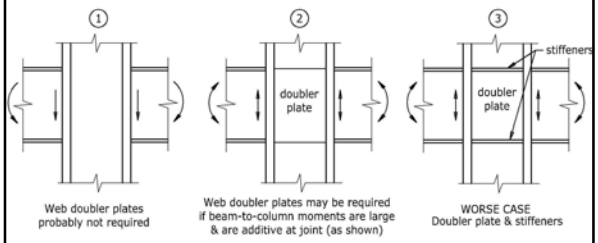
Moment connections

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.

2

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!

3

Require connections to be designed per the requirements of the building code, AISC 360-05 & AISC 341-05

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

4

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

Example of what ***not*** to specify:

"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 *usually* be used for all of the above. (They may have to be pre-tensioned.)

5

AISC 360-05, Section J1.10

Limitations on Bolted and Welded Connections

Pretensioned joints, ***slip-critical*** joints 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 columns 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: ….
(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.

5

AISC 341-05, Section 7.2

Bolted Joints

All bolts shall be ***pretensioned*** high strength bolts and shall meet the requirements for slip-critical faying surfaces….Bolts shall be installed in standard holes or in short-slotted holes perpendicular to the applied load. For brace diagonals, oversized holes shall be permitted when the connection is designed as a slip-critical joint… **The available shear strength of bolted joints using standard holes shall be calculated as that for bearing-type joints**….

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.

5

Allow the use of one-sided 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."

6

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

7

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

8

Permit fabricators the option of designing and detailing their preferred connections

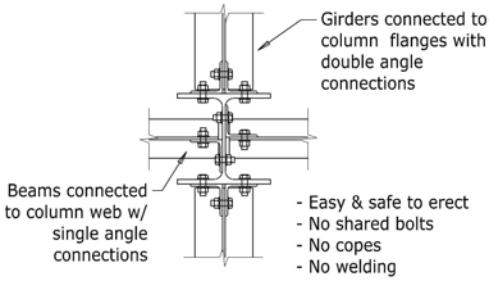
"Structural steel connections shall be designed in accordance with the requirements of the building code and with AISC 360-05 using connection design procedures documented in publications such as the AISC *Engineering Journal*, the AISC *Steel Construction Manual*, 13th Edition and the AISC *Steel Construction Manual Design Examples*."

Specify reasonable constraints as appropriate:

- Maximum permitted connection eccentricity on supports
- Fully rigid moment connections (versus semi-rigid)

9

Frame girders to column flanges; beams to webs



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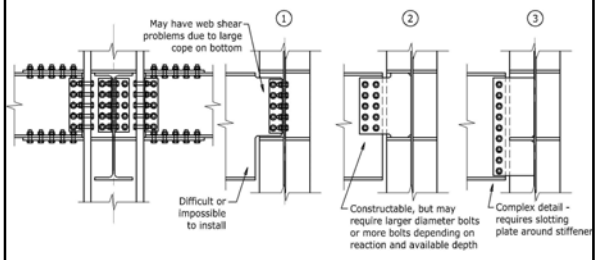
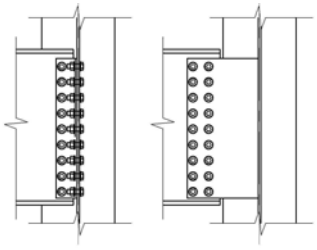
Size columns to avoid the need for stiffeners



11

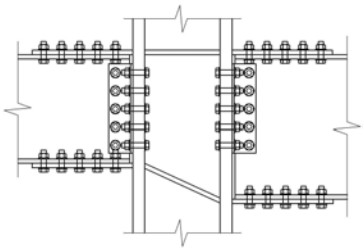
Size columns to avoid the need for stiffeners



Eliminating stiffeners allows the use of economical connections to the columns.

11

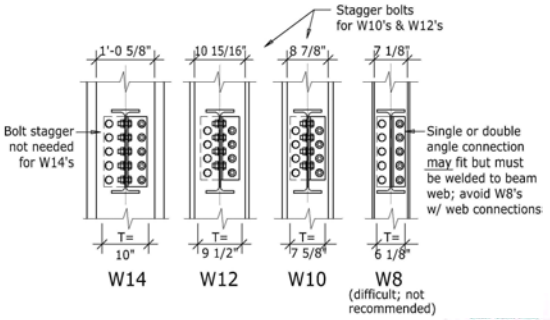
Where column stiffeners can't be avoided, make opposing beams the same depth



