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Course Description

Weld Inspection: What Matters and What Doesn't

November 13, 2014

Attendees at this live webinar will learn all about weld discontinuities (which ones matter and which ones don't) and what nondestructive testing (NDT) methods do and don't tell us. In addition, the presentation will offer advice on determining which NDT methods are appropriate for different situations.

Learning Objectives

- Become familiar with common terminology and configurations in welded connections.
- Gain an understanding of what is important (and what is not) when inspecting welded connection.
- Gain an understanding of nondestructive testing methods for welded connections.
- Learn and understand the weld inspection requirements in the applicable codes and standards.

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Weld Inspection: What Matters and What Doesn't

written and presented by
Duane K. Miller, Sc. D., P.E.
Manager, Engineering Services,
The Lincoln Electric Company,
Cleveland, OH.

structural STEEL

There's always a solution in steel.

WELD INSPECTION

What Matters? And What Don't?

There's always a solution in steel.

WELD INSPECTION

What Matters? And What Don't?

Delivery of a structure that will meet the present and future needs of the Owner.

There's always a solution in steel.

WELD INSPECTION

What Matters? And What Don't?

Achieving a level of perfection that will not affect the present or future performance of the structure.

Perfection

"People call me a perfectionist, but I'm not. I'm a 'rightist.' I do something until it's right, and then I move on to the next thing."

James Cameron
Canadian Film Director
1954-

WELD INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

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WELD INSPECTION

THEN

What Matters? And What Don't?

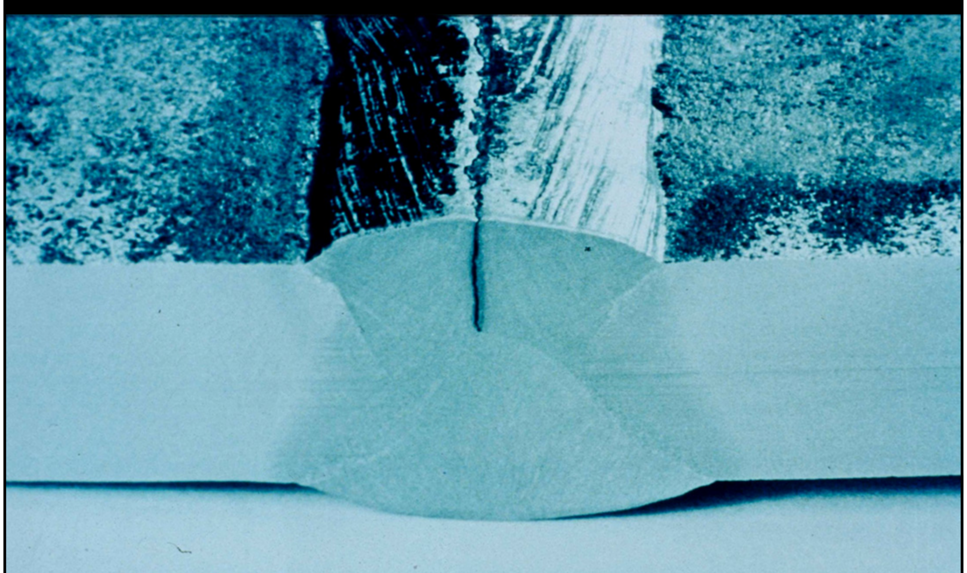
14

WELD INSPECTION

What Matters? And What Don't?

15

Crack in the weld



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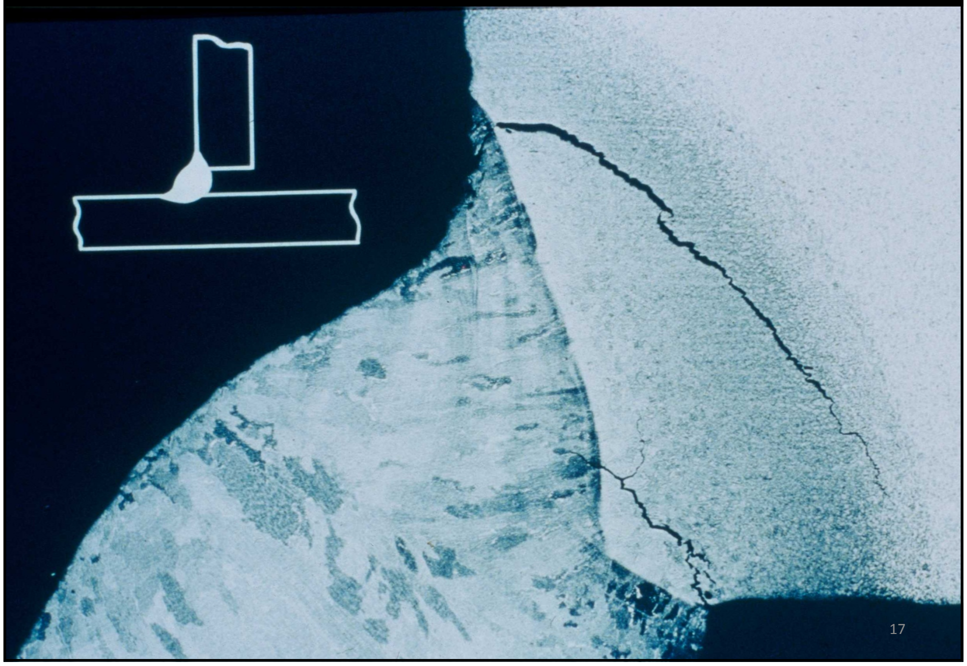
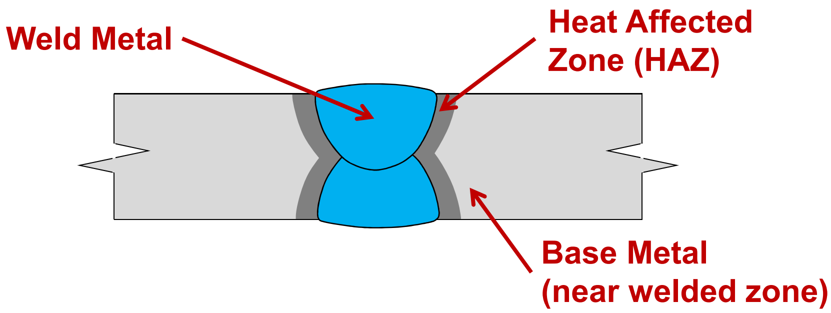
Crack in the heat affected zone



Lamellar tear

18

Welded Connection
~~WELD~~ INSPECTION



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Welded Connection
~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
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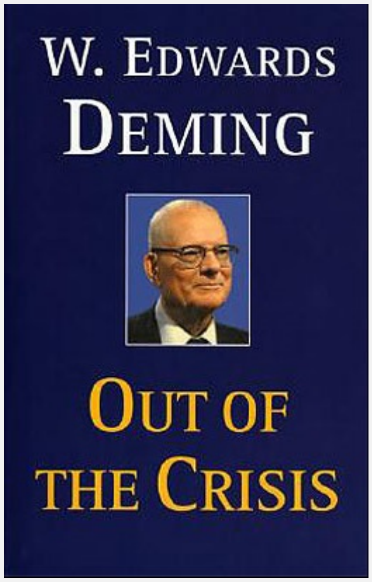
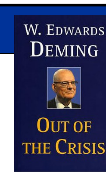


Out of the Crisis (1986)

W. Edwards Deming
1900-1993

21

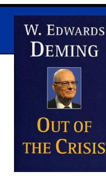
Deming: Out of the Crisis



Defects are not free. Somebody makes them, and gets paid for making them.

22

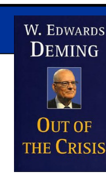
Deming: Out of the Crisis



The supposition is prevalent the world over that there would be no problems in production or service if only our production workers would do their jobs in the way that they we taught. Pleasant dreams. The workers are handicapped by the system, and the system belongs to the management.

23

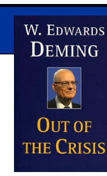
Deming: Out of the Crisis



Quality comes not from inspection, but from improvement of the production process.

24

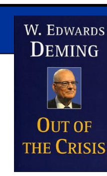
Deming: Out of the Crisis



As Harold S. Dodge said many years ago, 'You cannot inspect quality into a product.' The quality is there or it isn't by the time it's inspected.

25

Deming: Out of the Crisis



We cannot rely on mass inspection to improve quality, though there are times when 100 percent inspection is necessary.

26

Welded Connection
~~WELD~~ INSPECTION

Background

Quality Theory

A quality program is more, much more, than mere after-the-fact inspection. A quality program must focus on the process.

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Welded Connection
~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

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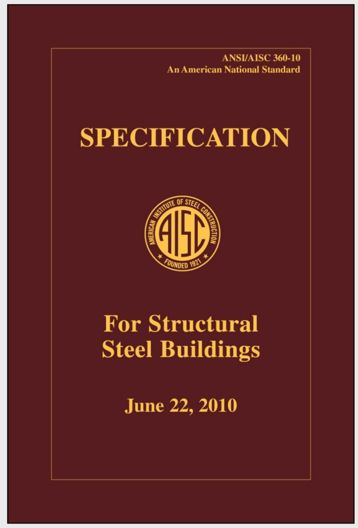
AISC 360-10

SPECIFICATION
For Structural
Steel Buildings



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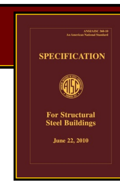
AISC 360-10 SPECIFICATION



CHAPTER N

QUALITY CONTROL AND QUALITY ASSURANCE

This chapter addresses minimum requirements for *quality control*, *quality assurance* and *nondestructive testing* for *structural steel* systems and steel elements of composite members for buildings and other structures.

30

AISC 360-10 SPECIFICATION

N5. MINIMUM REQUIREMENTS FOR INSPECTION OF STRUCTURAL STEEL BUILDINGS

4. Inspection of Welding

Observation of welding operations and visual inspection of in-process and completed welds shall be the primary method to confirm that the materials, procedures and workmanship are in conformance with the construction documents.

31

TABLE N5.4-1
Inspection Tasks Prior to Welding

Inspection Tasks Prior to Welding	QC	QA
Welding procedure specifications (WPSs) available	P	P
Manufacturer certifications for welding consumables available	P	P
Material identification (type/grade)	O	O
Welder identification system[1]	O	O
Fit-up of groove welds (including joint geometry) • Joint preparation • Dimensions (alignment, root opening, root face, bevel) • Cleanliness (condition of steel surfaces) • Tacking (tack weld quality and location) • Backing type and fit (if applicable)	O	O
Configuration and finish of access holes	O	O
Fit-up of fillet welds • Dimensions (alignment, gaps at root) • Cleanliness (condition of steel surfaces) • Tacking (tack weld quality and location)	O	O
Check welding equipment	O	—

[1] The fabricator or erector, as applicable, shall maintain a system by which a welder who has welded a joint or member can be identified. Stamps, if used, shall be the low-stress type.

