Night School 26: Developing an Eye for Connection Design

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Session 5 – Welds
August 10, 2021 | Larry Muir

Smarter. Stronger. Steel.

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AISC Live Webinars

Course Description

Welds
August 10, 2021

The session will cover the basics of welded connections. This session will consist of a review of applicable welding codes, the basics of welded joints and weld types, and required weld metal strength levels. Welded connection details will be discussed. This session will also allow for an extended Q&A and requested topics from the audience, collected in advance of the session.

AISC Live Webinars

Learning Objectives

1. Describe how longer, single-pass fillet welds are usually more economical than shorter, multi-pass welds.
2. Explain how weld positions affects the safety and economy of a welded connection.
3. Define toughness as it relates to welds.
4. Explain load angle effects on the strength of a welded connection.

Night School 26: Developing an Eye for Connection Design

Session 5: Welds
August 10, 2021

Larry Muir, PE, Consultant

Smarter. Stronger. Steel.

Welds

Due to time constraints we will only cover the most common types of welds and address some of the more common questions.

For a more in-depth discussion of welded connections please refer to the **AISC Steel Design Guide 21 "Welded Connections – A Primer for Engineers"** by Duane Miller of Lincoln Electric.

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Basics

Specifying Welds

Welds generally are not required to develop the strength of the parts they join.

Do not over-specify welds. Give the fabricator the freedom to choose between fillet welds or groove welds based on economy.

Longer single pass fillet welds are usually more economical than shorter multi-pass welds.

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Basics

Common Types of Welds

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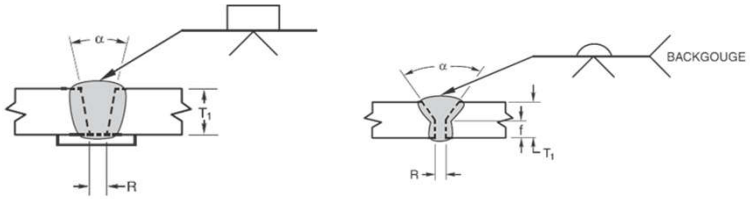
Basics

Complete Joint Penetration Groove



Complete joint penetration (CJP) groove welds provide complete fusion through the joint that develops the strength of the welded parts.

CJP groove welds require backing or backgouging.

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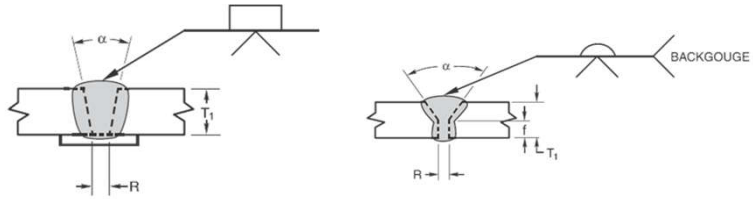
Basics

Complete Joint Penetration Groove



CJP groove welds are simple to design, but expensive.

High heat input and restraint can lead to weld cracking and/or distortion of the assembly.

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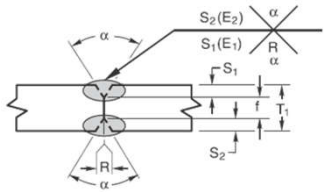
Basics

Partial Joint Penetration Groove



Partial joint penetration (PJP) groove welds do not provide complete fusion through the joint.

PJP groove welds do not require backing or backgouging.

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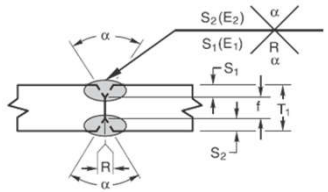
Basics

Partial Joint Penetration Groove



PJP groove welds do require a groove which involves additional labor compared to a fillet weld.

PJP groove welds have considerably less available strength when subjected to tension.

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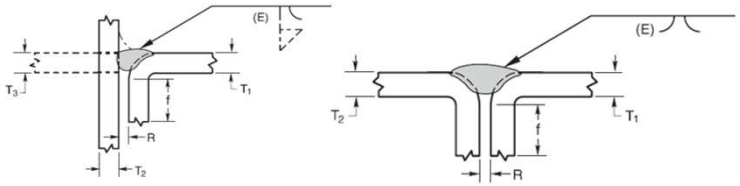
Basics

Flare-Bevel Groove



Flare-bevel groove welds are a type of PJP groove weld most commonly used to connect to HSS.

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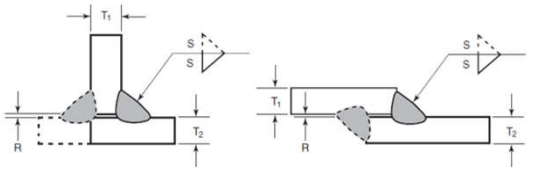
Basics

Fillet



Fillet welds are the most common and generally the most economical welds used.

Fillet welds do not fuse completely through the joint, do not require a groove.

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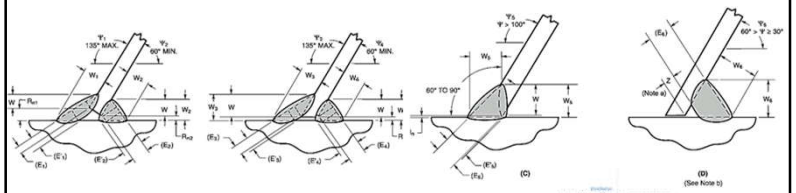
Basics

Skewed “Fillet”



Some of these welds are treated similar to fillets and some are treated more like PJP welds.

It can be a difficult topic to wrap one’s head around.