Square stiffeners are less expensive than skewed stiffeners

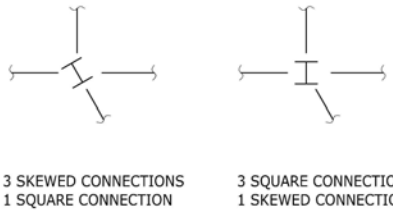
12

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



13

Orient columns to minimize skewed connections

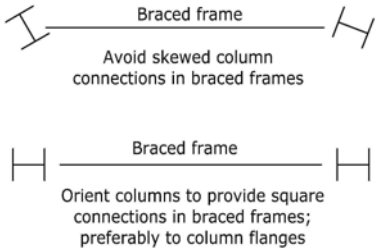


3 SKEWED CONNECTIONS
1 SQUARE CONNECTION

3 SQUARE CONNECTIONS
1 SKEWED CONNECTION

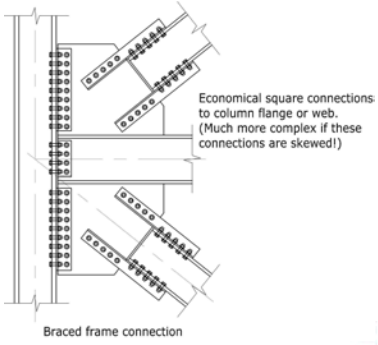
14

Orient columns in braced frames square



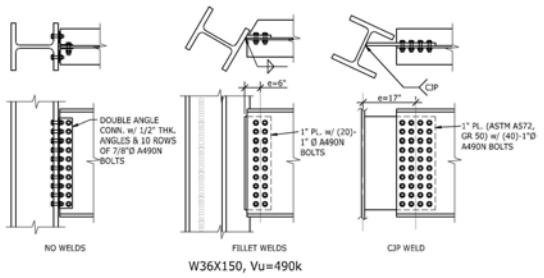
15

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



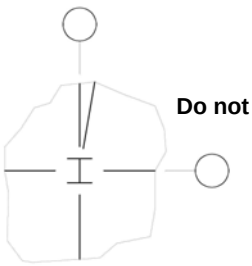
15

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



16

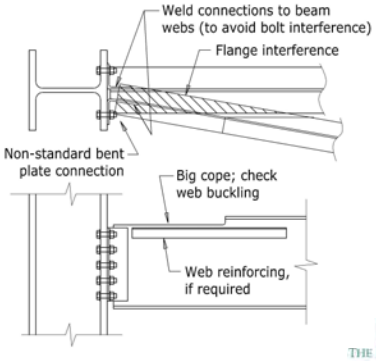
Configure framing so that no more than one beam frames to any one side of a column



Do not do this!

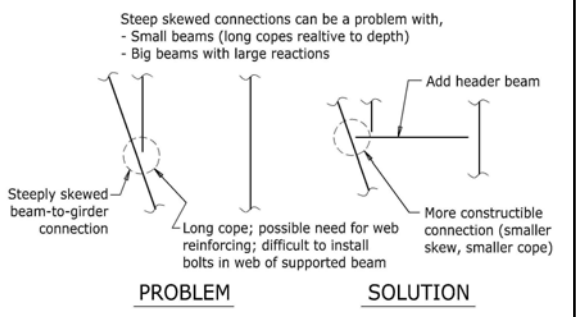
17

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



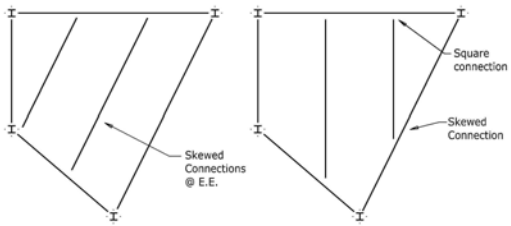
17

Head off steeply skewed connections



18

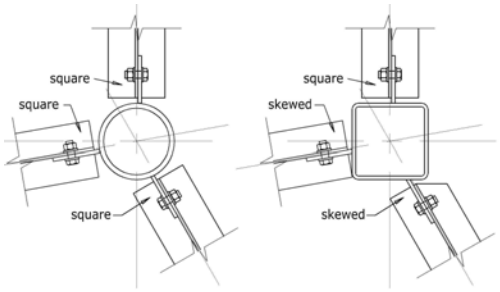
Configure framing to minimize skewed connections