32

TABLE N5.4-2
Inspection Tasks During Welding

Inspection Tasks During Welding	QC	QA
Use of qualified welders	O	O
Control and handling of welding consumables • Packaging • Exposure control	O	O
No welding over cracked tack welds	O	O
Environmental conditions • Wind speed within limits • Precipitation and temperature	O	O
WPS followed • Settings on welding equipment • Travel speed • Selected welding materials • Shielding gas type/flow rate • Preheat applied • Interpass temperature maintained (min./max.) • Proper position (F, V, H, OH)	O	O
Welding techniques • Interpass and final cleaning • Each pass within profile limitations • Each pass meets quality requirements	O	O

33

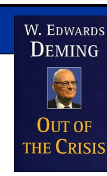
TABLE N5.4-3
Inspection Tasks After Welding

Inspection Tasks After Welding	QC	QA
Welds cleaned	O	O
Size, length and location of welds	P	P
Welds meet visual acceptance criteria • Crack prohibition • Weld/base-metal fusion • Crater cross section • Weld profiles • Weld size • Undercut • Porosity	P	P
Arc strikes	P	P
k-area[1]	P	P
Backing removed and weld tabs removed (if required)	P	P
Repair activities	P	P
Document acceptance or rejection of welded joint or member	P	P

[1] When welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, visually inspect the web *k*-area for cracks within 3 in. (75 mm) of the weld.

34

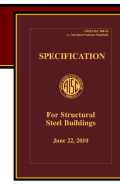
Deming: Out of the Crisis



Quality comes not from inspection, but from improvement of the production process.

35

AISC 360-10 SPECIFICATION



5. Nondestructive Testing of Welded Joints

5b. CJP Groove Weld NDT

For structures in Risk Category III or IV of Table 1-1, Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake and Ice Loads, of ASCE/SEI 7, Minimum Design Loads for Buildings and Other Structures, UT shall be performed by QA on all CJP groove welds subject to transversely applied tension loading in butt, T- and corner joints, in materials 5/16 in. (8 mm) thick or greater. For structures in Risk Category II, UT shall be performed by QA on 10% of CJP groove welds in butt, T- and corner joints subject to transversely applied tension loading, in materials 5/16 in. (8 mm) thick or greater.

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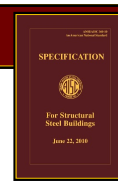
AISC 360-10 SPECIFICATION



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5b. CJP Groove Weld NDT

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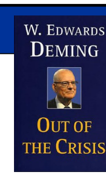
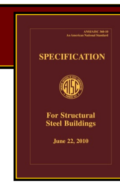
Deming: Out of the Crisis



We cannot rely on mass inspection to improve quality, though there are times when 100 percent inspection is necessary.

38

AISC 360-10 SPECIFICATION



5. Nondestructive Testing of Welded Joints

5b. CJP Groove Weld NDT

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Inspection frequency reflects risk.

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Welded Connection

~~WELD~~ INSPECTION

Background

NDT and Quality Programs

Chapter N and AWS D1.1 focus on both process control as well as NDT. Neither relies solely on 100% nondestructive testing.

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Welded Connection
~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

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AWS A3.0 Standard Welding Terms and Definitions

Discontinuity

An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

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AWS A3.0 Standard Welding Terms and Definitions

Defect.

A discontinuity or discontinuities that by nature of accumulated effect render a part or product unable to meet applicable acceptance standards or specifications. The term designates rejectability.

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Types of Weld Discontinuities

- **Two dimensional** (planar) **2D**
- **Three dimensional** (volumetric) 3D

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Types of Weld Discontinuities

V

- **Easily Visually Discerned**
- **Requires Volumetric NDT**

NDT

45

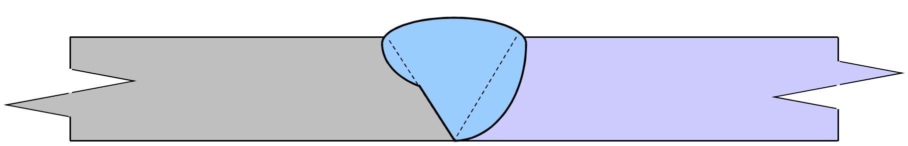
AWS A3.0 Standard Welding Terms and Definitions

2D

Incomplete fusion (IF).

A weld discontinuity in which fusion did not occur between the weld metal and the fusion faces or the adjoining weld beads.

NDT



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AWS A3.0 Standard Welding Terms and Definitions

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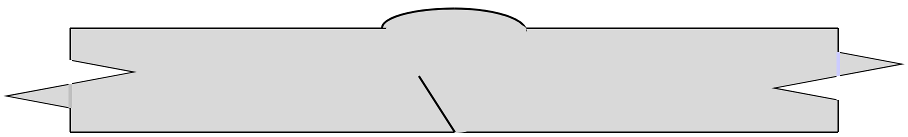
NDT



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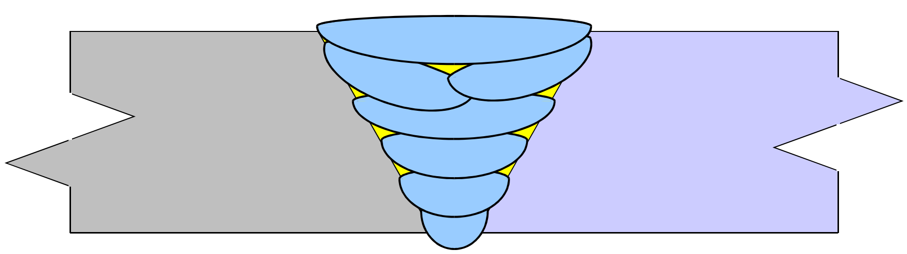
AWS A3.0 Standard Welding Terms and Definitions

2D 3D

Incomplete fusion (IF).

A weld discontinuity in which fusion did not occur between the weld metal and the fusion faces or the adjoining weld beads.

NDT



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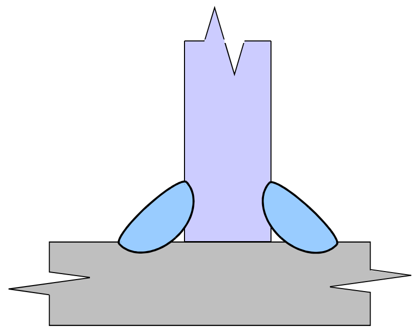
AWS A3.0 Standard Welding Terms and Definitions

2D 3D

Incomplete fusion (IF).

A weld discontinuity in which fusion did not occur between the weld metal and the fusion faces or the adjoining weld beads.

N D T



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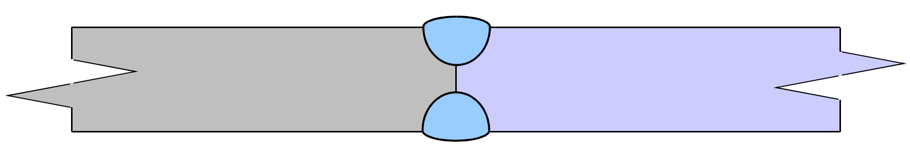
AWS A3.0 Standard Welding Terms and Definitions

2D

Incomplete joint penetration (IJP).

A joint root condition in a groove weld in which weld metal does not extend through the joint thickness.

N D T



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AWS A3.0 Standard Welding Terms and Definitions

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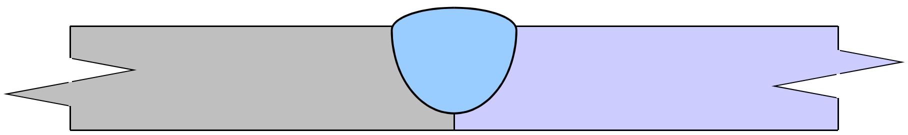

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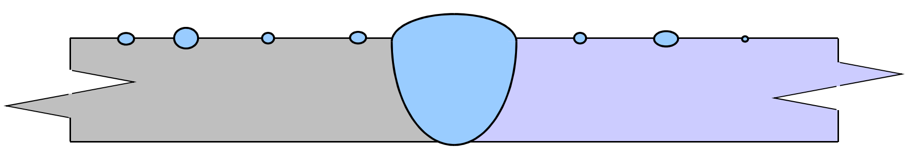
AWS A3.0 Standard Welding Terms and Definitions

3D

spatter

The metal particles expelled during fusion welding that do not form part of the weld.

V



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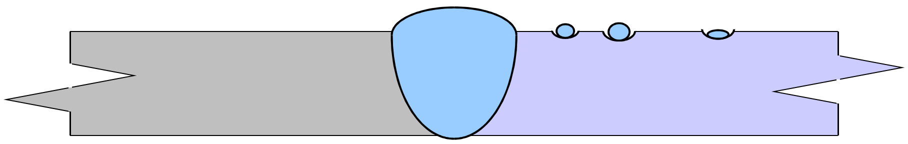
AWS A3.0 Standard Welding Terms and Definitions

3D

Arc strike

A discontinuity resulting from an arc, consisting of any localized melted metal, heat-affected metal, or change in the surface profile of any metal object.

V



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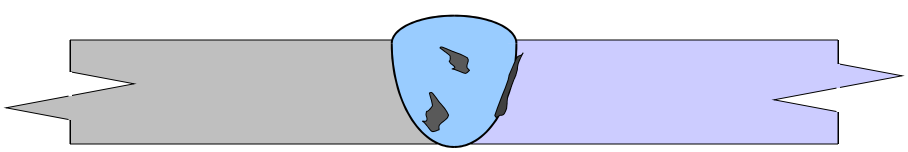
AWS A3.0 Standard Welding Terms and Definitions

3D

Slag intrusion

A discontinuity consisting of slag in weld metal or along the weld interface.

NDT



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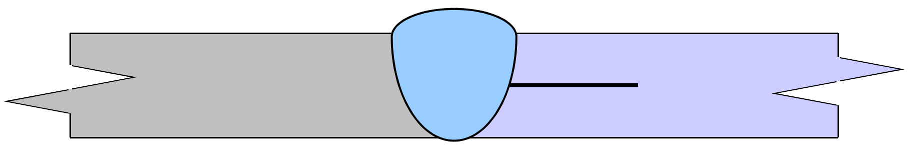
AWS A3.0 Standard Welding Terms and Definitions

2D

lamination

A type of discontinuity with separation or weakness generally aligned parallel to the worked surface of a metal.

NDT



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AWS A3.0 Standard Welding Terms and Definitions

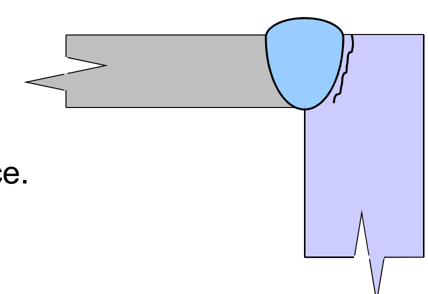
2D

Lamellar tear

A subsurface terrace and step-like crack in the base metal with a basic orientation parallel to the wrought surface created by tensile stresses in the through-thickness direction of the base metals weakened by the presence of small disperse, planar-shaped, nonmetallic inclusions parallel to the metal surface.