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Basics

Sizing Fillet Welds for Economy

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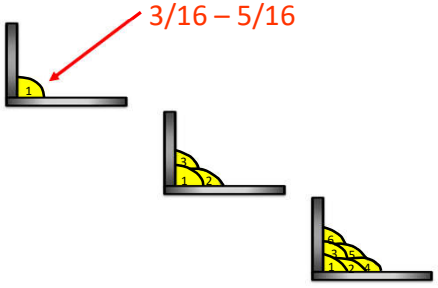
Basics

Use Single Pass Welds



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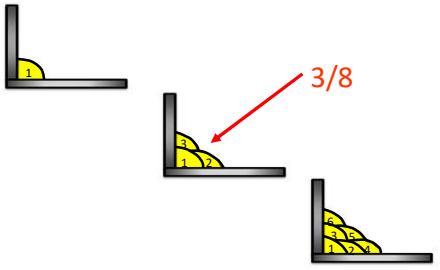
Basics

Use Single Pass Welds



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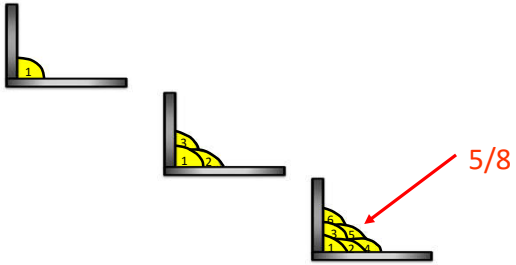
Basics

Use Single Pass Welds



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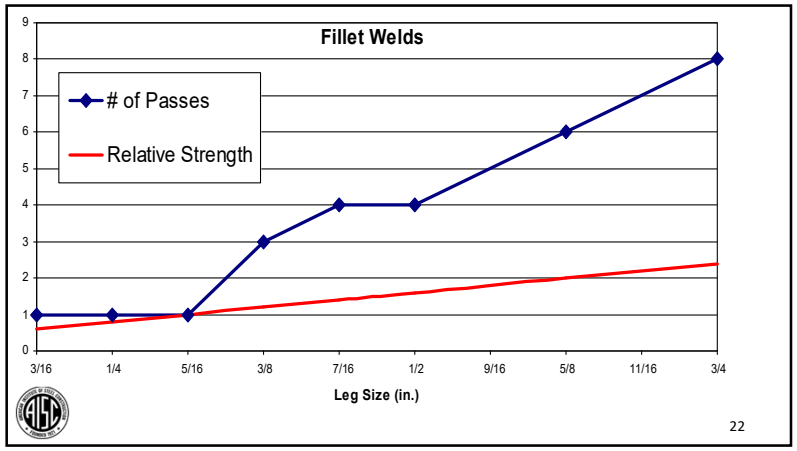

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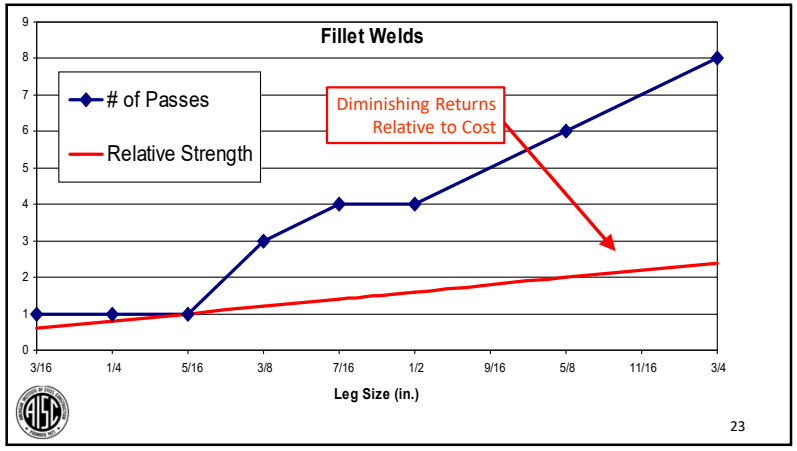

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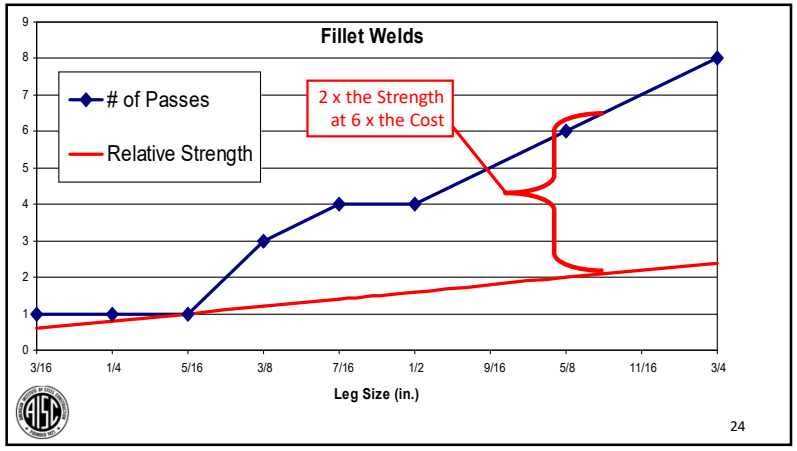

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Basics

Welding Positions

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Basics

Weld Positions

- Welds are more easily made in the flat or horizontal positions.
- Material can usually be rotated into the flat or horizontal position in the shop.
- Material can usually not be rotated in the field.

