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Kinked Connections
July 25, 2019

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Course Description

Kinked Connections – What Are They And How to Deal With Them
July 25, 2019

"Kinked connections" are those where loads flowing through the connections follow an eccentric load path, creating secondary moments and stresses. Kinked connections, if not properly addressed during design, can add unnecessary cost and complexity to a structure, and can lead to problems and headaches for designers, including RFIs and change orders. This webinar will review the need for engineers to find kinked connections in their models during design, and either eliminate the kinks or deal with them. Examples of various kinked connection configurations will be reviewed, and the role of the AISC Code of Standard Practice will be discussed.

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Learning Objectives

- List connections that have well-established parameters for safely addressing eccentricity, as provided in the AISC *Steel Construction Manual*.
- List the two options for how to treat member reinforcing at connections, according to the AISC *Code of Standard Practice*.
- Describe the benefits of creating thoughtful conceptual details during the design phase of a project.
- Explain why engineers should be aware of the potential negative effects of eccentric structural load paths.

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Kinked Connections

What Are They and How To Deal With Them

July 25, 2019

Cliff Schwinger, PE

THE HARMAN GROUP
structural engineering
parking planning and design

PHILADELPHIA | NEW YORK

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Seminar Objectives

- What are "kinked connections"?
- How to spot them
- How to deal with them
- Examples
- Review EOR's responsibility (per ANSI/AISC 303-16) regarding how to deal with all connections, including kinked connections.

9

Survey question

What is your primary role?

1. EOR
2. Fabricator
3. Erector
4. Connection designer
5. Contractor
6. Educator
7. Student
8. Other

10

What are Kinked Connections?

Connections where loads follow irregular, 3-dimensional, jogging load paths.

Smooth load path

Kinked load path
(possible problem)

Kinked connections induce *secondary stresses* in members.

11

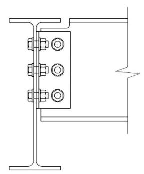
What are Kinked Connections?

"Common eccentricities" versus "unusual eccentricities"

- Most standard shear connections have small eccentricities (common eccentricities) which are readily addressed by connection designers.
- The term "kinked connections" in this presentation focuses on connections with unusual eccentricities that are often not fully appreciated by the EOR during design.

12

Common connection eccentricities



Common connection eccentricities

Double-Angle Connections

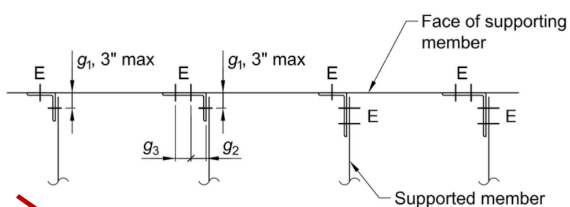
DESIGN TABLE DISCUSSION (TABLES 10-1, 10-2 AND 10-3) **10-9**

The eccentricity on the supported side of double-angle connections may be neglected for connections with a single vertical row of bolts through standard or short-slotted holes with dimension *a* [see Figure 10-4(a)] not exceeding 3 in. The eccentricity should be considered for the design of double-angle connections with two or more vertical rows of bolts on the supported side of the connection and for the design of double-angle connections welded to the supported member.

To provide for flexibility, the maximum angle thickness for use with workable gages should be limited to 5/8 in. Alternatively, the shear-connection ductility checks illustrated in Part 9 can be used to justify other combinations of gage and angle thickness.

Common connection eccentricities

Single-Angle Connections



Notes: E indicates that eccentricity must be considered in this leg.
Gages g_1, g_2 and g_3 are workable gages as shown in Table 1-7A.

Fig. 10-14. Eccentricity in angles.

Common connection eccentricities

Single-Plate Shear Connections

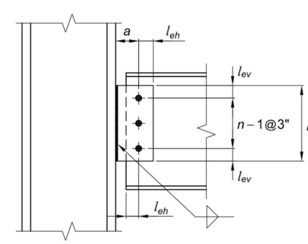


Fig. 10-11. Single-plate connection—Conventional Configuration.

10-88 DESIGN OF SIMPLE SHEAR CONNECTIONS

Table 10-9
Design Values for Conventional Single-Plate Shear Connections

n	Hole Type	e, in.	Maximum t_p or t_w, in.
2 to 5	SSLT	$a/2$	None
	STD	$a/2$	$d/2 + 1/16$
6 to 12	SSLT	$a/2$	$d/2 + 1/16$
	STD	a	$d/2 - 1/16$

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Common connection eccentricities

Extended Single-Plate Shear Connections

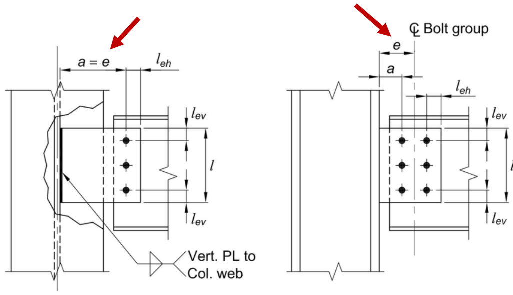

Fig. 10-12. Single-plate connection—Extended Configuration.

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17

Common connection eccentricities

Beam web shear splices

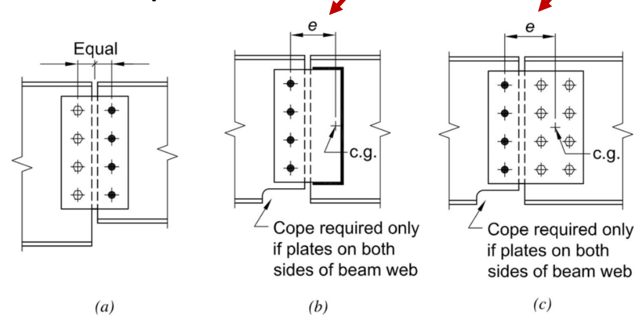


Fig. 10-16. Plate-type shear splices.

18

Common connection eccentricities

Miscellaneous eccentricities at offset beam-to-column connections

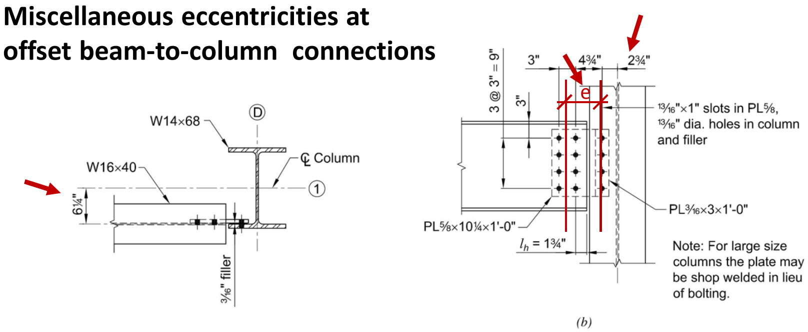


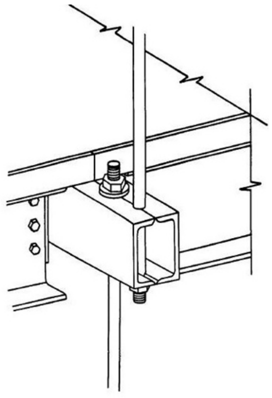
Fig. 10-29. Offset beam connected to column.

19

So what is a "kinked connection"?