Configure skewed framing to provide square connections at one end

19

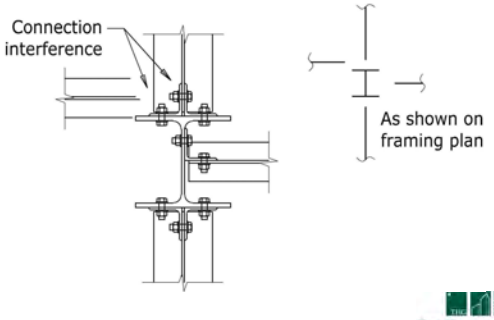
Favor pipe columns over square/rectangular HSS when there are skewed connections



All connections to pipe columns are square

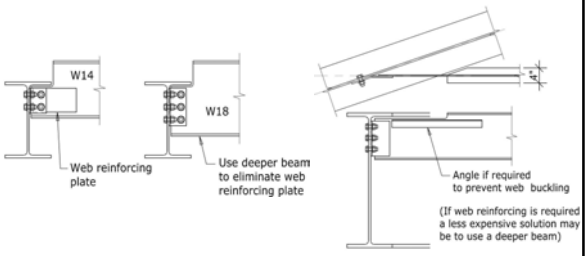
20

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



21

Increase beam depth to avoid web reinforcement

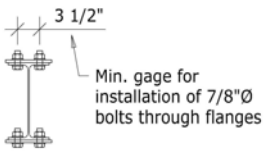


Possible situations requiring web reinforcing:

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

22

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.)

23

Size members to have sufficient strength at the net section

Rule-of-thumb:

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

24

Communicate and coordinate

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

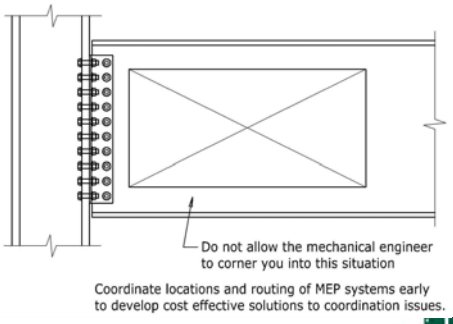
Failure to proactively communicate & coordinate early can box you into a corner. *("You should have told us this would be a problem two months ago…")*

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 head off coordination problems

25

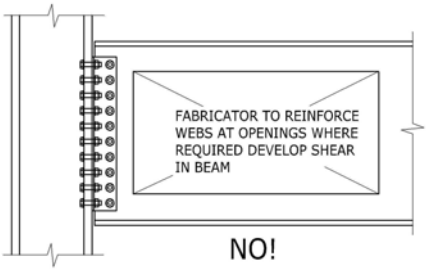
Here's what can happen when you don't anticipate, coordinate communicate…



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

26

Do not delegate design of reinforcing around beam web openings



27

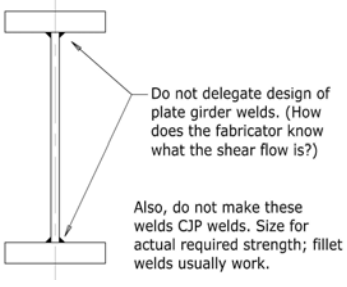
Provide sufficient information on the drawings to minimize uncertainty among bidders

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.

28

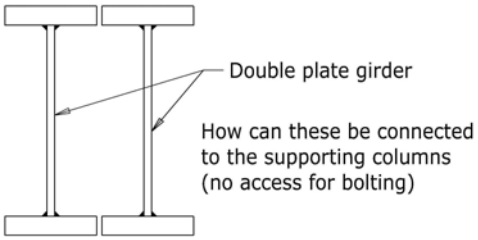
Do not delegate design of plate girder welds



Use fillet welds sized for required strength

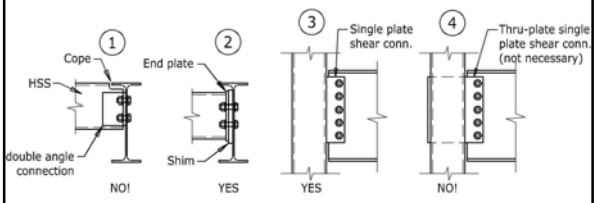
29 & 30

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



31

Configure HSS framing to simplify connections



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

33

Select efficient diagonal braces

Single angles: Good for small loads (tension only)

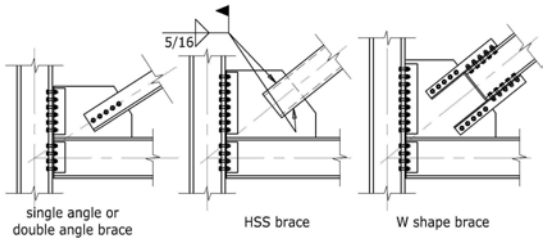
Double angles: Efficient connections (double shear bolts)