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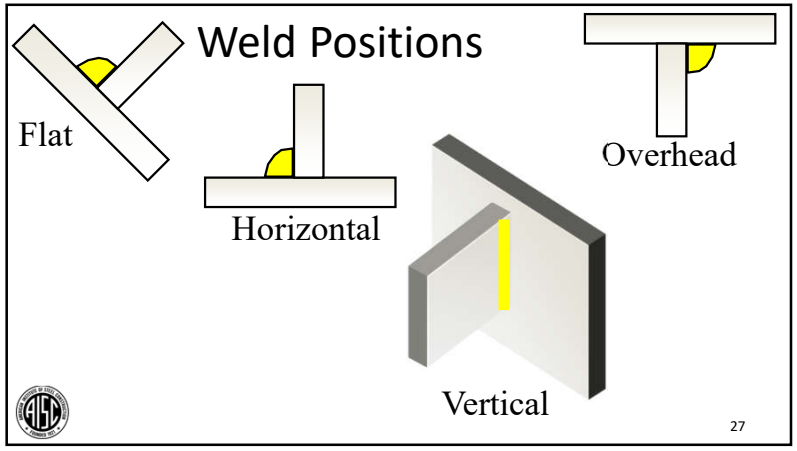

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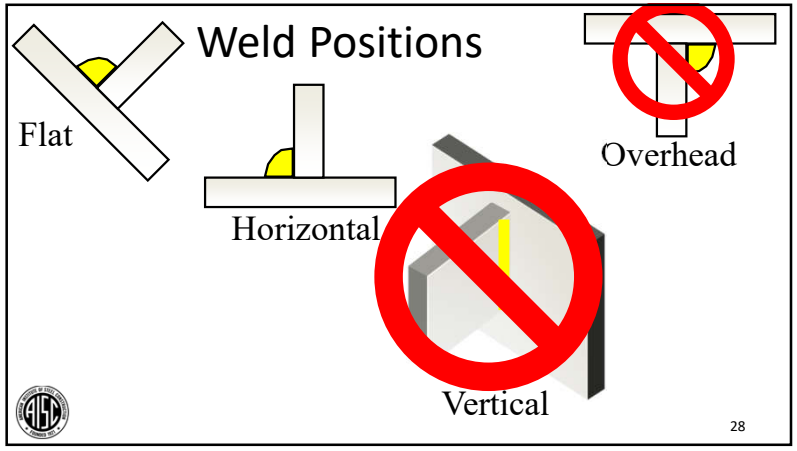

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Basics

Use of Single Sided Welds

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Basics

Single Sided Welds

- It is usually preferable to use two-sided partial penetration or fillet welds whenever possible.
- One-sided welds are sometimes appropriate when resisting shear.
- One-sided welds should not be used to resist tension

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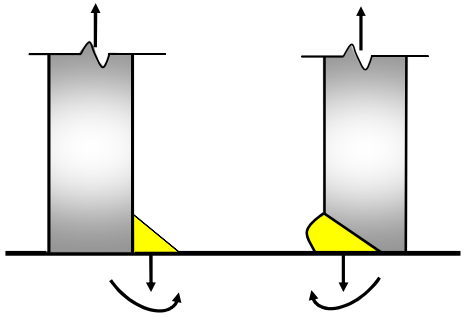
Basics

Single Sided Welds



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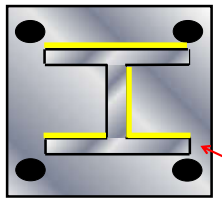
Basics

Appropriate Uses of Single Sided Welds



Column Base Plate Welds

Contractors must weigh the benefits against the risks of incidental loading.

Flange-to-Web Welds for Built-Up Sections

Welds in Shear

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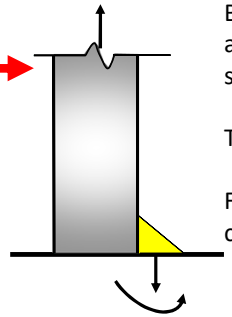
Basics

One-Sided Welds

Unintentional loading (erection, handling, etc.)



Both typical design loads and accidental or incidental loading should be considered.

The weld cannot tell the difference.

Failure to consider all implications can get someone killed.

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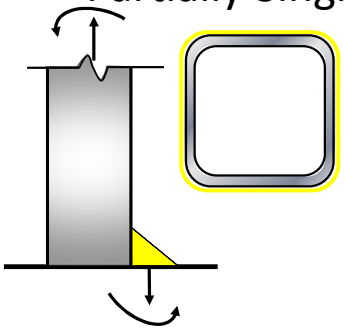
Basics

Partially Single Sided Welds



The flexibility of the rectangular HSS wall only partially prevents rotation about the root of the weld.

Therefore, the directional strength increase is not fully realized.

Rectangular HSS are the only shapes explicitly addressed in the Specification.

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Behavior

Behavior of Fillet Welds

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Behavior

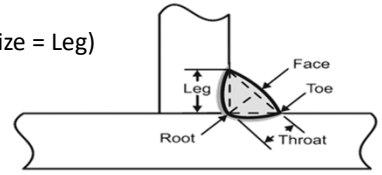
Behavior of Fillet Welds

Fillet welds are assumed to fracture through the throat, which is shown here at the assumed angle of 45°.