NDT

V



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AWS A3.0 Standard Welding Terms and Definitions

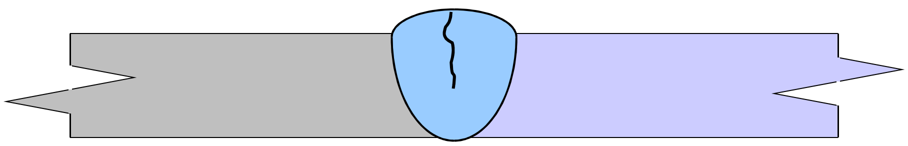
2D

crack

A fracture-type discontinuity characterized by a sharp tip and a high ratio of length and width to opening displacement.

NDT

V



Crack in weld

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AWS A3.0 Standard Welding Terms and Definitions

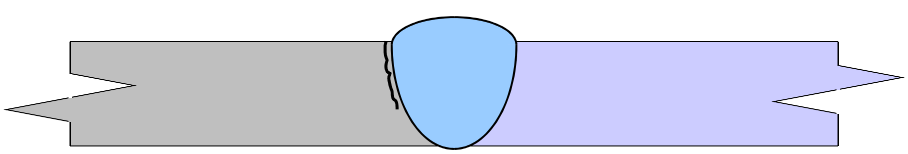
2D

crack

A fracture-type discontinuity characterized by a sharp tip and a high ratio of length and width to opening displacement.

NDT

V



Crack in heat affected zone

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AWS A3.0 Standard Welding Terms and Definitions

3D

Porosity

Cavity-type discontinuities formed by gas entrapment during solidification or in a thermal spray deposit

NDT

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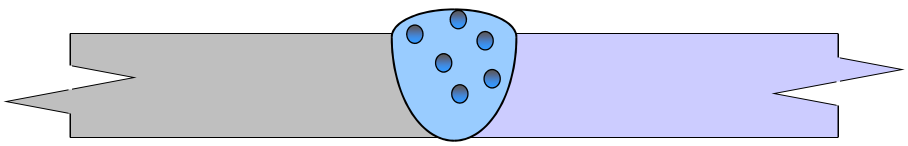

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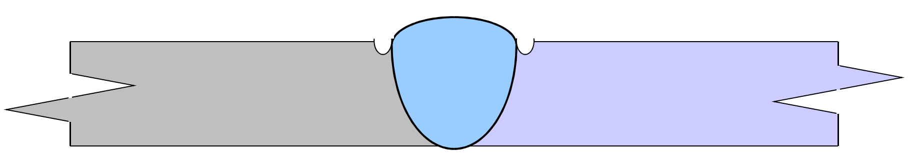
AWS A3.0 Standard Welding Terms and Definitions

3D

Undercut

A groove melted into the base metal adjacent to the weld to or weld root and left unfilled by weld metal.

V



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3D

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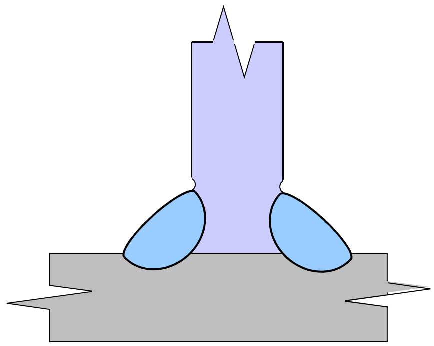

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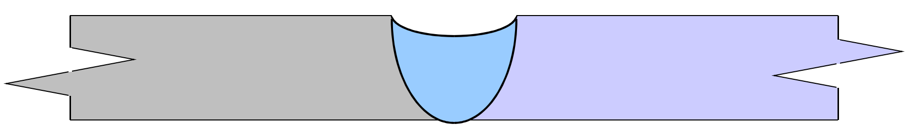
AWS A3.0 Standard Welding Terms and Definitions

3D

Underfill

A groove weld condition in which the weld face or root surface is below the adjacent surface of the base metal.

V



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AWS A3.0 Standard Welding Terms and Definitions

2D 3D

Overlap

The protrusion of weld metal beyond the weld toe of weld root.

NDT

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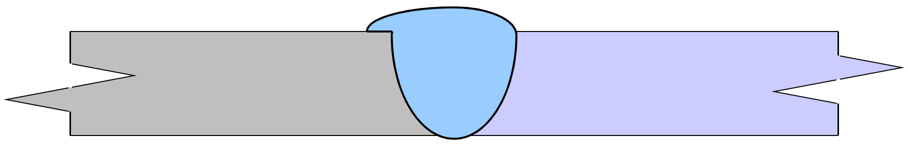

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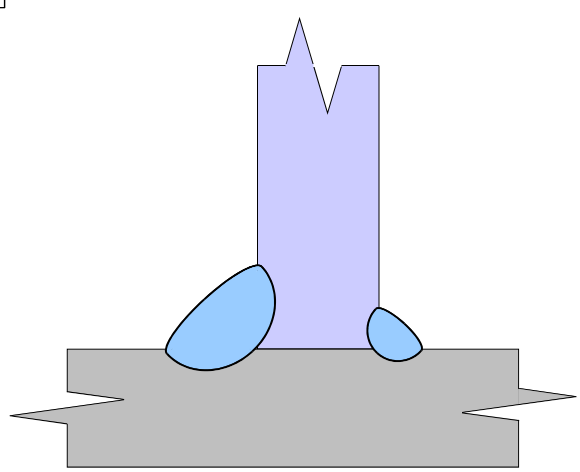
Discontinuities

3D

Undersize

V



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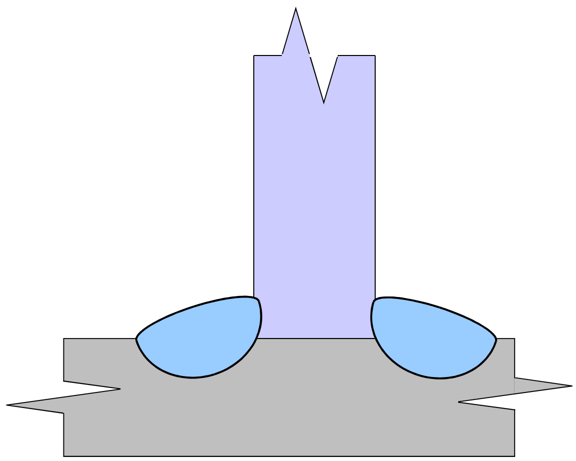
Discontinuities

3D

Unequal Leg Size



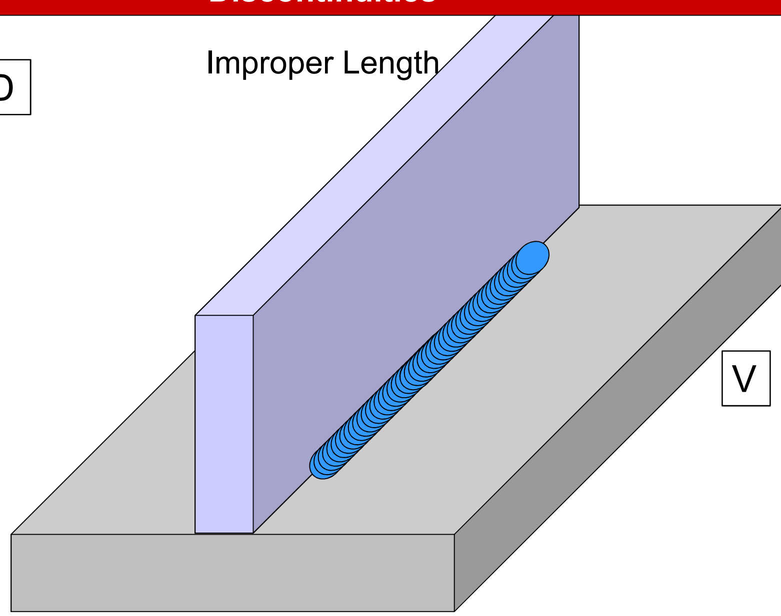
V

65

Discontinuities

3D

Improper Length



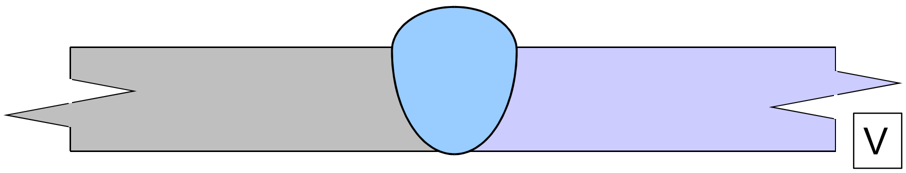
V

66

Discontinuities

3D

Excessive Reinforcement



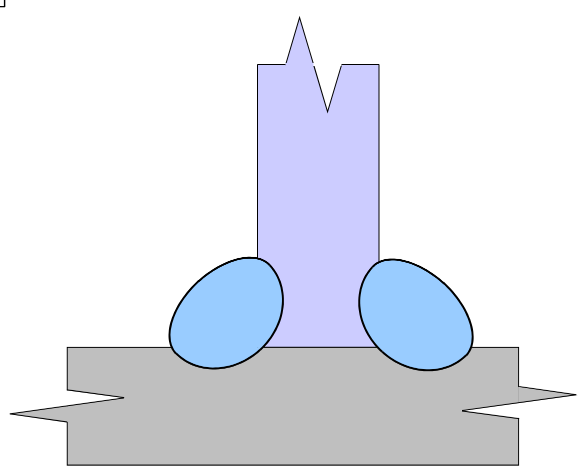
V

67

Discontinuities

3D

Excessive Reinforcement



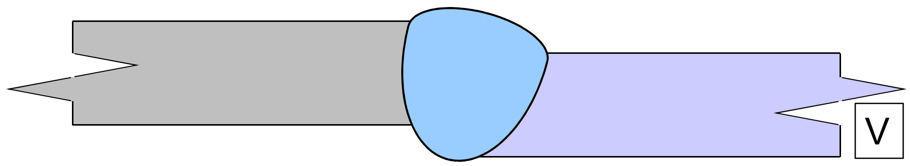
V

68

Discontinuities

3D

Misalignment

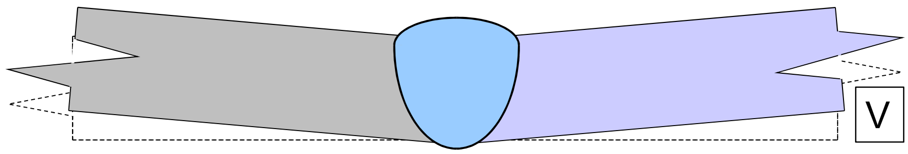


69

Discontinuities

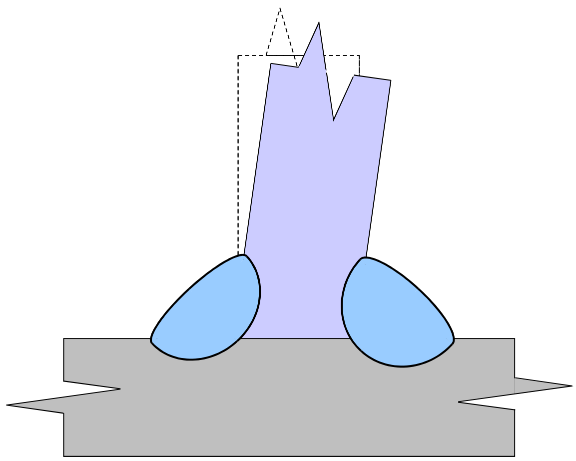
3D

Excessive Angular Distortion



70

Discontinuities



71

	2D	3D
Visual	Cracks Lamellar tears	Spatter Arc Strikes Porosity Undercut Overlap Size/Length Misalignment Distortion
NDT	Incomplete fusion Incomplete penetration Laminations Lamellar tears Cracks Overlap	Slag inclusions Porosity