20

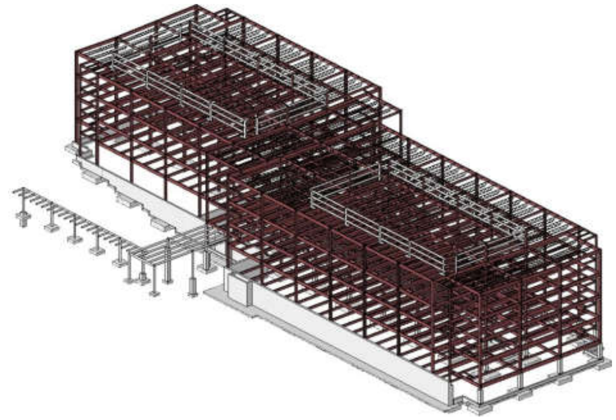
What is a "kinked connection"?



As Built

21

Will your model flag the kinked connections?



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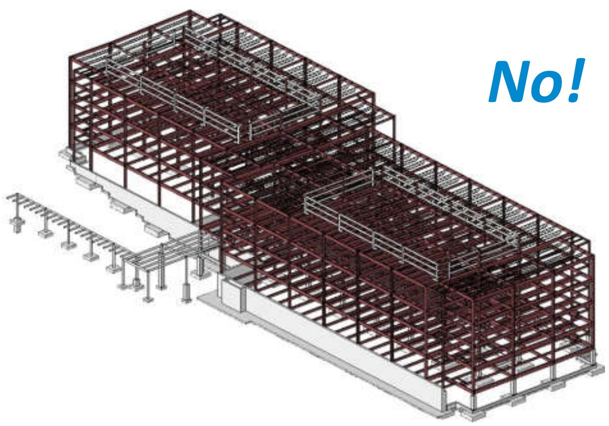
Will your model flag the kinked connections?



No!

23

Why is awareness of kinked connections important?

- Kinked connections induce secondary stresses in members.
- Failure to consider the secondary stresses can result in connection failure.
- Secondary stresses usually add complexity and cost to connection details.
- Failure to consider kinked connection details during design will lead to RFI's, arguments, and change orders during construction.

24

Why the label, "kinked connections"?

Why the label, *"kinked connections"* ?

- "It's easy to spot a yellow car when you're always thinking of a yellow car."

Why the label, *"kinked connections"* ?

- "It's easy to spot a yellow car when you're always thinking of a yellow car."
- It's easier to spot kinked connections when you're always thinking of kinked connections

Why the label, *"kinked connections"* ?

- "It's easy to spot a yellow car when you're always thinking of a yellow car."
- It's easier to spot kinked connections when you're always thinking of kinked connections
- It's easier to spot problems if they have a name.

Connection Design Responsibility

29

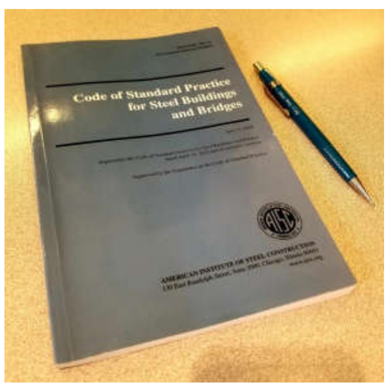
Connection design responsibility

The Code of Standard Practice is the roadmap for navigating how to deal with connections on the contract documents.

30

Connection design responsibility

Recommended summer reading



31

Survey question

Have you read the ANSI/AISC 303-16 Code of Standard Practice?

1. Yes
2. No
3. I read a few pages.

32

Connection design responsibility

From Section 1.9:

1.9.2. The *structural engineer of record* shall be responsible for the structural adequacy of the design of the structure in the completed project. The *structural engineer of record* shall not be responsible for the means, methods and safety of erection of the *structural steel* frame. See also Sections 3.1.4 and 7.10.

33

Connection design responsibility

From 4.4.1 Commentary:

From the inception of this Code, AISC and the industry in general have recognized that only the *owner's designated representative for design* has all the information necessary to evaluate the total impact of *connection* details on the overall structural design of the project. This authority traditionally has been exercised during the approval process for the *approval documents*. The *owner's designated representative for design* has thus retained responsibility for the adequacy and safety of the entire structure since at least the 1927 edition of this Code.

34

Connection design responsibility

4.4. Approval

Except as provided in Section 4.5, the *approval documents* shall be submitted to the *owner's designated representatives for design* and construction for review and approval. The *approval documents* shall be returned to the *fabricator* within 14 calendar days.

Final *substantiating connection information*, if any, shall also be submitted with the *approval documents*. The *owner's designated representative for design* is the final authority in the event of a disagreement between parties regarding the design of *connections* to be incorporated into the overall *structural steel* frame. The *fabricator* and licensed engineer in responsible charge of *connection* design are entitled to rely upon the *connection* design criteria provided in accordance with Section 3.1.1. *Revisions* to these criteria shall be addressed in accordance with Sections 9.3 and 9.4.

35

Three options for connection design

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

36

Three options for connection design

(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.

37

"Member reinforcement at connections"

- "Member reinforcement at connections" is usually reinforcement required to address secondary stresses.
- "Member reinforcement at connections" is member design, not connection design (however it can be delegated to the fabricator's licensed connection design engineer when using Option #3B).

38

"Concept connection details"

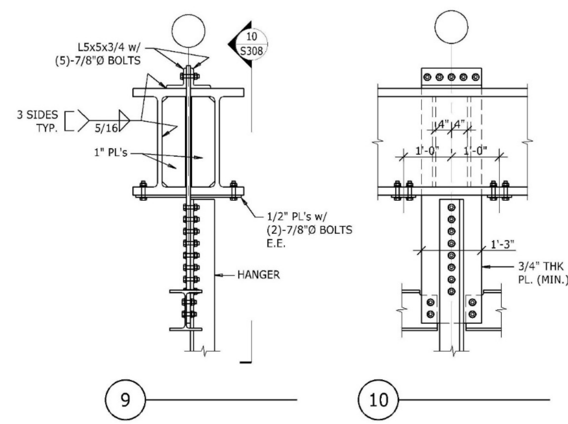
Details showing,

- Connection configurations
- Member reinforcement at the connections ("…conceptual configuration of reinforcement…")

Concept connection details serve as a basis for connection design by the fabricator's licensed connection design engineer and provide a way for fabricators bidding the project to estimate the cost of unusual connections.

39

Concept connection detail



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Why provide concept connection details?

Why provide "concept connection details"?

- Required by the Code of Standard Practice ("…conceptual configuration of reinforcement…").
- Allows fabricators to better estimate cost and levels the playing field among all bidders.
- Provides guidance for connection designers.
- Gives EOR opportunity to find and resolve kinked connection issues (and constructability / connection designability issues) during design.

Why provide "concept connection details"?

- The time to think about how connection details affect the performance and behavior of the structural framing is during design.
- The time to find kinked connections is during design – not during shop drawing review.
- EOR has options during design.
- The number of options for solving connection design problems is reduced if problems are not discovered until shop drawing review.

Why provide "concept connection details"?

Concept connection details,

- Reduce RFI's
- Reduce arguments
- Reduce change orders
- Minimize chances of mistakes slipping through
- Enhance safety

How to deal with kinked connections

45

Dealing with kinked connections

- Remember: The engineer-of-record is ultimately responsible for the safe design of all connections – even when delegating connection design.
- Understand ANSI/AISC 303-16 rules regarding connection design responsibility.