The effective area of the weld is therefore:

A_w=(weld size)(sin 45°)(weld length)

(weld size = Leg)



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Behavior

Load Angle Effects

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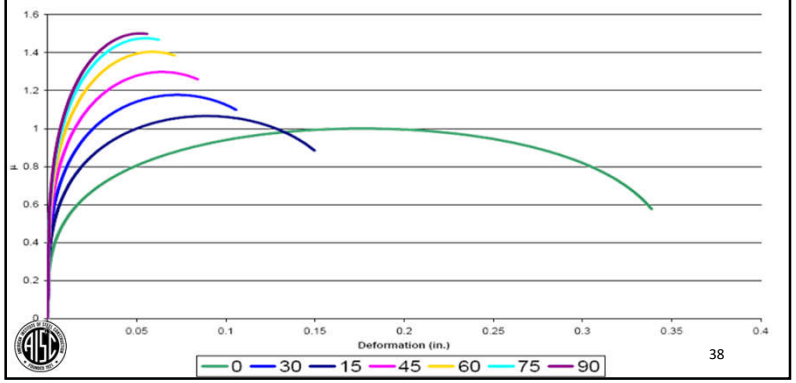
Behavior

Manual Figure 8-5



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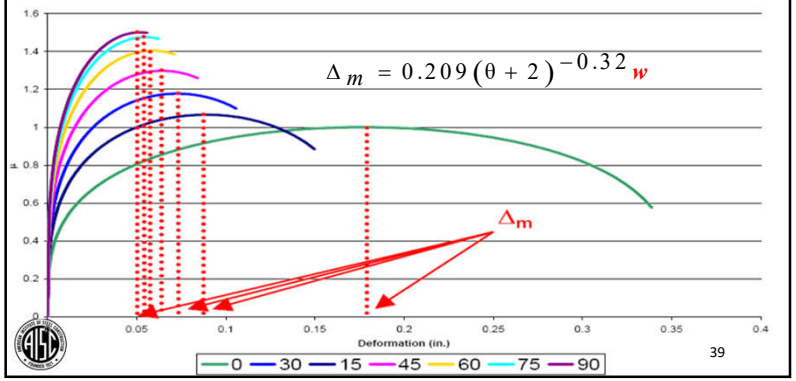
Behavior

Manual Figure 8-5



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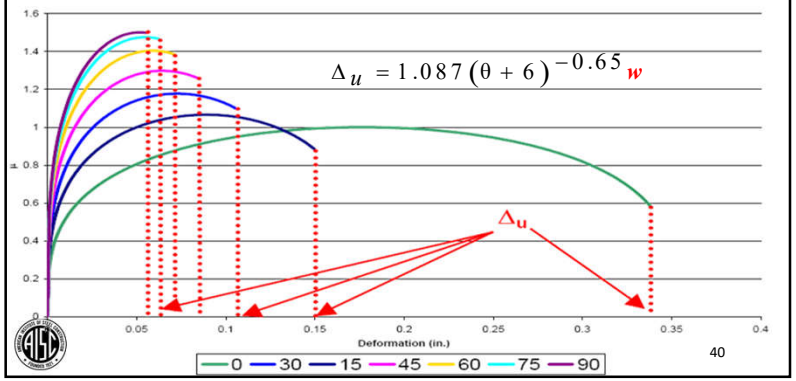
Behavior

Manual Figure 8-5



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Behavior

Strain Compatibility

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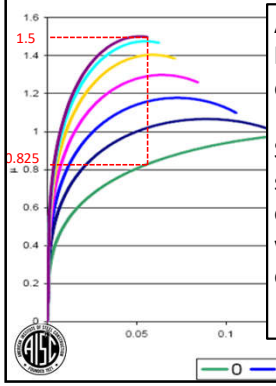
Behavior

Manual Figure 8-5



Assume we have a weld group with both longitudinally and transversely loaded elements.

Strain compatibility requires us to limit the strength of the more ductile element based on the deformation consistent (compatible) with ultimate deformation of the less ductile element.

(ii) $R_n = 0.85\ R_{nwl} + 1.5R_{nwt}$ (J2-10b)

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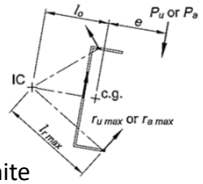
Behavior

Strain Compatibility

Though requiring a lot of calculation, the simplest way to ensure strain compatibility is to use the instantaneous center of rotation method.

The method satisfies equilibrium, strain compatibility, and the available strength.

The instantaneous center of rotation method is finite element analysis on whatever the opposite of steroids is.



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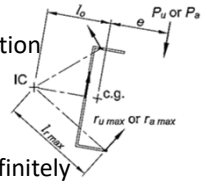
Behavior

Strain Compatibility

The instantaneous center of rotation method is in most cases iterative and onerous to apply manually.

It is not true that the instantaneous center of rotation method is only applicable to eccentrically loaded weld groups.



The instantaneous center of rotation is located infinitely far from the center of gravity when the load is applied concentrically.

The instantaneous center of rotation is located at the center of gravity when the weld group is subjected to pure moment.

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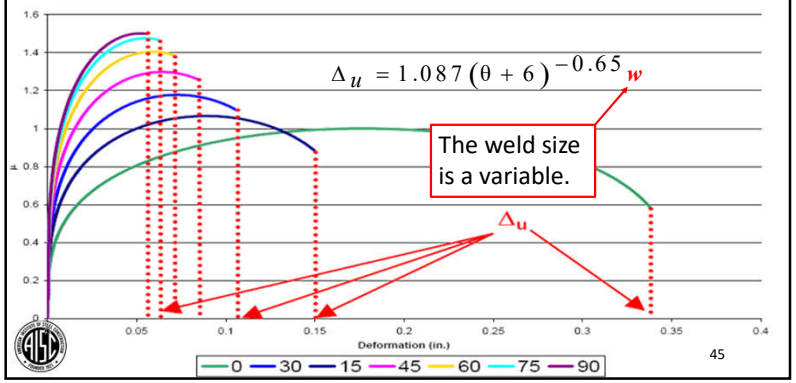
Behavior