Welded Connection

~~WELD~~ INSPECTION

Background

Weld Discontinuities

- Discontinuities and defects
- 3D and 2D
- Visible and detectable only with NDT

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Welded Connection

~~WELD~~ INSPECTION

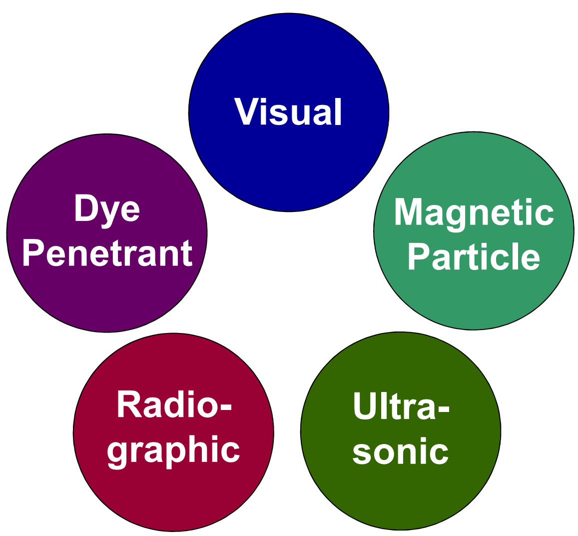
Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

74

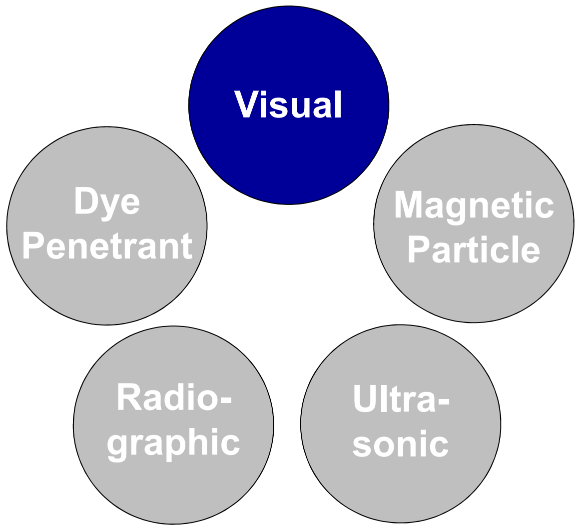
The Big Five
Of Africa

The Big Five
Of Weld Inspection



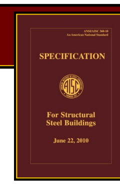
76

The Big Five Of Weld Inspection



77

AISC 360-10 SPECIFICATION



N5. MINIMUM REQUIREMENTS FOR INSPECTION OF STRUCTURAL STEEL BUILDINGS

4. Inspection of Welding

Observation of welding operations and visual inspection of in-process and completed welds shall be the primary method to confirm that the materials, procedures and workmanship are in conformance with the construction documents.

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TABLE N5.4-1
Inspection Tasks Prior to Welding

Inspection Tasks Prior to Welding	QC	QA
Welding procedure specifications (WPSs) available	P	P
Fit-up of fillet welds • Dimensions (alignment, gaps at root) • Cleanliness (condition of steel surfaces) • Tacking (tack weld quality and location)	O	O
Check welding equipment	O	—

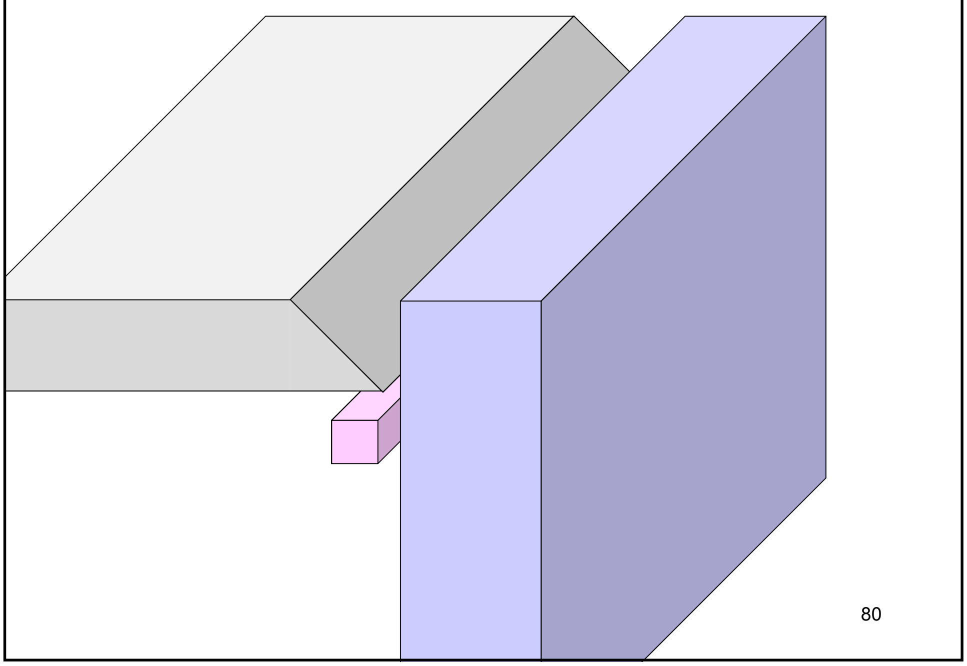
[1] The fabricator or erector, as applicable, shall maintain a system by which a welder who has welded a joint or member can be identified. Stamps, if used, shall be the low-stress type.

Fit-up of groove welds (including joint geometry)

- **Joint preparation**
- **Dimensions (alignment, root opening, root face bevel)**
- **Cleanliness (condition of steel surfaces)**
- **Tacking (tack weld quality and location)**
- **Backing type and fit (if applicable)**

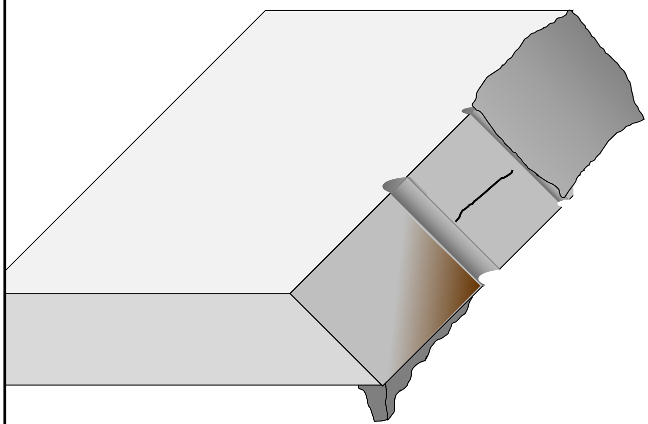
79

Prior to Welding



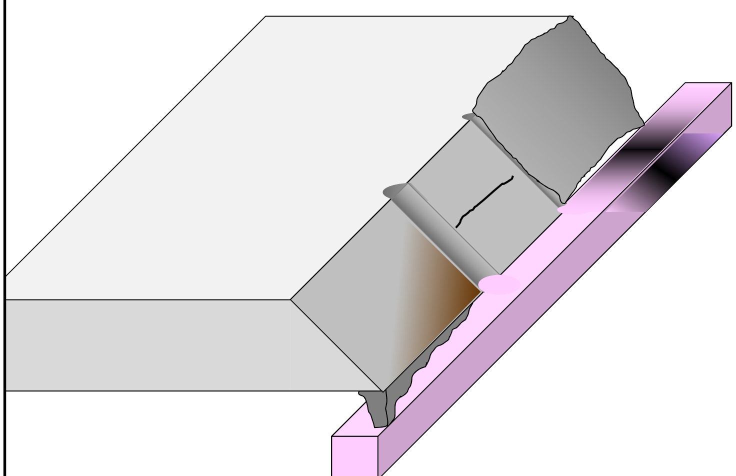
80

Prior to Welding



81

Prior to Welding



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Prior to Welding

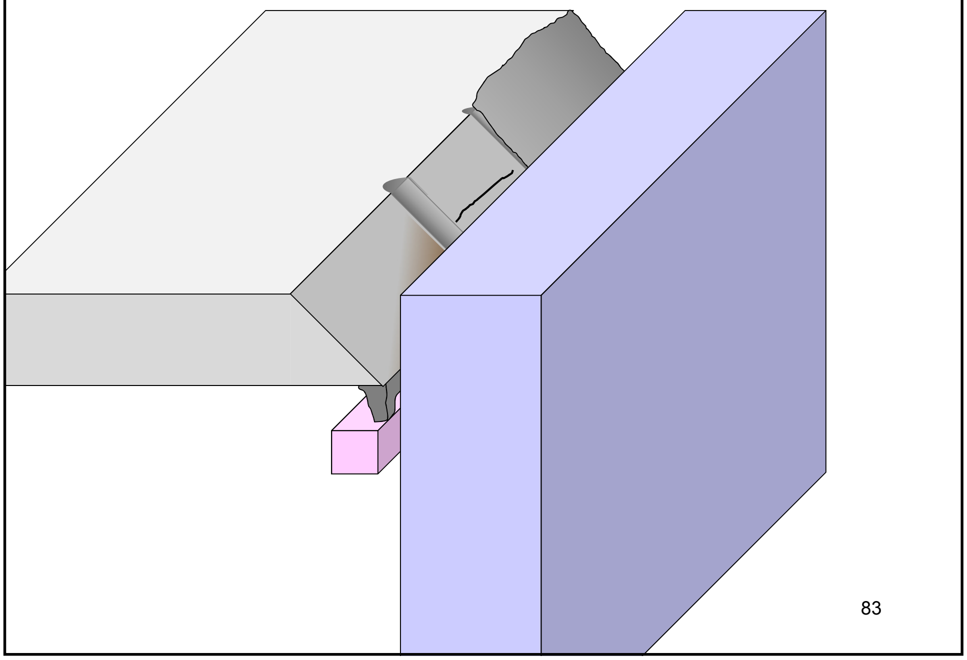

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TABLE N5.4-2
Inspection Tasks During Welding

WPS followed
- **Settings on welding equipment**
- **Travel speed**
- **Selected welding materials**
- **Shielding gas type/flow rate**
- **Preheat applied**
- **Interpass temperature maintained (min./max.)**
- **Proper position (F, V, H, OH)**

Welding techniques • Interpass and final cleaning • Each pass within profile limitations • Each pass meets quality requirements	O	O

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During Welding

85

TABLE N5.4-3
Inspection Tasks After Welding

Welds meet visual acceptance criteria

- **Crack prohibition**
- **Weld/base-metal fusion**
- **Crater cross section**
- **Weld profiles**
- **Weld size**
- **Undercut**
- **Porosity**

Document acceptance or rejection of welded joint or member	P	P

[1] When welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, visually inspect the web *k*-area for cracks within 3 in. (75 mm) of the weld.