46

Dealing with kinked connections

- Find the kinked connections **during design** (*Do not* kick the can down the road)
- Eliminate the kinks if possible (by reframing) – or deal with them.

47

Dealing with kinked connections

- Is member reinforcement at the connection required due to a kinked load path?
- EOR must either fully design and detail member reinforcement at the connections (Option #3A), or provide concept connection details and bidding quantities (Option #3B) on the structural drawings.
(Note: Concept connection details should be provided for kinked connections, regardless of whether or not member reinforcement at the connections is required.)

48

Dealing with kinked connections

- Can the connections be designed (connection designability)?
- Can the connections be built (constructability)?
- Is there anything unusual about how loads travel through the connections?
- Is member reinforcement at the connections required?

49

Dealing with kinked connections

- Show reactions/member forces.
- Follow loads through the connections.
- Envision the deflected shape!
- Remember the fundamentals:

$$\sum F_{x,y,z} = 0$$
$$\sum M_{x,y,z} = 0$$

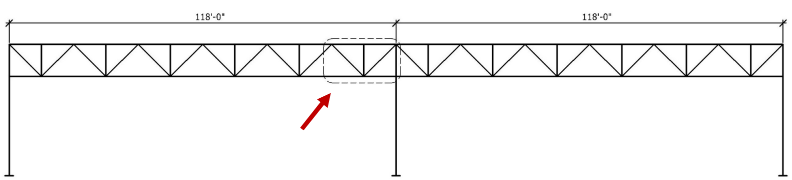
Kinked connections are *everywhere!*

50

The importance of concept connection details

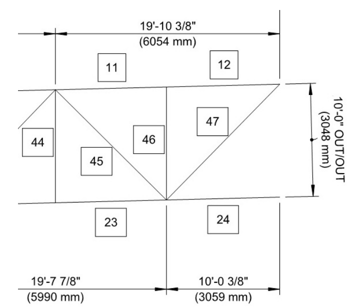
For all non-standard connections:

- How will the connections be configured?
- Can cost-effective connections be designed?
- Can the framing be easily erected?
- Provide concept connection details.



51

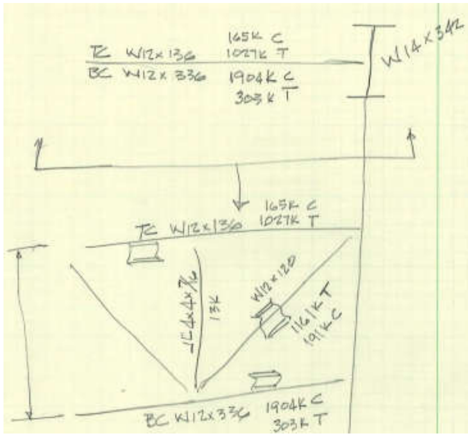
The importance of concept connection details



There were no concept connection details.

52

The importance of concept connection details

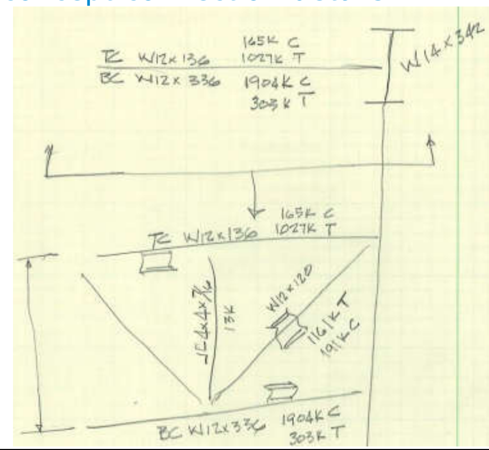


53

The importance of concept connection details

Suggestions:

1. Make all members W14's
2. Rotate members and use bolted connections with gusset plates



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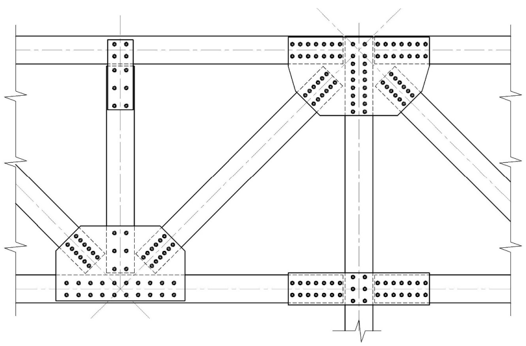
The importance of concept connection details



Don't kick the can down the road. The time to think about the connections is during design.

55

Examples of kinked connections

56

Hyatt Regency Connection Failure

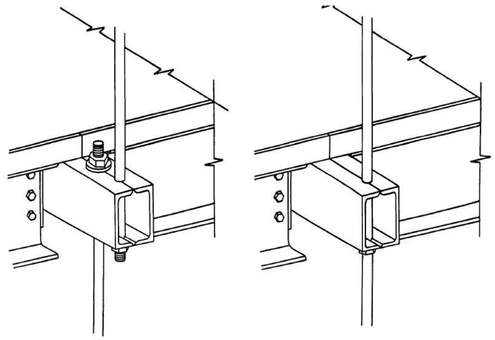
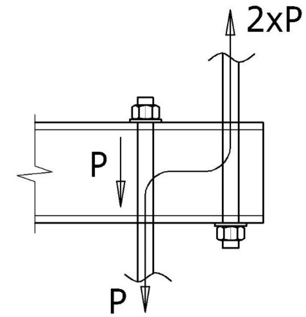


Figure 10.2 Comparison of interrupted and continuous hanger rod details.

57

Hyatt Regency Connection Failure



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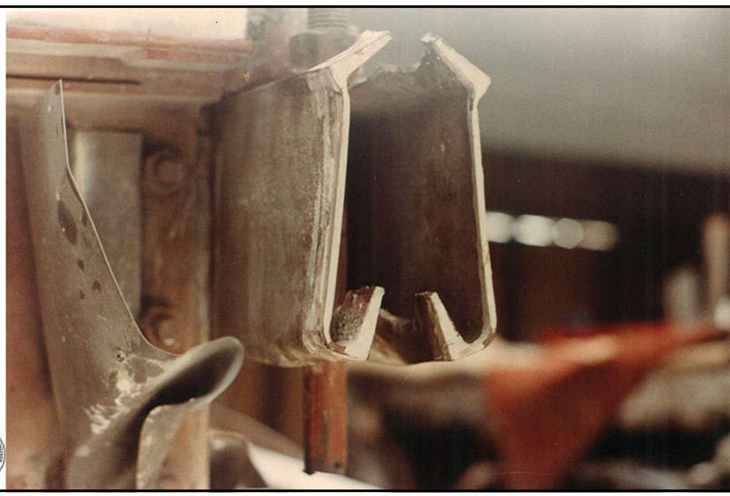

59

60

Hyatt Regency Connection Failure

NBS BUILDING SCIENCE SERIES 143

Investigation of the Kansas City Hyatt Regency Walkways Collapse

R. D. Marshall
E. O. Pfrang
E. V. Leyendecker
K. A. Woodward

Center for Building Technology
National Engineering Laboratory

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Washington, DC 20234

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued May 1982

61

Hyatt Regency Connection Failure

Based on measured weights of damaged walkway spans and on a videotape showing occupancy of the second floor walkway just before the collapse, it is concluded that the maximum load on a fourth floor box beam-hanger rod connection at the time of collapse was only 31 percent of the ultimate capacity expected of a connection designed under the Kansas City Building Code. It is also concluded that had the original hanger rod arrangement not been changed, the ultimate capacity would have been approximately 60 percent of that expected under the Kansas City Building Code. With this change in hanger rod arrangement, the ultimate capacity of the walkways was so significantly reduced that, from the day of construction, they had only minimal capacity to resist their own weight and had virtually no capacity to resist additional loads imposed by people.