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)

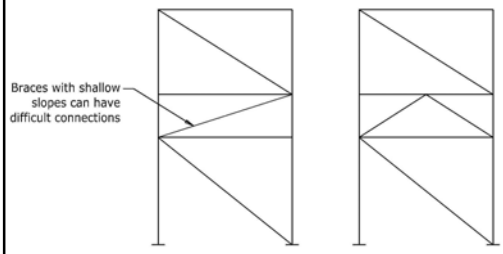
34

Select efficient diagonal braces



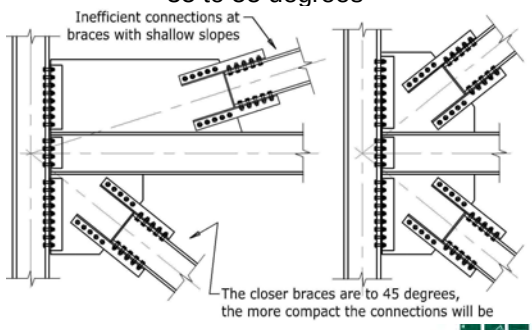
34

Configure slopes of diagonal braces at 35 to 55 degrees



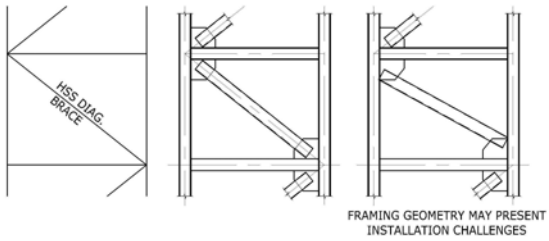
35

Configure slopes of diagonal braces at 35 to 55 degrees



35

Verify that framing can be installed



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

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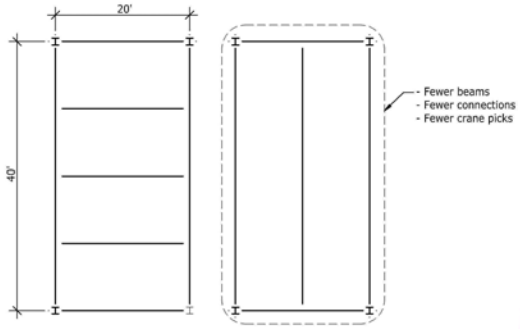
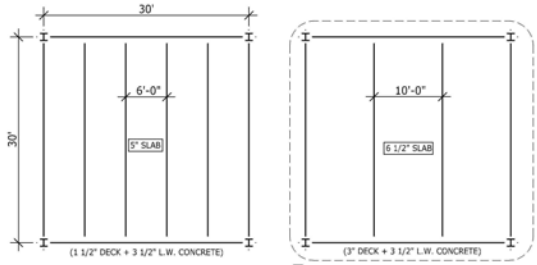
Configure framing to minimize the number beams



37

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

38

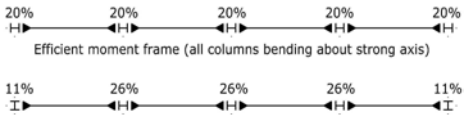
For seismic design use R=3 when possible

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

Ordinary Concentric Steel Braced Frames and Ordinary Steel Moment Frames are not so “ordinary”!

40

Orient columns in moment frames for strong axis bending



Efficient moment frame (all columns bending about strong axis)

Inefficient columns at each end (bending about weak axis)

Where column orientation can not be changed, consider eliminating weak axis column moment connections

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

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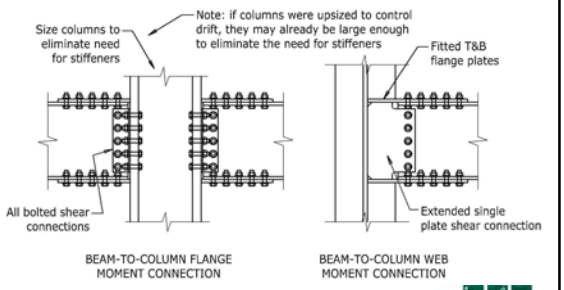
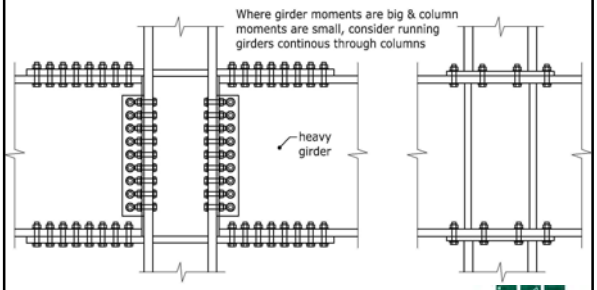
Strong axis beam-to-column moment connections are generally less complex than weak axis beam-to-column moment connections