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After Welding

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NDT Methods: Visual Inspection

Advantages

- The primary way to perform Chapter N inspections
- Prior-During-After welding
- Low cost
- Part of “process control”
- Is the only inspection method that can actually improve quality

Limitations

- Easy to overlook
- Easy to minimize
- Good light needed
- Good eyesight needed
- Limited to visually discernable effects

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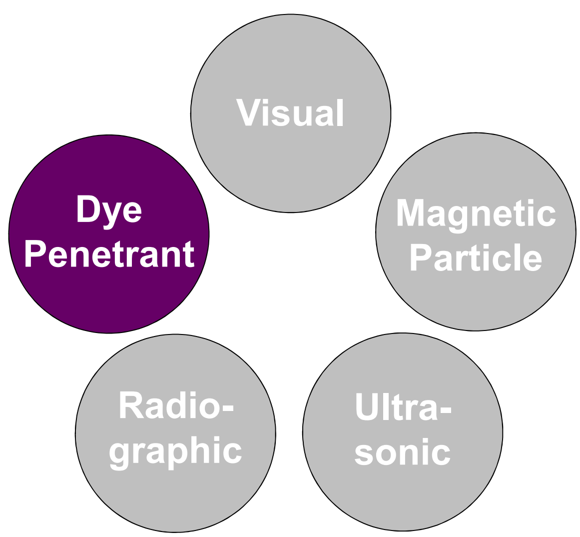
The Big Five
Of Weld Inspection

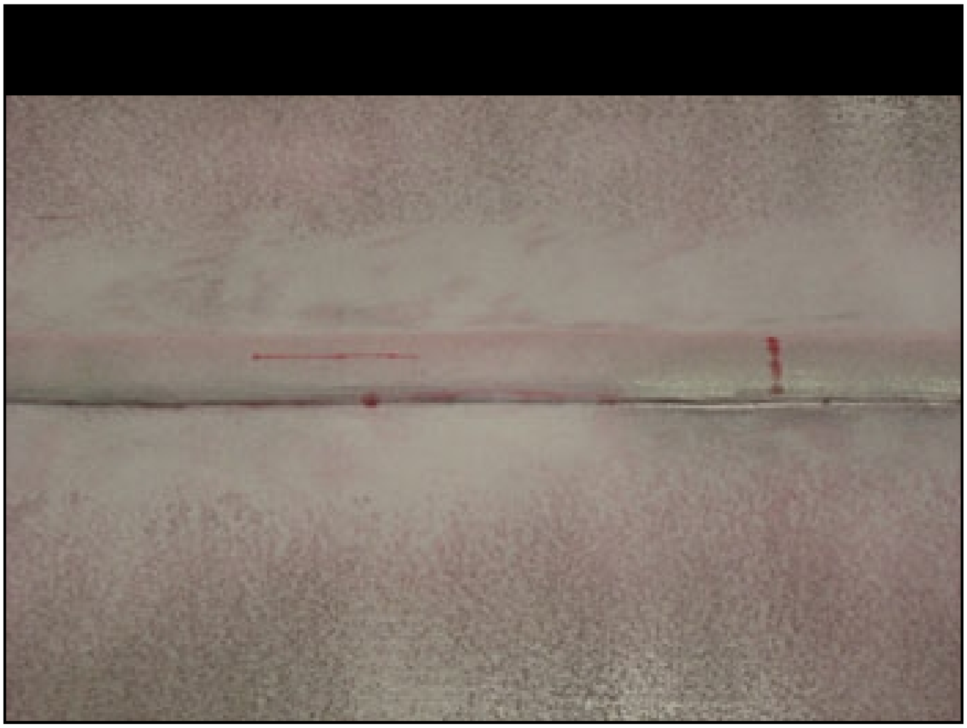


90


SPOTCHECK
SKC-S
Cleaner/Remover


SPOTCHECK
SKL-SP1


SPOTCHECK
SKD-S2
Developer
MAGNAFLUX



NDT Methods: Dye Penetrant Testing (PT)

Advantages

- Greatly enhances visual inspection
- Easy to perform
- Low cost
- Works on non-magnetic material
- Very effective on surface-breaking cracks

Limitations

- Limited to surface-breaking discontinuities
- Messy
- Interpretation may be difficult (weld toes)

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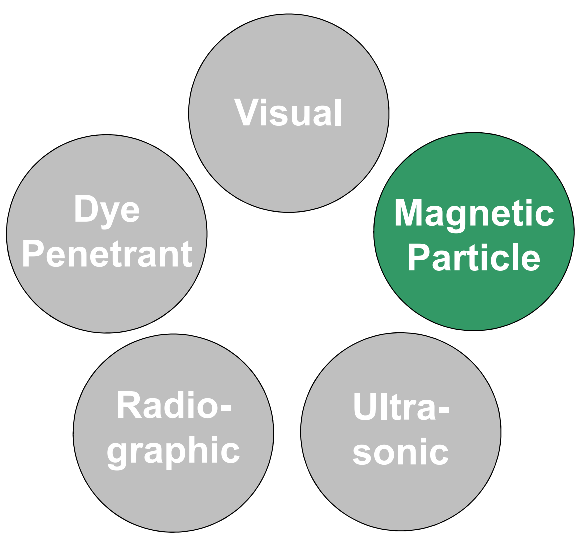
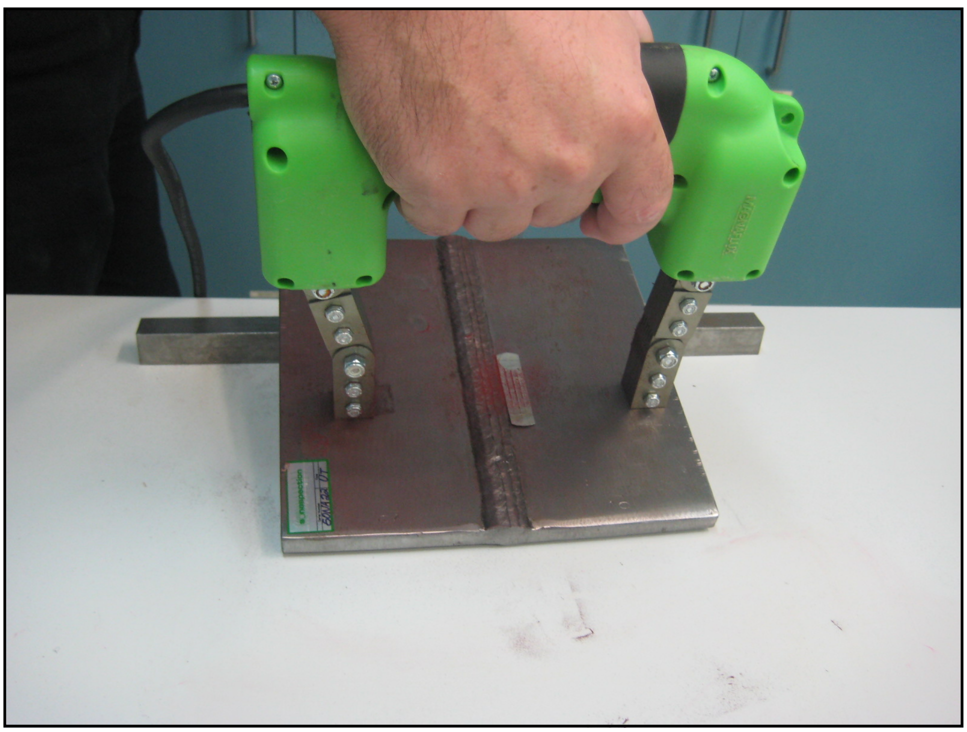
The Big Five Of Weld Inspection



98

99



NDT Methods: Magnetic Particle Testing (MT)

Advantages

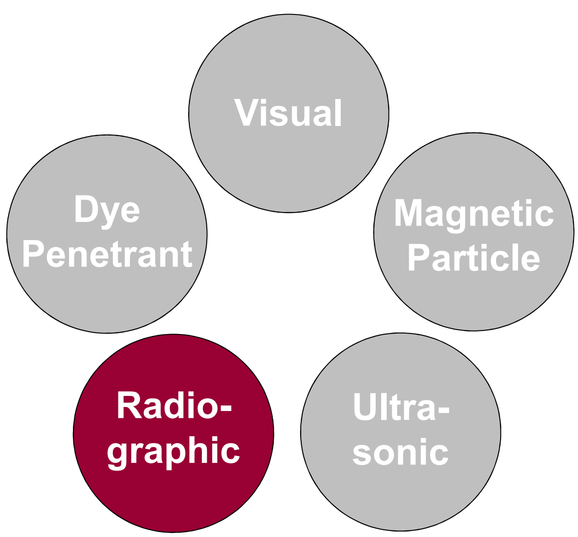
- Greatly enhances visual inspection
- Easy to perform
- Low cost
- Very effective on surface-breaking cracks
- Some sub-surface detection capability

Limitations

- Limited to near surface discontinuities
- Interpretation may be difficult (weld toes)
- With prod method, may leave arc strikes
- Material must be magnetic