Overstress in original connection detail: Strength ratio = 1/0.6 = 1.67

Overstress in revised connection detail: Strength ratio = 1/0.31 = 3.23

62

Hyatt Regency Connection Failure

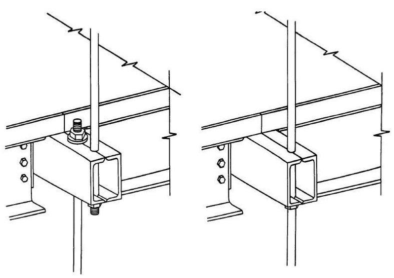


Figure 10.2 Comparison of interrupted and continuous hanger rod details.

Overstress in original connection detail: Strength ratio = 1/0.6 = 1.67

Overstress in revised connection detail: Strength ratio = 1/0.31 = 3.23

63

Hyatt Regency Connection Failure

CHRONOLOGY AND CONTEXT OF THE HYATT REGENCY COLLAPSE

By Gregory P. Luth[1]

ABSTRACT: This paper presents a brief chronology of the events that preceded the collapse of the walkways at the Kansas City Hyatt Regency Hotel, including the prior failure that occurred during construction and the evolution of the detail that caused the catastrophe. Many of the facts surrounding the case were not publicized, due to the litigation. Some were not brought out during the litigation. No attempt will be made to affix responsibility, as these issues were resolved years ago. The chronology is followed by a discussion of the events that contributed to the collapse and of the changes that have been made in the industry toward preventing a similar occurrence.

INTRODUCTION

On July 17, 1981, two walkways at the Hyatt Regency Hotel in the Crown Center development in Kansas City, Missouri, collapsed during a "tea dance." A full chronology of events is provided in table form (Table 1). The result of the collapse was that 114 people lost their lives and numerous others were injured. It is worthwhile to look back on the events leading up to the events of July 17 to determine what actions or omissions contributed to the tragedy and what actions might have averted the tragedy. The writer was a recent graduate working in the offices of the firm that performed the structural design of the Hyatt Regency. This paper presents a brief, objective, and factual summary of those events in chronological sequence in order to provide a context in which the profession might study and evaluate the lessons of the failure.

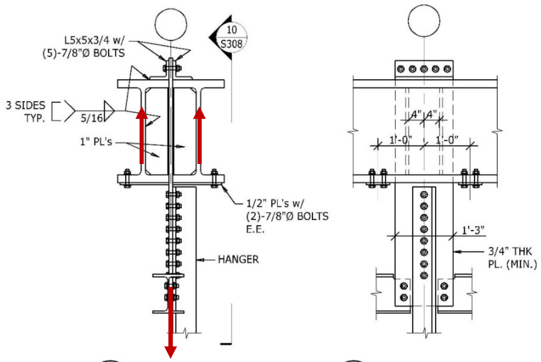
The project design was performed under the "fast track" method of delivery that came into vogue in the latter part of the 1970s. As with many projects delivered by this method, construction preceded design, structural design preceded ar-

(120 ft), supported on slide bearings that rested on concrete corbels on the function block end. One side of the atrium roof structure would be supported on a system of vertical frames that formed a "sun screen" and also functioned to support a four-story glass wall. Communication between the function block and hotel floors was provided by a system of walkways at the 2nd, 3rd, and 4th floors.

Production of construction documents was ongoing between July 1977 and January 1978. Because of architectural constraints, the sunscreen structure evolved into a vertical truss that picked up loads at the roof on one chord and dropped them off at the first floor at the other chord in order to avoid loading the concrete floor system at the first floor. The inside chord of the sunscreen truss, which functions as a column, was designed to be provided with lateral support by structural tubes that also supported the curtain wall. Early schemes called for the walkways to be supported on posts off of the concrete floor at the first level. Later, the decision was made to suspend the walkways from the roof structure to give a light and airy feel to the atrium space. Fig. 1 shows floor plans of the roof

64

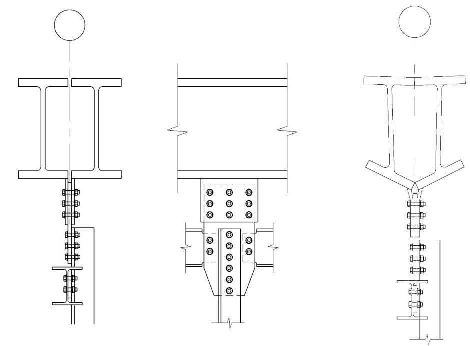
Hanger below double beam



65

Hanger below double beam

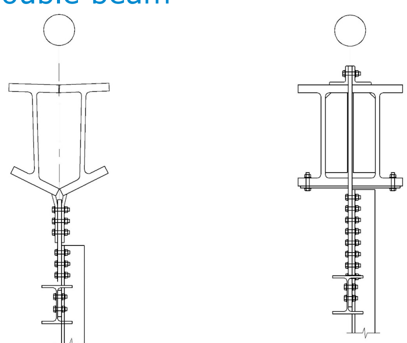
A possible result of not following the Code of Standard Practice and not providing "concept connection details"



No!

66

Hanger below double beam



Kink in load path inducing secondary stresses in members

Concept connection detail addressing secondary stresses

67

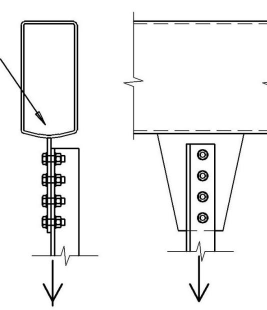
Hanger below HSS beam

Who is responsible for checking the secondary stresses in the HSS?
(Both the EOR and connection design engineer)

Who is ultimately responsible for the structural adequacy of the design of the completed project? (Section 1.9.2) *(The EOR)*

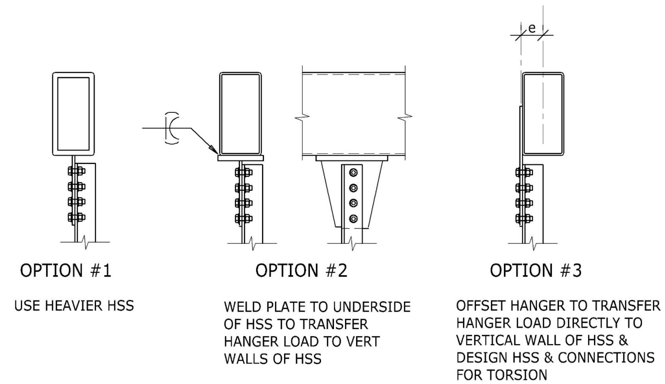
Who is responsible for providing project specific details showing conceptual configuration of reinforcement at the connections? (Section 3.1.2)
(The EOR)

Secondary flexural stresses in bottom of HSS at hanger connection



68

Hanger below HSS beam

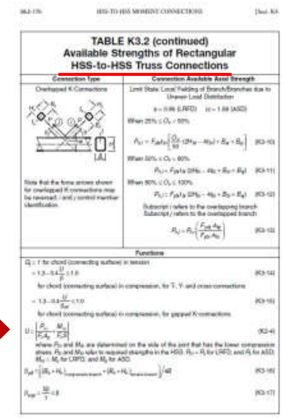


Possible hanger options (there are more)