Manual Figure 8-5



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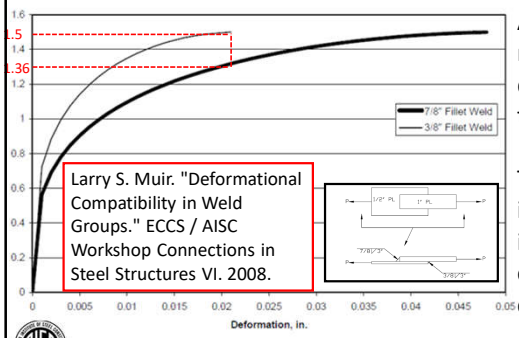
Behavior

Manual Figure 8-5



Larry S. Muir. "Deformational Compatibility in Weld Groups." ECCS / AISC Workshop Connections in Steel Structures VI. 2008.

A larger weld requires more deformation to develop its full strength than a smaller weld.

The directional strength increase is simple to implement for many common conditions, but care is required.

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Behavior

Behavior of CJP Groove Welds

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Behavior

Behavior of CJP Groove Welds

CJP groove welds will develop the strength of the parts joined, so the behavior of the joint is largely governed by the behavior of the base metal.

CJP groove welds are strong enough. The question then becomes are they tough enough.

"I'd climb the Empire State, fight Muhammad Ali
Ain't that tough enough"

~~~ Jerry "Boogie" McCain

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~~~

Behavior

Behavior of CJP Groove Welds

Toughness is the ability of a material to absorb energy and plastically deform without fracturing.

Toughness is related to the area under the stress–strain curve.

In order to be tough, a material must be both strong and ductile – like steel.

Fracture toughness is a measure of the amount of energy required to propagate a preexisting flaw. All steel and all welds have preexisting flaws.

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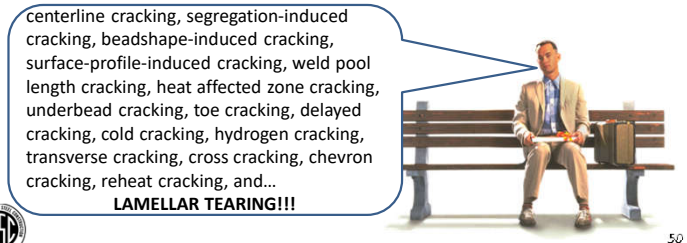
Behavior

Behavior of CJP Groove Welds

There are lots of things that can cause welds to crack.

Design Guide 21 addresses many of them.



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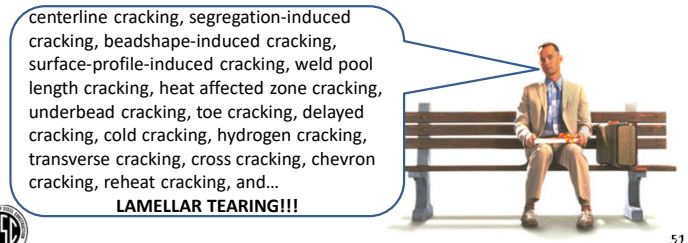
Behavior

Behavior of CJP Groove Welds

Like Forrest below many engineers seem to focus too much on one aspect of weld cracking and perhaps too little on the other aspects.



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Behavior

Lamellar Tearing

From Design Guide 21:

- "Current steel-making practices have helped to minimize lamellar tearing tendencies."
- "Unlike hydrogen-related cracking which is typically delayed, lamellar tearing usually occurs while the weld is cooling and shrinking."

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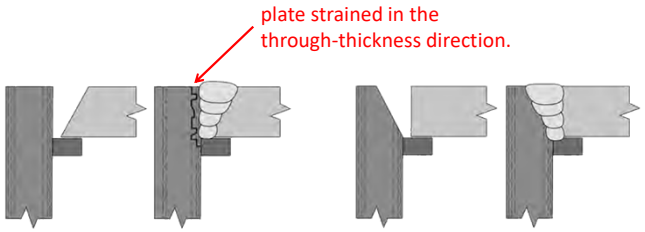
Behavior

Lamellar Tearing

It is often possible to modify a specific weld joint detail to minimize lamellar tearing tendencies.



Sensitive to lamellar tearing

Preferred detail

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Behavior

Behavior of Welds

From Design Guide 21: "larger than necessary welds result in more shrinkage, which in turn leads to more distortion and higher residual stresses, along with increased cracking and tearing tendencies."

Welding is not quite as simple as bolting, but your goal should still be to not screw things up.

There are a lot of things to consider.

- Part 2 of Manual – "Avoiding Brittle Fracture"
- Continuing Education Archive – Anything by Duane Miller
- Know when you need help – Can you approve a WPS?

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Behavior

Behavior of Welds

Fourteen Principles of (Welded) Connection Design – Design Guide 21

1. A good welded connection is strong enough to transfer all the applied loads through the connection in an efficient manner.
2. A good welded connection has a clear and direct load path.
3. A good welded connection places welds in regions of low stress.
4. A good welded connection does not introduce stress raisers.
5. A good welded connection is not constrained.
6. A good welded connection does not subject the weld to bending.
7. A good welded connection protects the toes and roots of the welds.
8. A good welded connection has a clearly defined throat.

Etc.

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Behavior

Behavior of Welds

My mama always said, "If you want to know more about welds, then you have to read AISC Design Guide 21."

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Design

Design of Fillet Welds

Design

Design of Fillet Welds

The AISC Specification provides two options for designing fillet welds and fillet weld groups.

1. 'Widout' the directional strength increase
2. 'Wid' the directional strength increase

Design

Design of Fillet Welds – Option 1- Without

Section J2.4(a) allows the strength of the weld to be calculated as $R_n=F_wA_w$.

This is commonly rewritten for E70 electrodes as:

R_n/Ω = 0.928 DL (ASD)

ϕR_n = 1.392 DL (LRFD)

Design

Design of Fillet Welds – Option 1- Without

This is derived from:

A_w = (weld size)(sin 45°)(weld length)
= (D/16)(sin 45°)(L)
= 0.0442 DL

D = weld size expressed in $^1/_{16}$ of an inch

F_w = $0.6F_{EXX}$ = 0.6(70) = 42 ksi

$R_n = F_w A_w$ = (42) (0.0442)DL= 1.8564DL

Design

Design of Fillet Welds – Option 1- Without

Finally applying the factor of safety, Ω, and the resistance factor, ϕ, we get the familiar expressions:

For ASD: R_n/Ω = (1.856/2)DL = 0.928DL
For LRFD: ϕR_n = 0.75(1.856)DL = 1.392DL