101

The Big Five Of Weld Inspection



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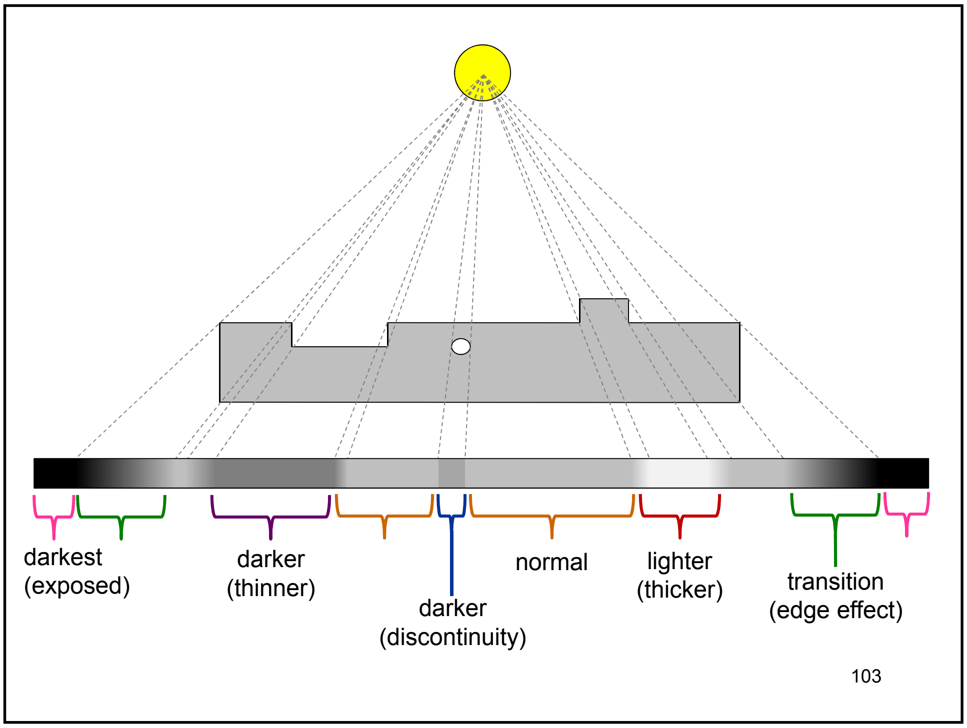
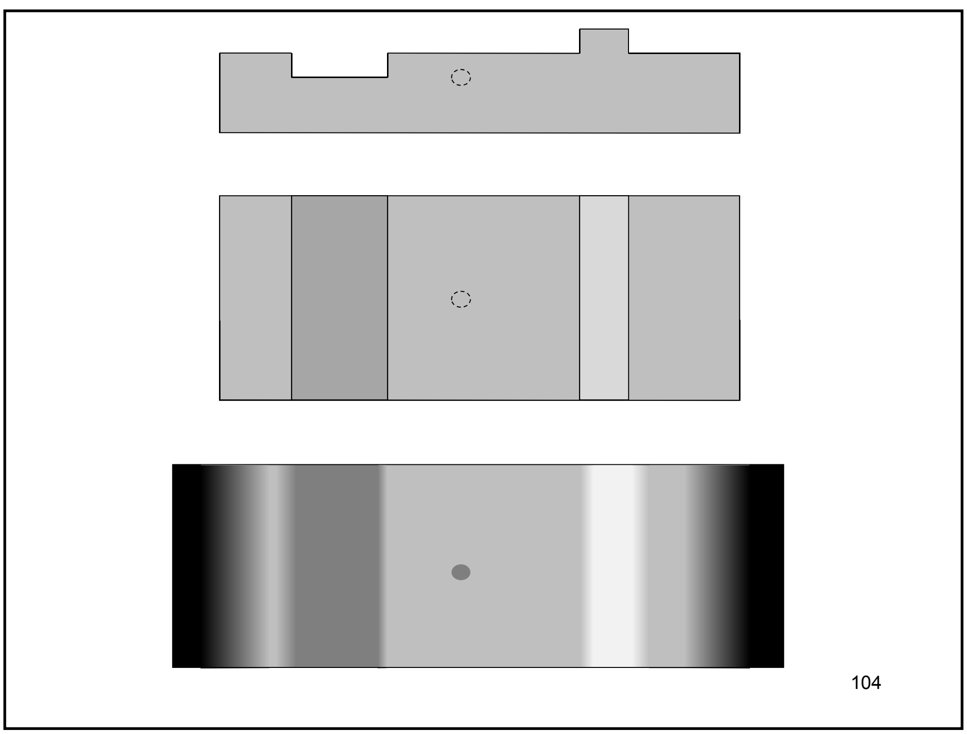

darkest
(exposed)
darker
(thinner)
darker
(discontinuity)
normal
lighter
(thicker)
transition
(edge effect)