69

HSS to HSS connections

See 15th Edition AISC Steel Construction Manual, pages 13-17 & 13-18

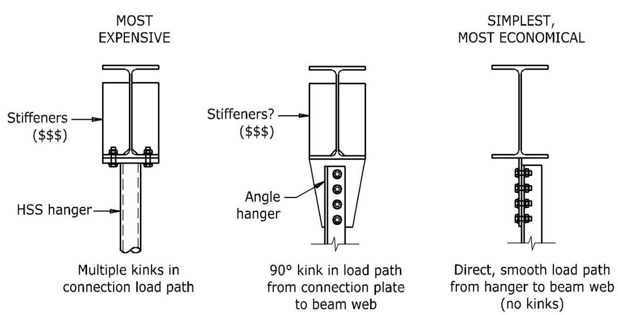


Demand-to-capacity ratio

$$U = \left| \frac{P_{ro}}{F_c A_g} + \frac{M_{ro}}{F_c S} \right|$$

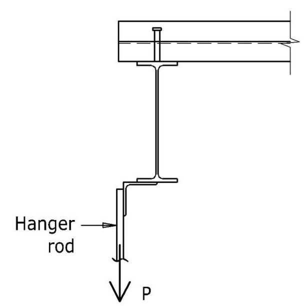
70

Hanger below W shape



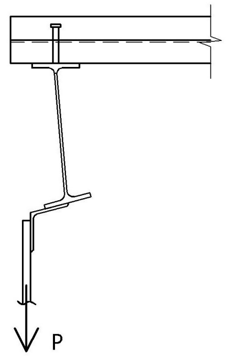
71

Eccentric hangers



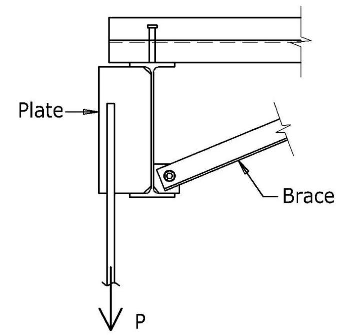
72

Eccentric hangers



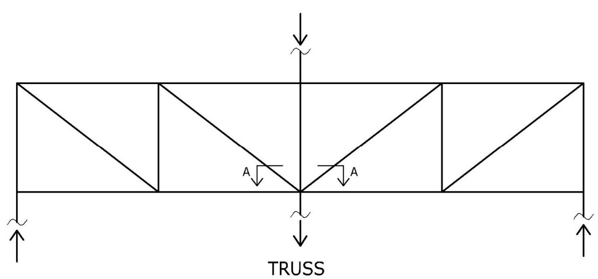
73

Eccentric hangers



74

Kink in tension connection



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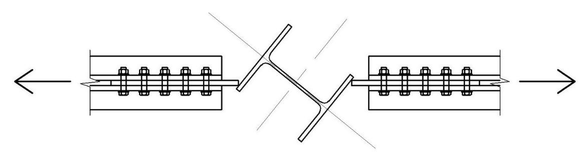
Kink in tension connection



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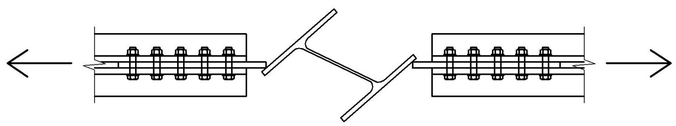
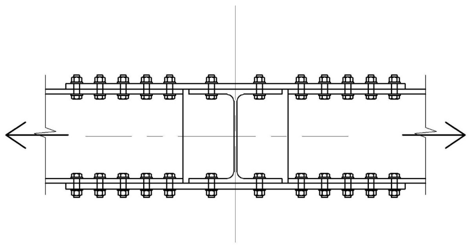
Kink in tension connection

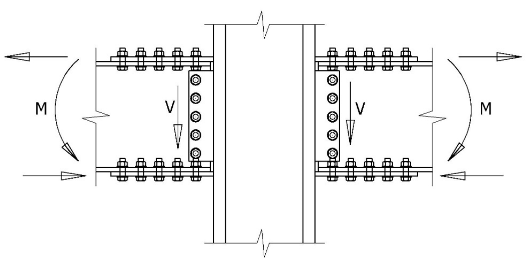


No good!

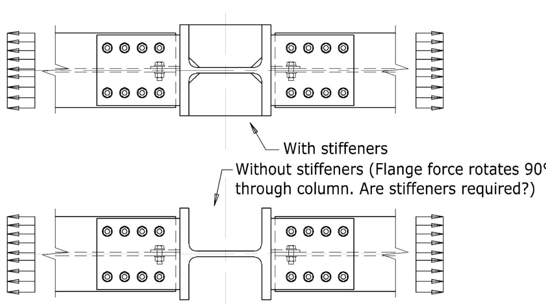
Kink in tension connection



Beam-to-column moment connection (w/o stiffeners)

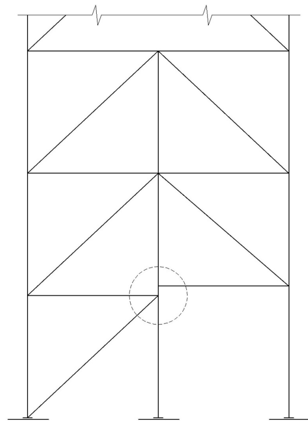


Beam-to-column moment connection (w/o stiffeners)



Check Specification Section J10 FLANGES AND WEBS WITH CONCENTRATED FORCES.
(Stiffeners are expensive. Consider upsizing columns to avoid stiffeners.)

Offset floor in braced frame



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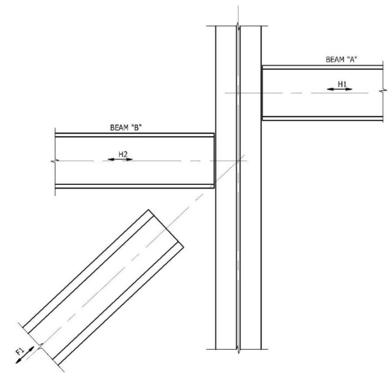
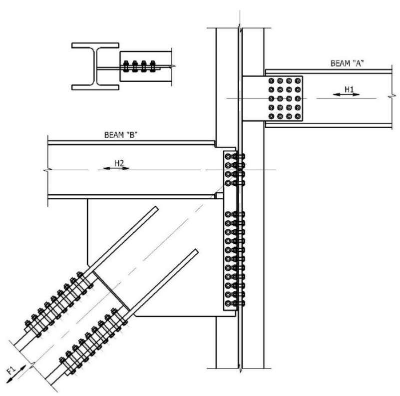
Offset floor in braced frame



82

Offset floor in braced frame



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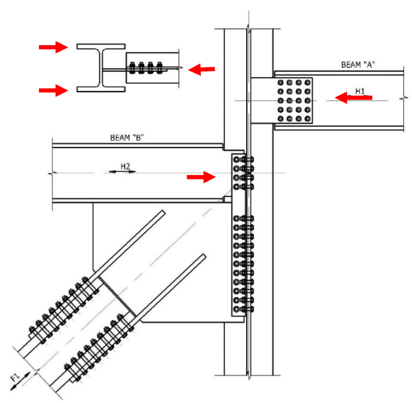
Offset floor in braced frame