And the units for the constants 0.928 (ASD) and 1.392 (LRFD) are kips per inch of length per 1/16 of weld leg.

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Design

Design of Fillet Welds – Option 2 - With

Section J2.4(b) allows the directional strength increase if strain compatibility of the various weld elements is considered.

$$R_n=0.6F_{EXX}(1.0+0.5\sin^{1.5}\theta)A_w$$

F_w = nominal unit stress, ksi
F_{EXX} = electrode classification number, i.e., minimum specified tensile strength, ksi
θ = angle of loading measured from the weld longitudinal axis, degrees

$\theta = 0^o$ $\theta = 90^o$

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Design

Design of Fillet Welds – Option 2 - With

Again this is more commonly written:

For ASD: $R_n/\Omega = 0.928(1.0+0.5\sin^{1.5}\theta)DL$
For LRFD: $\phi R_n = 1.392(1.0+0.5\sin^{1.5}\theta)DL$

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Design

Design of Fillet Welds – Option 2 - With

A User Note to Section J2.4(b) states:

"The instantaneous center method is a valid way to calculate the strength of weld groups consisting of weld elements in various directions based on strain compatibility."

We already discussed this related to behavior.

Design is easier if you understand behavior.

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Design

Design of Groove Welds

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Design

Design of Groove Welds

- The design of partial-joint-penetration (PJP) groove welds is very similar to the design of fillet welds. Except:
  - The directional strength increase does not apply.
  - The available tension stress is reduced.
- The available strength is given in Table J2.5 and the effective throat is given in Table J2.1.

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Design

Design of Groove Welds

- Complete-Joint-Penetration (CJP) welds, also sometimes referred to as Full Pen. Welds, are intended to develop the strength of the base metal.
- The filler metal must meet the requirements shown in Table J2.5.

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Economy

Economy of Welded Details

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Economy

Economy of Welded Details

- Do not over-specify welds.
  - allow fabricator to choose the weld best suited to the shop.
- Use single pass fillets where possible.
- Utilize the directional strength increase.
- Use PJP instead of CJP where possible.
- Avoid indiscriminate use of all-around symbol.

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Economy

Economy of Welded Details

- Favor the horizontal and flat positions.
- Avoid welding galvanized material.
- Welds do not in general need to develop the strength of the base metal.
- Excess welding can result in distortion.
- Select a preparation that minimizes weld volume for groove welds.
- In most cases backing for CJP can be left in place.

70

FAQs

Frequently Asked Questions

Q: Can the strength of an existing fillet weld be increased by adding passes?

A: Yes.

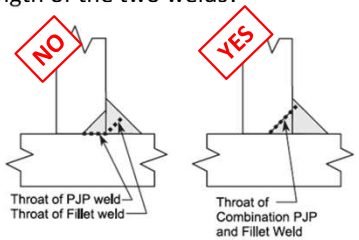
71

FAQs

Frequently Asked Questions

Q: Is the strength of a PJP reinforced with a fillet weld calculated by simply adding the strength of the two welds?

A: NO.



72

FAQs

Frequently Asked Questions

Q: Can the strength of an existing CJP groove weld be increased by adding weld (i.e. a reinforcing fillet)?

A: No. The strength of a CJP groove weld is limited by the base metal. The only way to increase the strength of the joint is to add material (base metal).

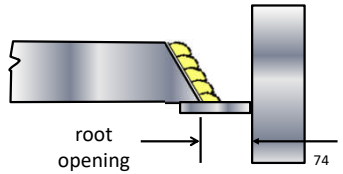
73

FAQs

Frequently Asked Questions

Q: Is there a way to address a CJP root opening that is too large?

A: Yes. Buttering passes can be applied to achieve prequalified geometry.



74

FAQs

Bolts vs. Welds

A rule of thumb is that welding should be done in the shop. Bolting can be done in either the shop or the field.

Obviously this is only a general rule, and exceptions are commonly encountered.

Fabricator preference should be considered. Note that a normally "welded" shop may prefer bolted connections if there is a lot of other welding already in the shop.

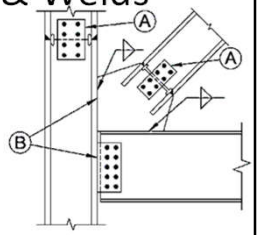
75

Sharing Load Between Bolts & Welds

Sharing of load between bolts and welds is not prohibited. It is addressed in *Specification* Section J1.8.

My advice is **DON'T DO IT**. I can count on one hand the number of times I have shared load between bolts and welds.

It is a complex topic and a bad idea. It is sometimes the only viable option for retrofit



Problematic bolted/welded member connections.
Fig. C-D2.2 – Commentary to Seismic Provisions.

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Welds

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Attendee-based Content

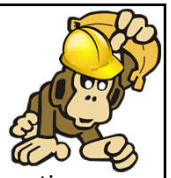
We have received quite a few questions and comments up to this point. Thank you for participating in our experiment.

By the very nature of this process I have had limited time to produce this discussion. The broad ideas are sound.

What follows is intended to be useful, not a definitive resource.

78

Bolts vs. Welds