103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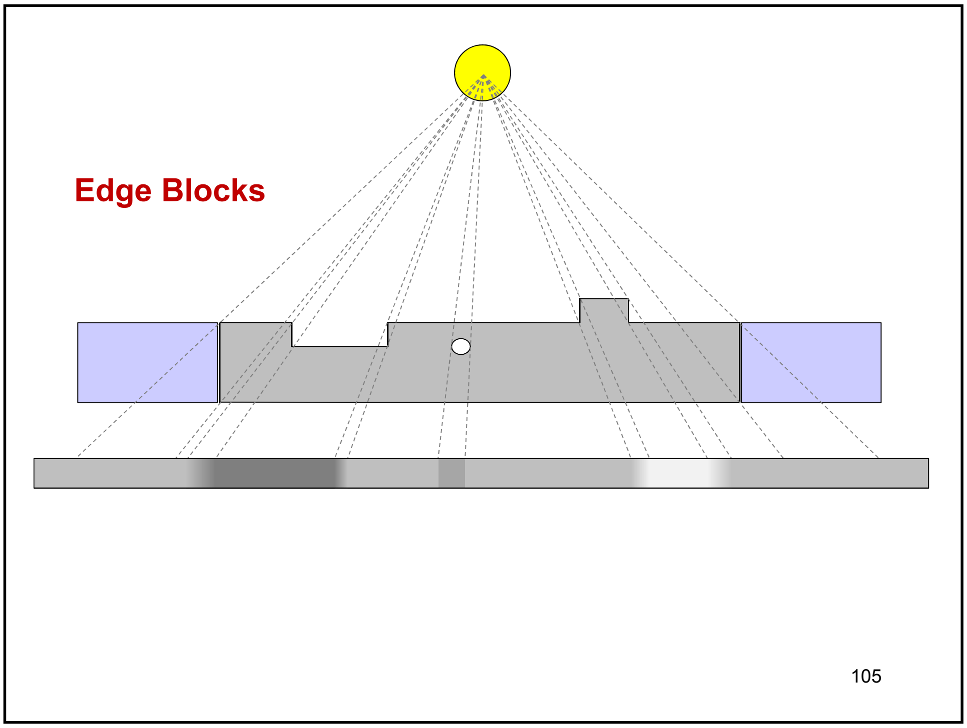
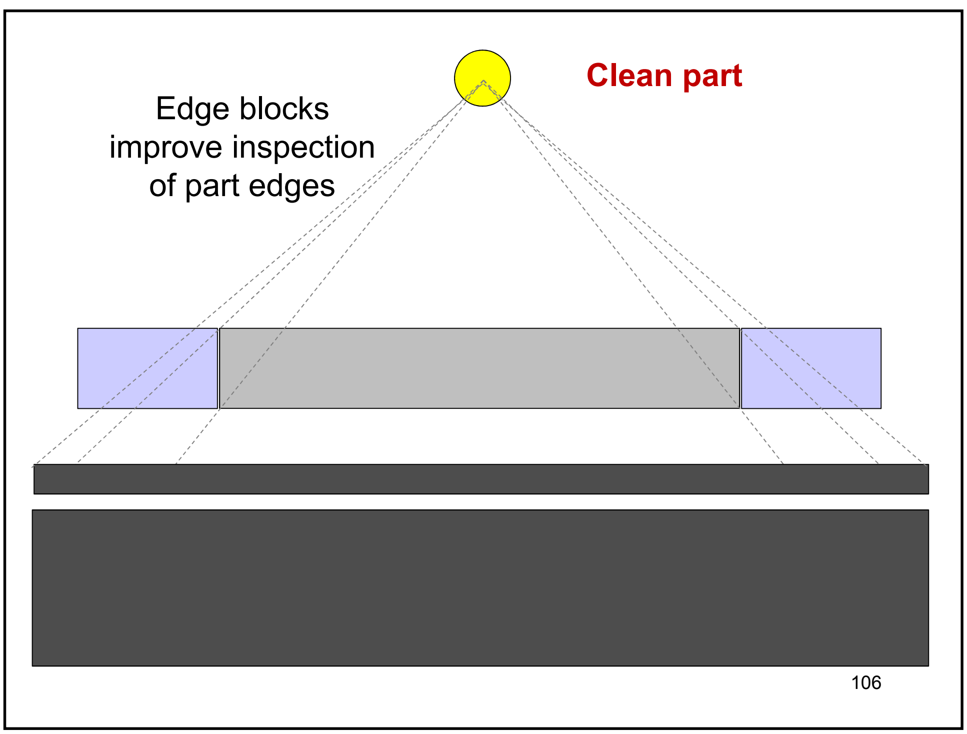
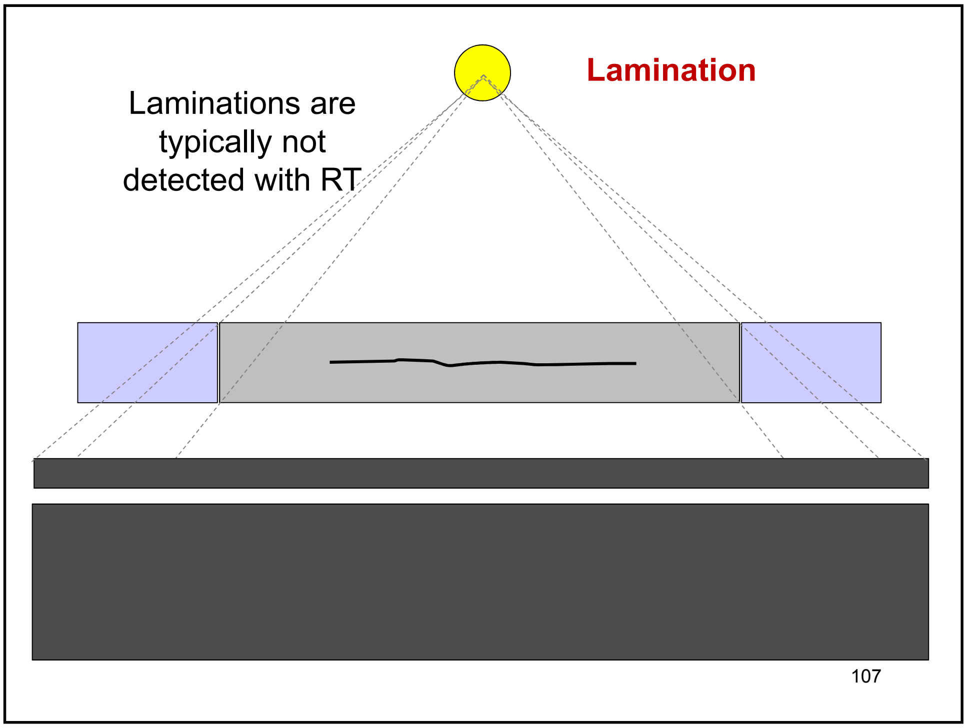
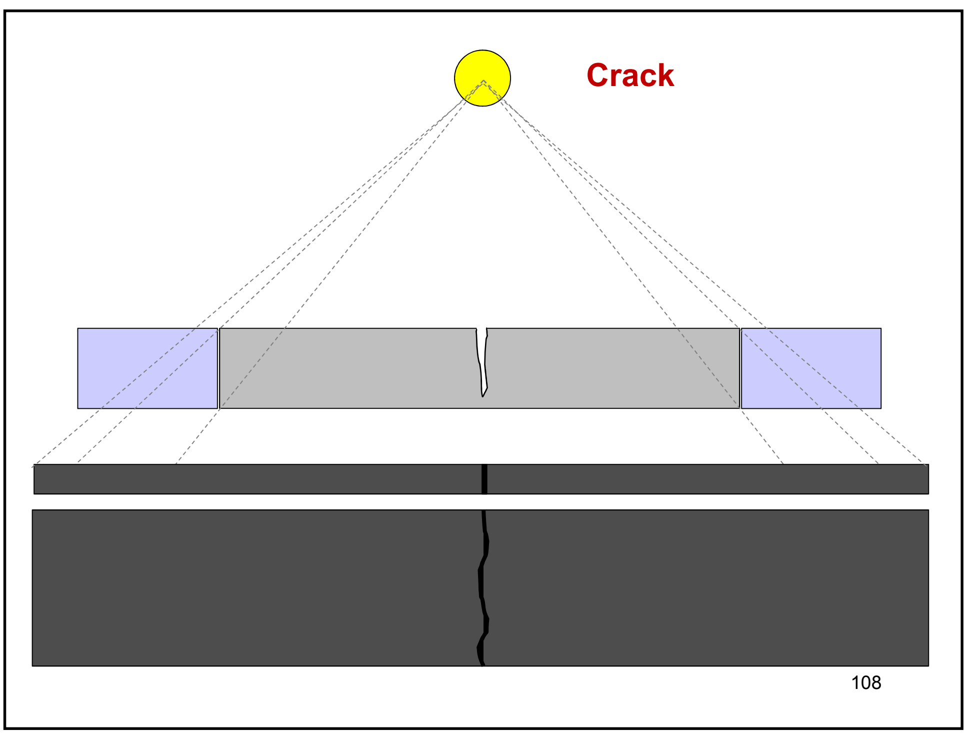
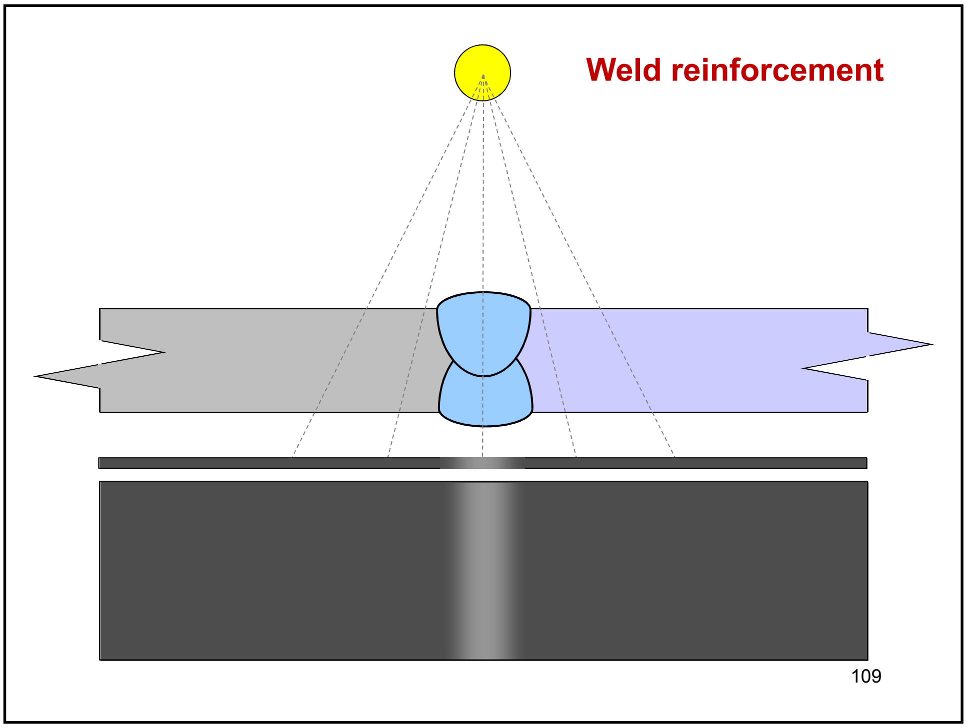
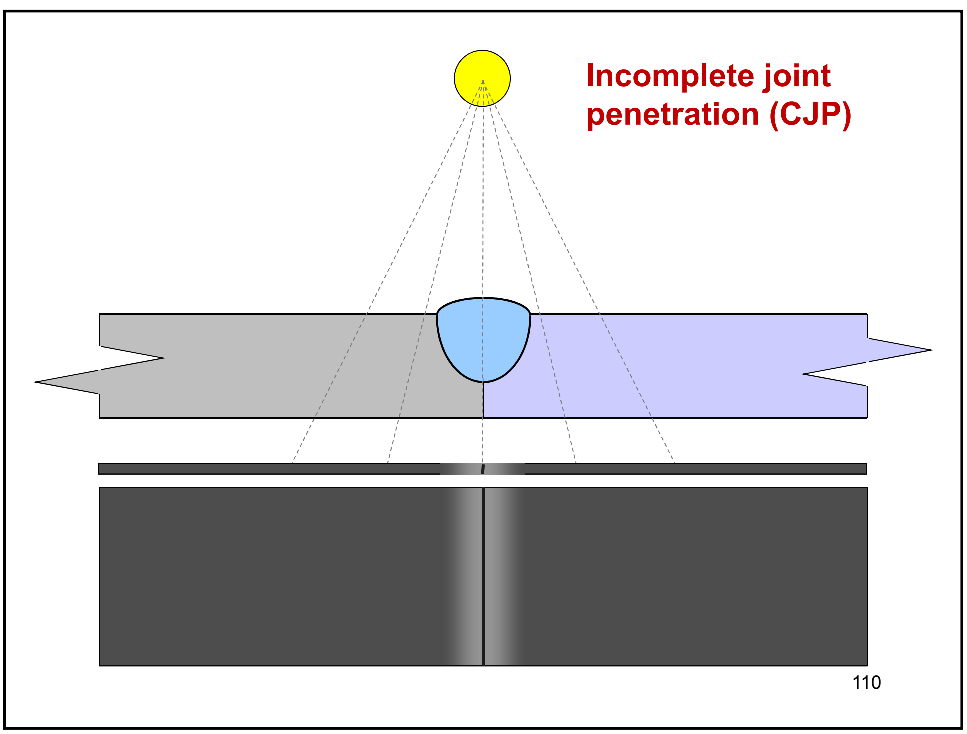