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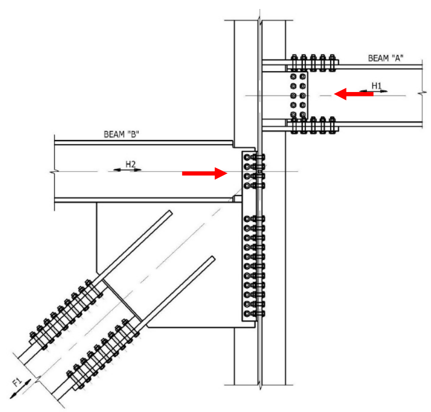
Offset floor in braced frame



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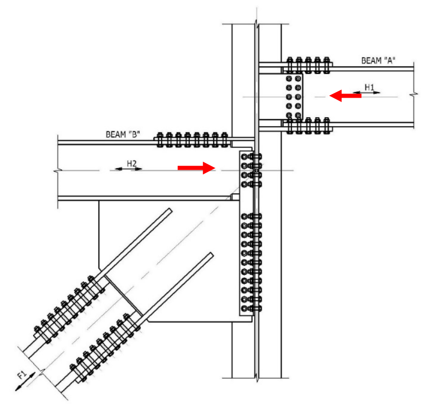
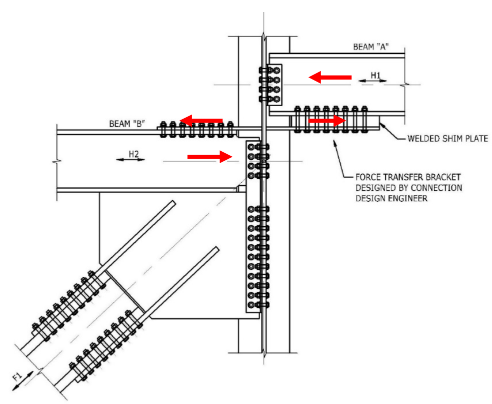
Offset floor in braced frame



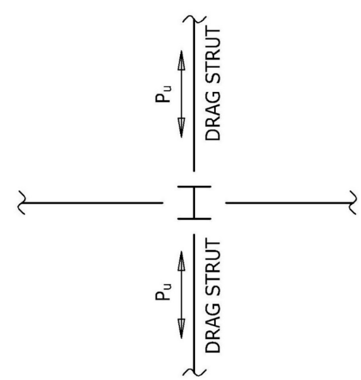
86

Offset floor in braced frame



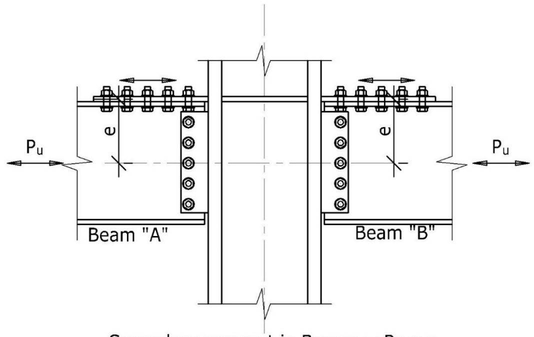
87

Drag strut connections



88

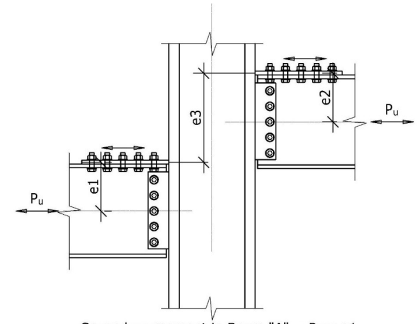
Drag strut connections



Secondary moment in Beams = Pu x e

89

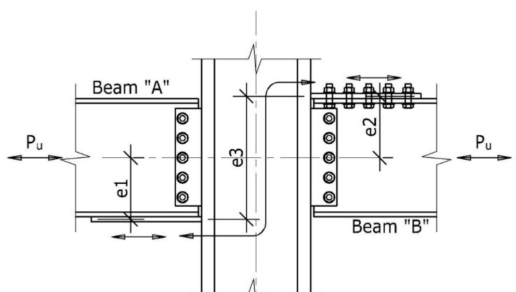
Vertically offset drag strut



Secondary moment in Beam "A" = Pu x e1
Secondary moment in Beam "B" = Pu x e2
Secondary moment in column = Pu x e3
Shear in column web

90

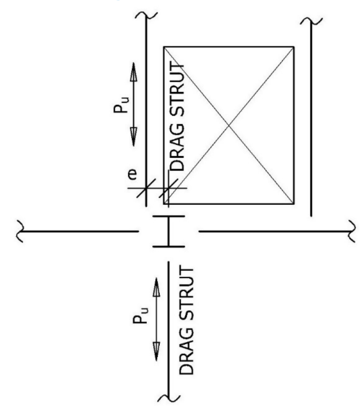
Vertical offset in drag strut connection



Secondary moment in Beam "A" = Pu x e1
Secondary moment in Beam "B" = Pu x e2
Secondary moment in column = Pu x e3
Shear in column web

91

Horizontally offset drag strut



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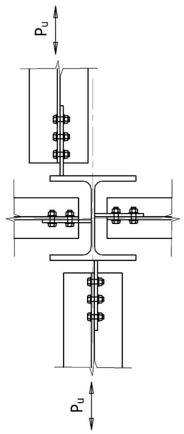
Horizontally offset drag strut



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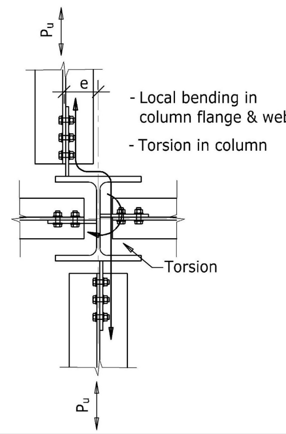
Horizontally offset drag strut



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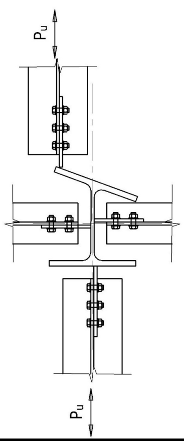
Horizontally offset drag strut



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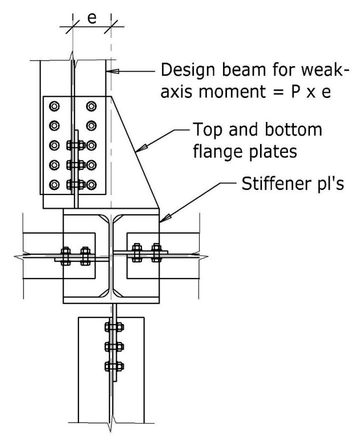
Horizontally offset drag strut



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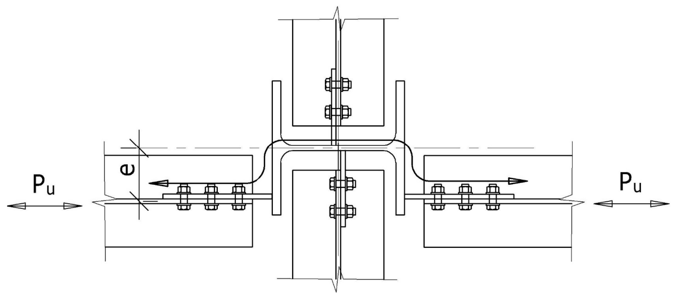
Horizontally offset drag strut