BOLTING SHOULD BE SIMPLE!!!

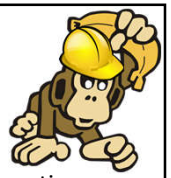
At the AISC Steel Solution Center we receive many more questions about bolts than about welds.

I suspect that if you could eliminate fit-up issues, one could train monkeys to install bolts in snug-tight joints.

KEEP BOLTING SIMPLE!!!

79

Bolts vs. Welds



BOLTING SHOULD BE SIMPLE!!!

At the AISC Steel Solution Center we receive many more questions about bolts than about welds.

I suspect that if you could eliminate fit-up issues, one could train monkeys to install bolts in snug-tight joints.

KEEP BOLTING SIMPLE!!!

I have a tremendous amount of respect for skilled ironworkers. Put their skills to work where it really matters.

Uncoordinated Conspiracy

There are a lot of products out there that are intended to make bolting simpler. These products can be useful when the bolting is complex, but most bolting in not complex and so simplification is not needed. Marketing efforts may convince you that you need something (pretensioning) you do not in fact need.

81

Uncoordinated Conspiracy

Inspectors also have incentives or assumptions related to pretensioning that might make you believe you need something you do not need. From *Specification* N5.6: "For snug-tight joints, pre-installation verification testing… and monitoring… are not applicable. The QCI and QAI **need not be present** during the installation of fasteners in snug-tight joints."

OTHER THINGS YOU MAY NOT NEED:

82

OR…

A secret international consortium have infiltrated our industry and are working to undermine bolting through a misinformation campaign intended to convince engineers that pretensioning is required when it is not.

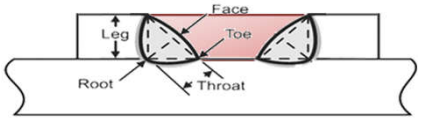
83

"Plug Welds" in Tension

Attendee Question: You have said regarding a fillet weld in a hole, being designed for tension, that the effective area would be the effective throat times the circumference of the circle. Is the effective throat the thickness of the material with the hole?

Answer: No.

The thickness of the material represents the weld size. The effective throat is 0.707 times the thickness of the material.



84

Yep.
That's it for the welding questions.

85

Painted Faying Surfaces

Attendee Question: What are the best methods of analyzing bolted connections with painted faying surfaces?

Answer: In general the same design methods are used for bolted connections with painted and unpainted faying surfaces.

The vast majority of bolted connections used in steel buildings can be left unpainted, installed as snug-tight, and designed as bearing-type connections.

86

Painted Faying Surfaces

Attendee Question: What are the best methods of analyzing bolted connection with painted faying surfaces?

Answer (cont.):The vast majority of bolted connections that must be painted but still fall within the scope of the *Specification* can be installed as snug-tight and designed as bearing-type connections. In such cases the presence of the paint is immaterial.

87

Painted Faying Surfaces

Attendee Question: What are the best methods of analyzing bolted connection with painted faying surfaces?

Answer (cont.): If the connection must be pretensioned but can still be designed as a bearing-type connection, then the only effect of the paint might be an inability to achieve or maintain the pretension.

This should only be a problem with very thick coatings (total coating thickness within the joint approaches 15 mils per surface).

88

Painted Faying Surfaces

The pretension in the joint pushes paint out of the faying surface. This can be time dependent (creep).

Pretension is reduced.

Loss of pretension (in rare cases where required) can lead to:

- Fatigue
- Loosening
- Slip

89

Painted Faying Surfaces

Attendee Question: What are the best methods of analyzing bolted connection with painted faying surfaces?

Answer (cont.): Other than to accommodate the use of oversize holes, slip critical connections are very rarely required.

When slip critical connections are required or a qualified faying surface is required the faying surfaces should be masked and left uncoated or a qualified coating must be used.

90

Preparation of Faying Surfaces

Attendee Question: How to evaluate bolted connections with less than ideal preparation of faying surfaces?

Answer: When slip critical connections are required the faying surfaces must be qualified:

- Unpainted clean mill scale steel
- Hot-dipped galvanized
- Paint tested in accordance with Appendix A of RCSC *Specification*.

91

Preparation of Faying Surfaces

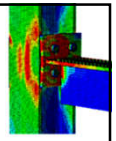
Attendee Question: How to evaluate bolted connections with less than ideal preparation of faying surfaces?

- Answer (cont.): “Where conditions are not covered by this Specification, designs are permitted to be based on tests or analysis, subject to the approval of the authority having jurisdiction. Alternative methods of analysis and design are permitted, provided such alternative methods or criteria are acceptable to the authority having jurisdiction.”

Use engineering judgment.

92

FEA



Attendee concerns related to FEA of bolted connections.