41

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



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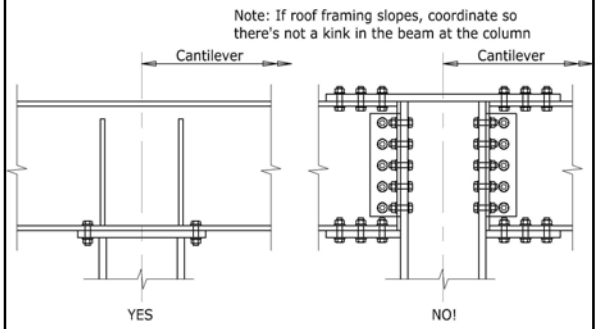
Run cantilevered roof beam over tops of columns



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Minimize the “gingerbread”

“Gingerbread” = little pieces of steel.

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

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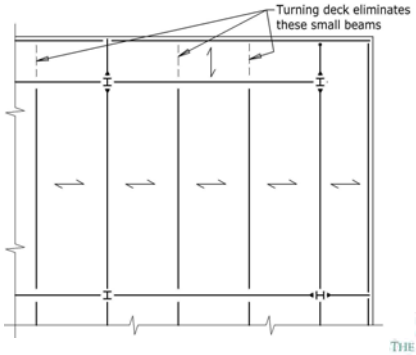
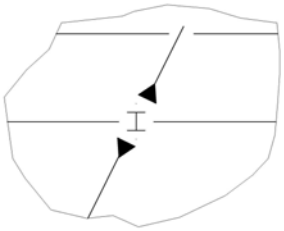
Selectively turn slab spans to reduce “gingerbread”



44

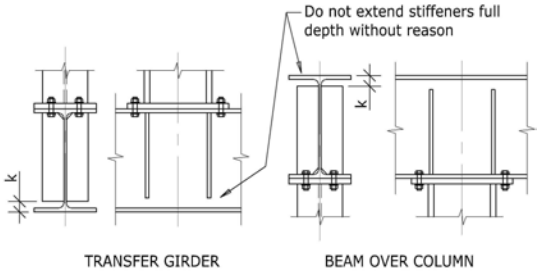
Avoid skewed beam-to-column moment connections



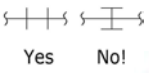
Difficult to detail

45

Avoid full depth stiffeners where possible



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



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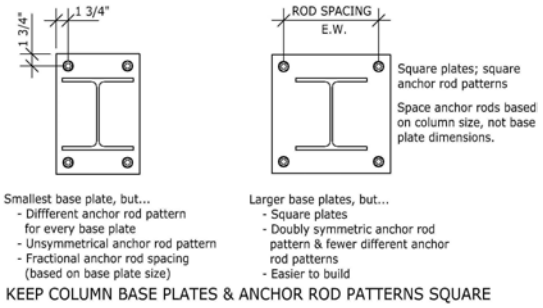
Simplify base plates and anchor rod details



KEEP COLUMN BASE PLATES & ANCHOR ROD PATTERNS SQUARE

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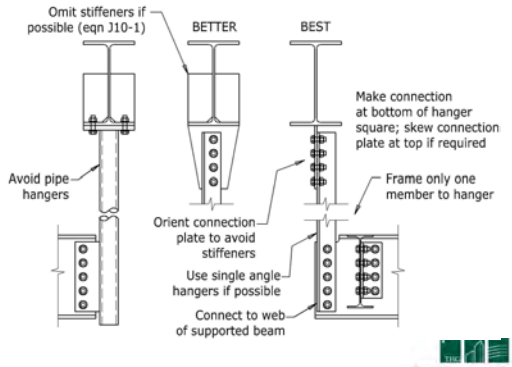
Some constructability tips for hangers



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Understand fabricator preferences regarding preferred connection details

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

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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

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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
- Rule-of-thumb: maximum camber = beam depth /10

(See AISC website for more camber guidelines.)

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Summary

To enhance constructability,

- Think about the connections
- Show the actual reactions, moments & axial forces
- Do not impose arbitrary constraints on 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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structural engineers
parking consultants

Thank you!

Questions?

cschwinger@harmangroup.com

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