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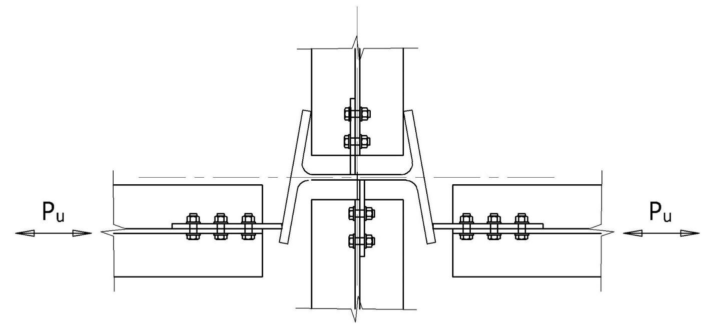
Horizontally offset drag strut



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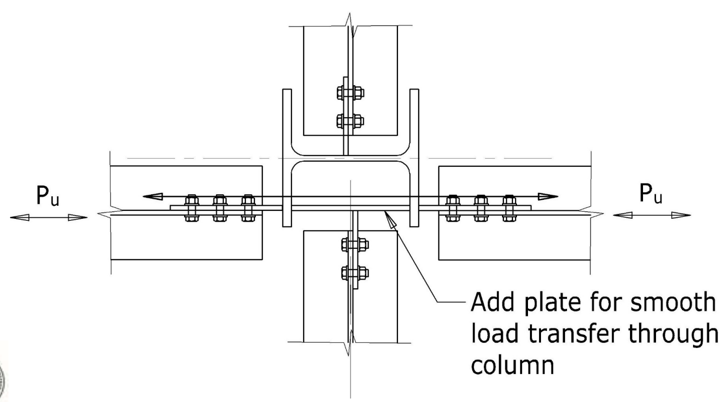
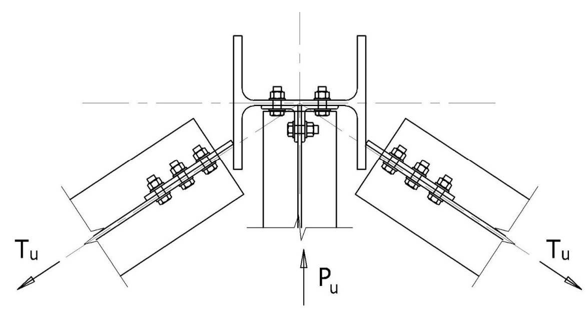
Horizontally offset drag strut



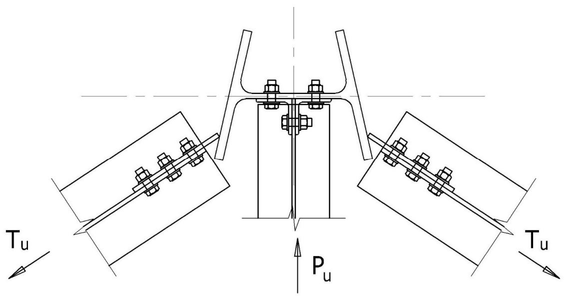
99

Tension ring connection



100

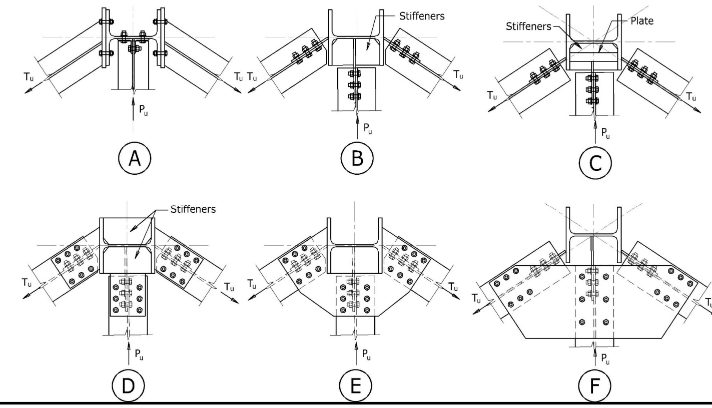
Tension ring connection



Survey Question

Which detail is “best” for connecting tension ring members?

1. A
2. B
3. C
4. D
5. E
6. F



Eccentric workpoint in truss

THE INDUSTRIAL MAGAZINE
VOL. X. AUGUST, 1909 No. 1

Secondary Stress in Framed Structures

By E. W. Pittman *

SECONDARY stresses in framed structures are due, primarily, to faulty details. Attention will be directed to some of the more common faults and inconsistencies that are of frequent occurrence in structural details, and an effort made to illustrate their effects upon the strength of the structures.

In the general design of an articulated structure, such as a bridge or roof truss, it is assumed that the axes of the various members meeting at a joint are concurrent; that is, intersecting at a common point, and that they are free to rotate about this point as elastic deformation takes place.

(*Manager, McClintic-Marshall Company, Pittsburgh Pa.)

Eccentric workpoint in truss

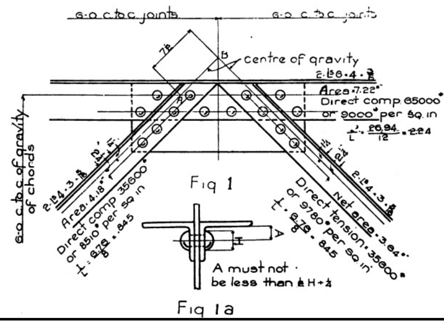
The computation of the resulting bending moments in the members is a rather tedious process, as it involves the determination of the angular displacement of each joint. For bridge trusses of ordinary proportions, the deflection is small, and the resulting bending stresses in the members may be safely neglected, but for the shallow trusses with deep gusset plates, they should be considered.

This condition of secondary stress is sometimes further accentuated by faulty joints, such as shown in Fig. 1. The axes of the members are noncurrent, and a bending moment is, therefore, induced at the joint. All members are bent in opposite directions at their ends, and by approximately the same amounts. This places them in double curvature and makes a point of contra flexure, or zero moment, at their centers. All members, therefore, resist the bending moment due to eccentricity in proportion to their relative rigidities. The angular displacement of the

Eccentric workpoint in truss

In order to make this result more tangible, and to illustrate the effect of this construction, let us assume an actual case and derive the numerical values of these secondary stresses.

Fig. 1 shows a joint in the top chord of a Warren truss. The make-up and properties of the several members are marked in the figure.



105

Eccentric workpoint in truss

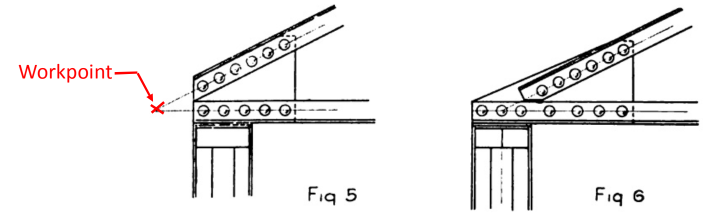


Fig. 5 shows the heel of a roof truss. This detail has been made familiar by its wide use, and yet the fault is pronounced. The three forces acting at the heel, namely the compression in the rafter, the tension in the bottom chord and the column, or wall, reaction are non-current. A bending moment results which induces large fibre stresses in the members. This detail is susceptible of the same analysis as the eccentric joint of the Warren truss.