- Interpretation of high stresses around bolt holes
- Modeling of bolts as beams
- Constraint equations
- Location of bolt attachment: At bearing at hole, under head or washer?
- Should bolt loads and stresses from finite element models be used at all?
- Would it be better to use traditional bolted joint analysis calculations?

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FEA

My tips:

- Bolted connections are intended to be simple and easy.
- Keep them simple.
- If you are even thinking about using FEA to design bolted connections you:
  - might consider whether your application should be designed using the *Specification* at all.
  - must really love FEA

FEA is not simple and easy. There are just as many assumptions to be made and just as much judgement involved in FEA.

94

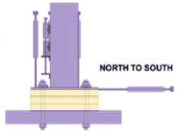
Thermal Breaks

Attendee Question: Can the presenter address thermal break connections?

Answer: Bolted connections incorporating materials other than steel and typical coatings are NOT addressed in either the AISC or RCSC specifications.

To my knowledge there are no standards.

Thermal breaks may be okay for "minor" connections.



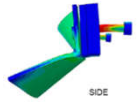
www.aisc.org/technical-resources/research/

95

Thermal Breaks

Attendee Question: Can the presenter address thermal break connections?

Answer: As a minimum I would consider:



- Bending in the bolt (similar to anchor rods in shear)
- The possibility of loss of pretension and its effect on loosening and fatigue
- Fire
- Rationality of increasing uncertainty relative to safety vs gain in thermal performance – stainless steel?

The 2020 RCSC Specification contains some Commentary. "Thermal break joints are not intended for primary load resisting systems."

96

Thermal Breaks

From Peterman report: "Manufactured structured thermal break assembly solutions are available that can be used in the design of cantilevered members such as those used to support a balcony… These solutions often involve forces substantially larger than those considered in this study.

The 2020 RCSC Specification contains some Commentary. "Thermal break joints are not intended for primary load resisting systems."

97

A Friendly Reminder - HOMEWORK!!!

Continue to submit your questions.

To prepare for Sessions 6 & 7 please be familiar with:

- Design Guide 29 – Example 5.11
- Design Guide 29 – Example A.1
- Manual Equations (9-2) & (9-3):
- Manual Design Examples – Example II.A-1B
- Manual Design Examples – Example II.A-19B
- The *Specification* Section J10.5 Web Compression Buckling

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Thank you!

AISC | Questions

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Individual Session Registrants

PDH Certificates

- All WFH individuals associated with a group registration will be issued a certificate.
- All individuals attending at your connection: you will receive an email on how to report their 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!

8-Session Registrants

PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

8-Session Registrants

Access to the quiz

Information for accessing the quiz will be emailed to you by Thursday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

Quiz and attendance records

Posted Thursday mornings. www.aisc.org/nightschool -- Click on Current Course Details.

Reasons for quiz

- EEU – You must take all quizzes and the final exam to receive EEU.
- PDHs – If you watch a recorded session, you must pass quiz for PDHs.
- REINFORCEMENT – Reinforce what you learn tonight. Get more out of the course.

Note: If you attend the live presentation, you do not have to take the quizzes to receive PDHs

8-Session Registrants

Access to the recording

Information for accessing the recording will be emailed to you by Thursday. The recording will be available for four weeks. (For 8-session registrants only.) EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

PDHs via recording

If you watch a recorded session, you must take *and pass* the quiz for PDHs.

8-Session Registrants

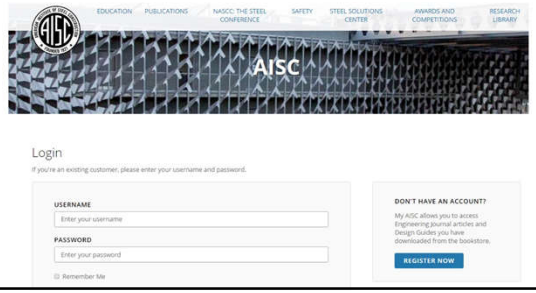
Night School Resources

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

8-Session Registrants

Night School Resources

Go to www.aisc.org and sign in.



8-Session Registrants

Night School Resources

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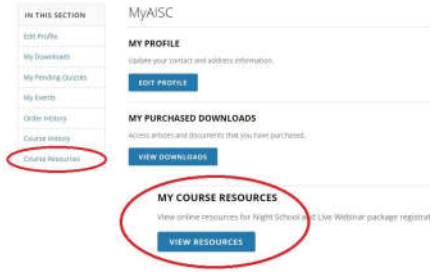


8-Session Registrants

Night School Resources

Course Resources

8-Session Registrants

Night School Resources

Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

8-Session Registrants

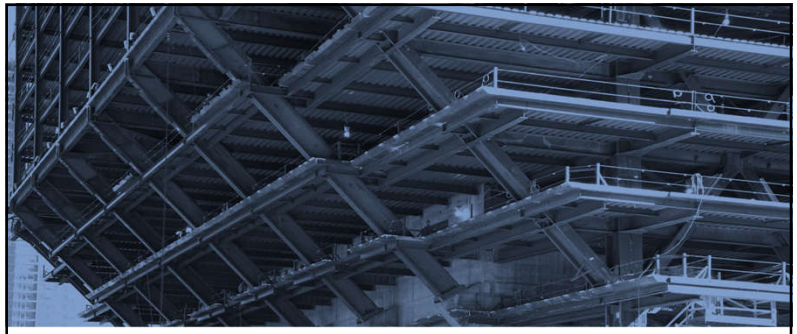
Night School Resources

- Weekly "quiz and recording" email.
- Weekly updates of the master quiz and attendance record, found at www.aisc.org/nightschool26. Scroll down to Quiz and Attendance records.
  - Updated on Friday mornings.

8-Session Registrants

Night School Resources

- Webinar connection information
  - Reminder email sent out Tuesday mornings
- Links to handouts also found here



AISC | Thank you

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