106

Eccentric workpoint in braces

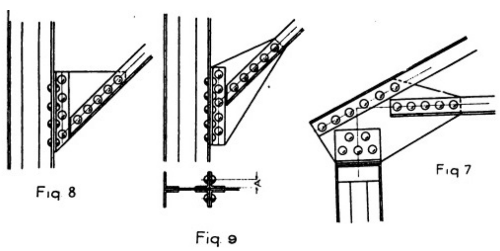
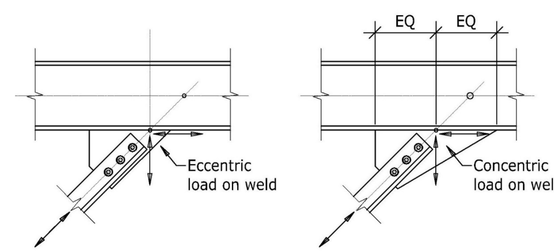


Fig. 8 shows the detail of a knee brace connection to a column, which is not uncommon in mill building construction. This detail is open to the same criticism as the other eccentric connections already discussed. It is especially to be condemned in view of the fact that the knee brace is subject to tension, as well as compression, and when the knee brace is in tension, the entire stress must be resisted by two rivet heads. Fig. 9 shows the proper detail for this connection. The gauge, *A*, for the rivets

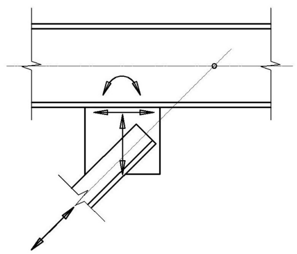
107

Eccentric workpoint in braces



108

Eccentric workpoint in braces

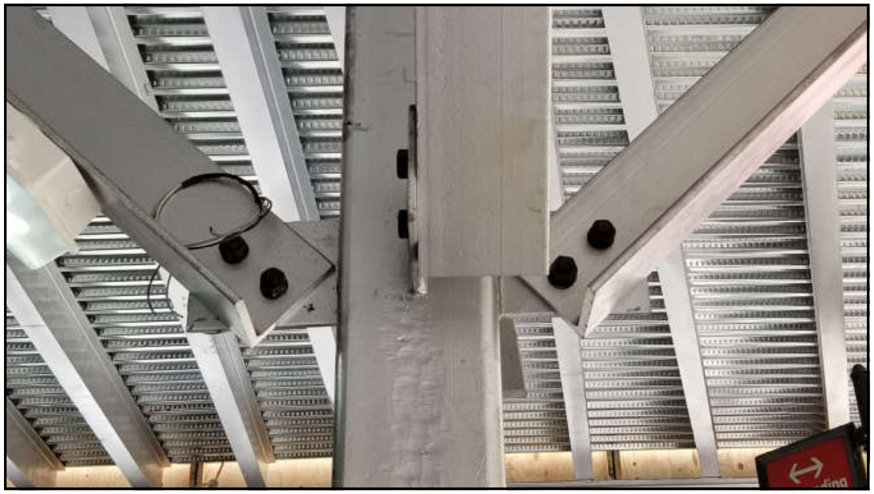


109

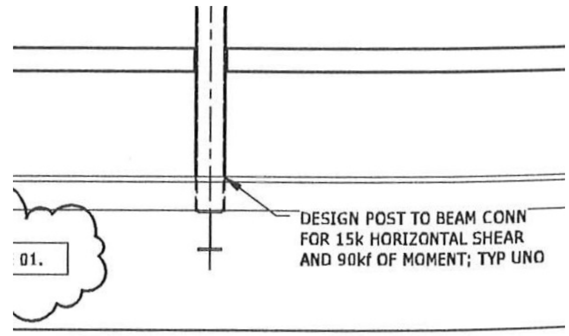
110

111

112

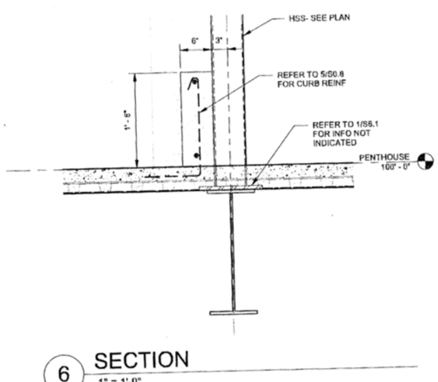


Screen wall posts



114

Screen wall posts



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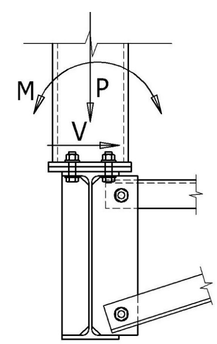
Screen wall posts



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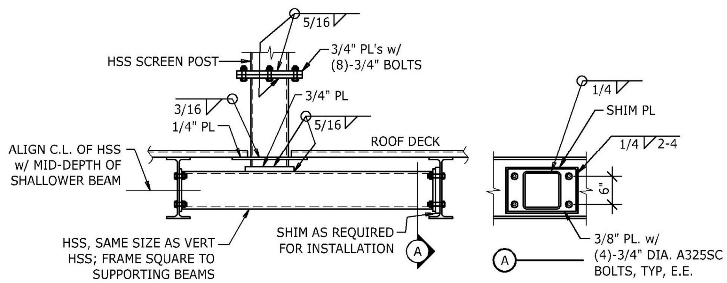
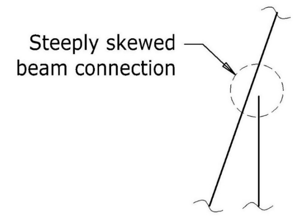
Screen wall posts



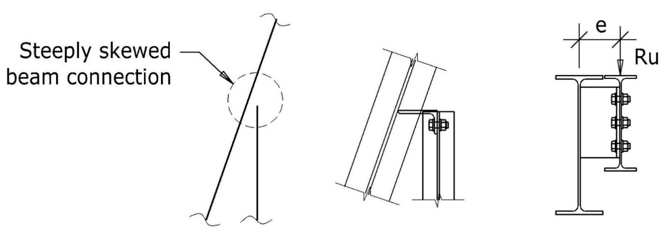
117

Steep skewed connections (w/ small reactions)



118

Steep skewed connections (w/ small reactions)



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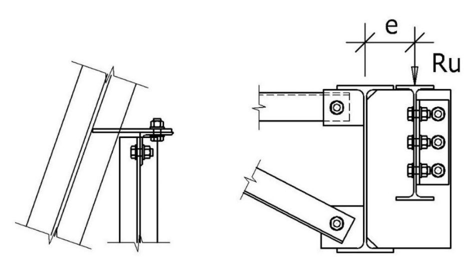
Steep skewed connections (w/ small reactions)



120

Summary

- The EOR is ultimately responsible for safe design of all connections
- Kinked connections are those with irregular, 3-dimensional jogged load paths
- The best load path is a smooth and direct load path
- Subtle changes can create kinked connections
- Computer models will not "find" the kinked connections

121

Summary

- Look for kinked connections during design
- Alter framing to eliminate the kinks or consider their effects on members
- Provide concept connection details
- Read and understand the AISC Code of Standard Practice
- Kinked connections are common. Always be on the lookout for them!

122

Thank you!

AISC | Questions?

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- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
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