Edge Blocks
105

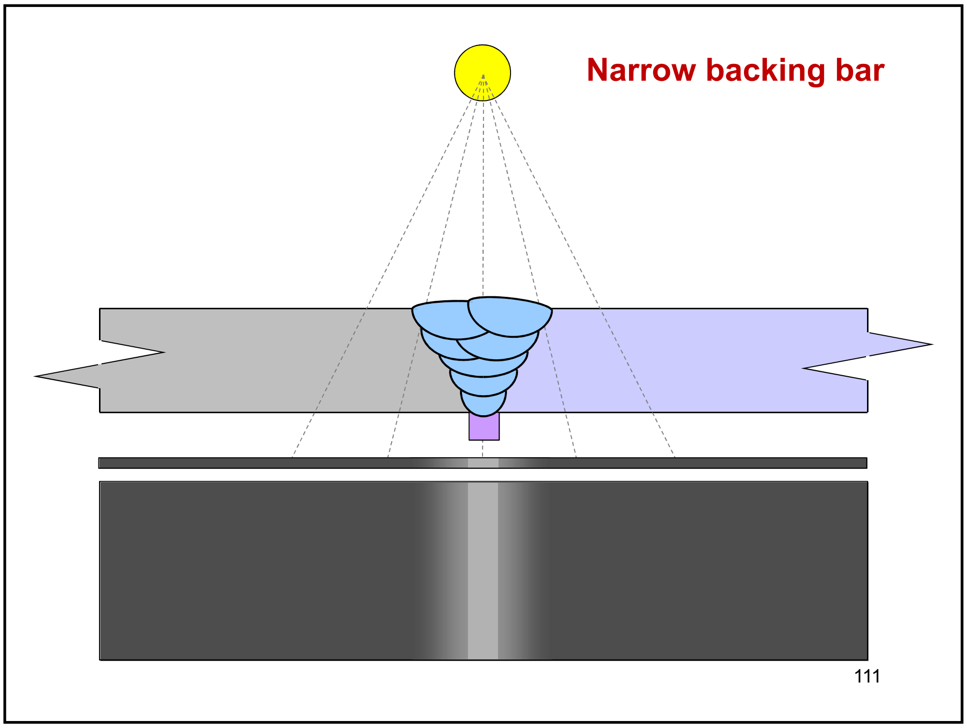

Clean part
Edge blocks
improve inspection
of part edges
106

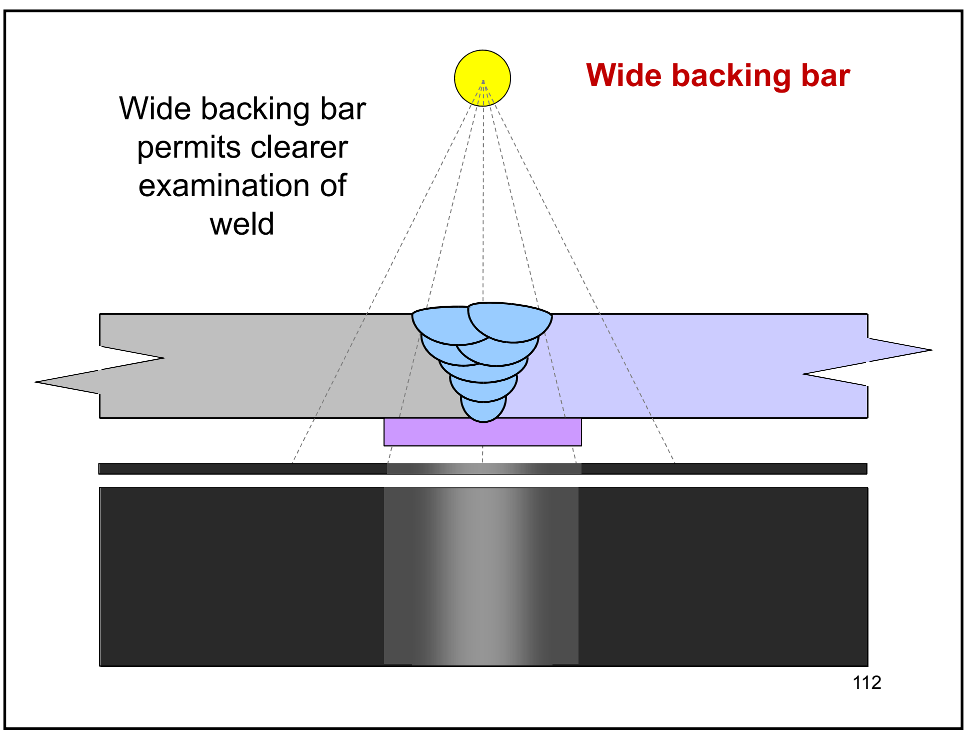

Lamination
Laminations are typically not detected with RT
107

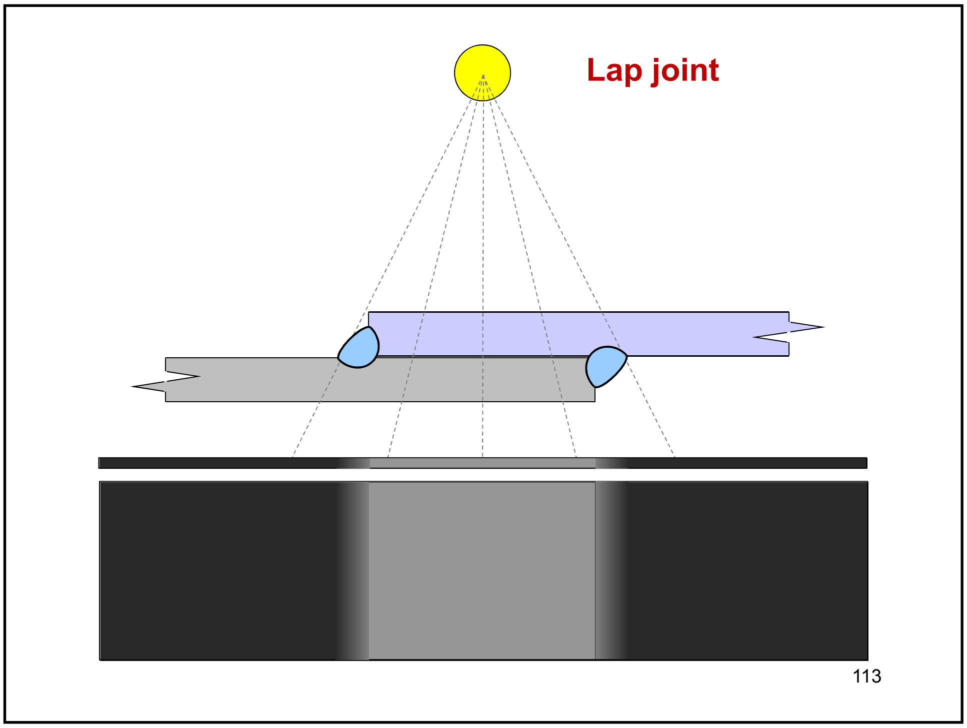

Crack
108

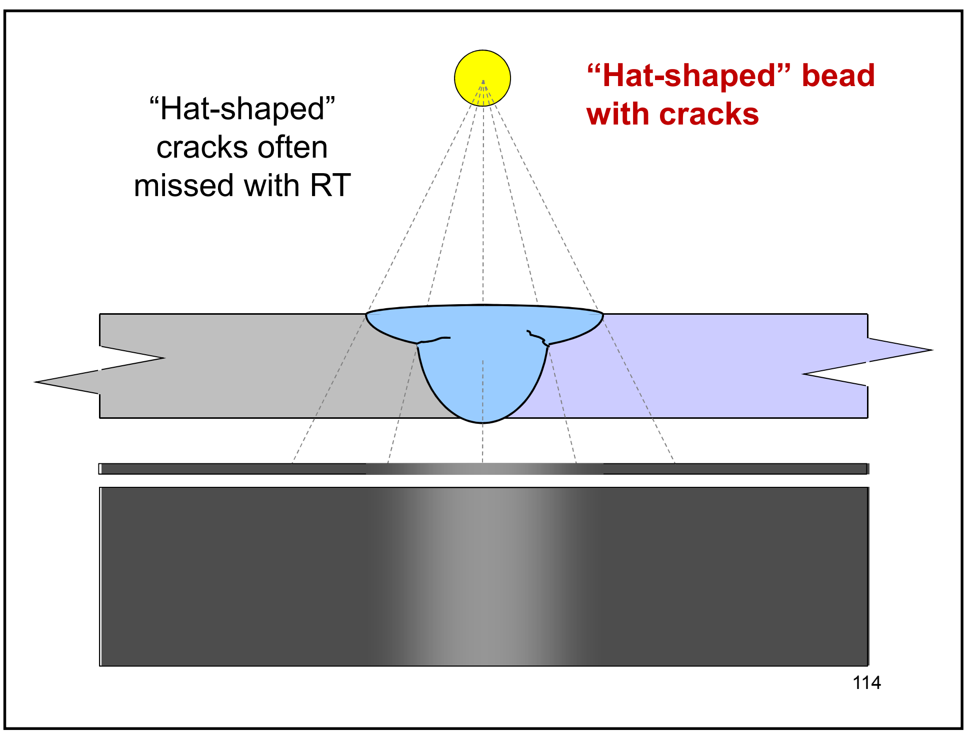

Weld reinforcement
109

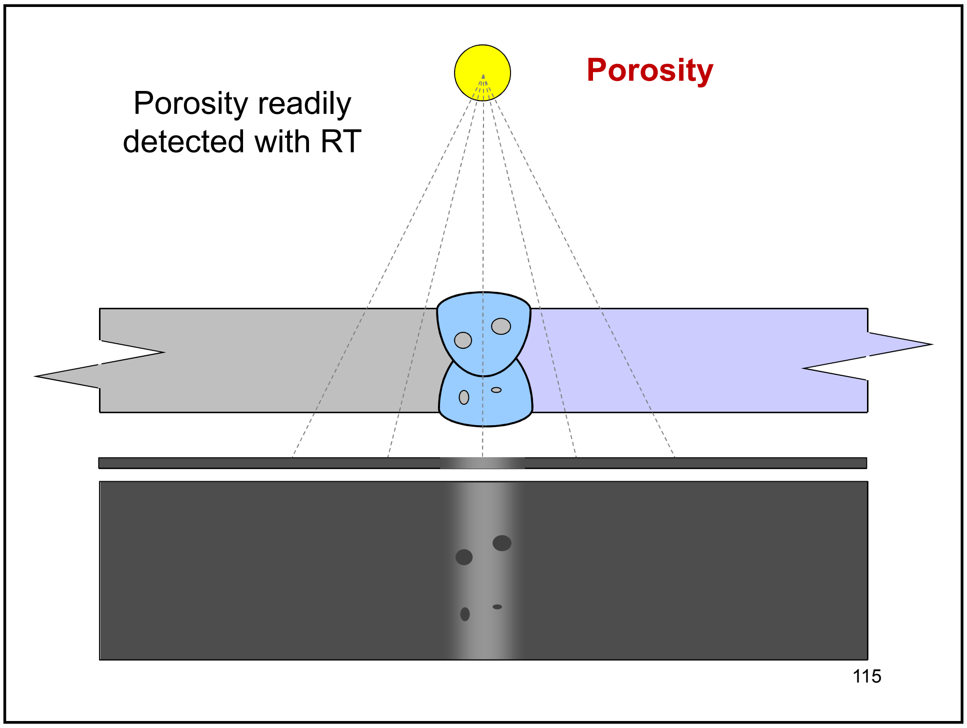

Incomplete joint
penetration (CJP)
110

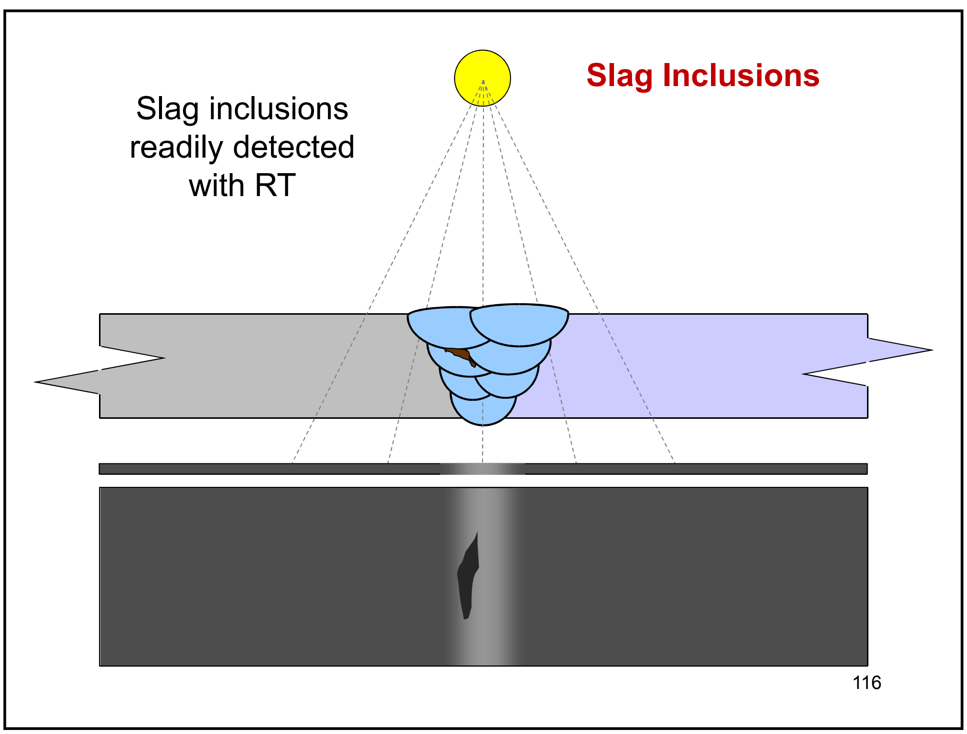

Narrow backing bar
111

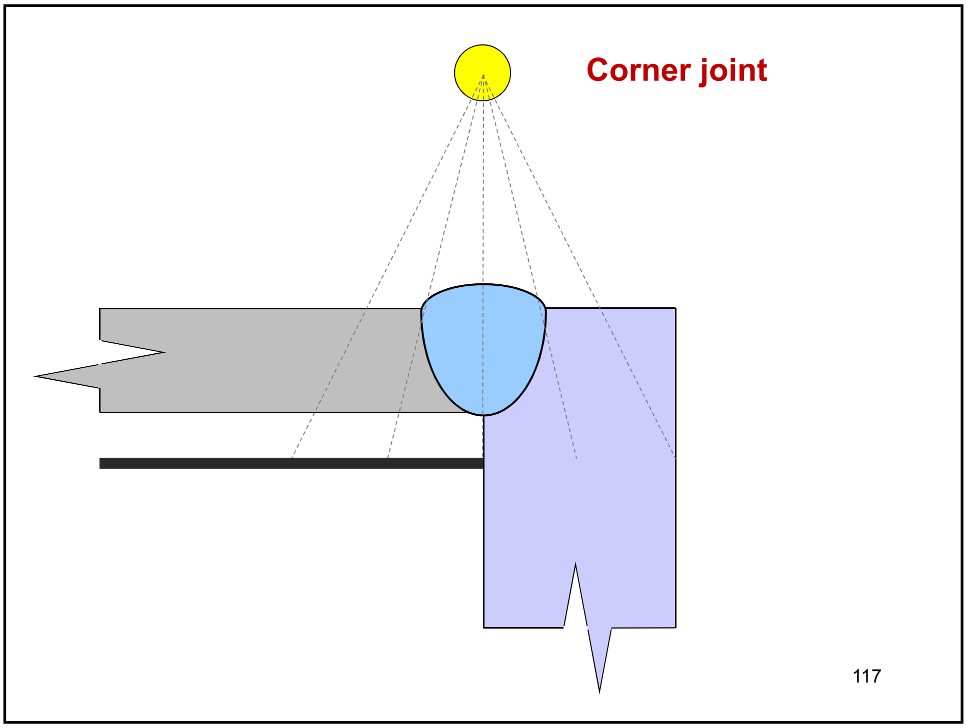

Wide backing bar
Wide backing bar permits clearer examination of weld
112

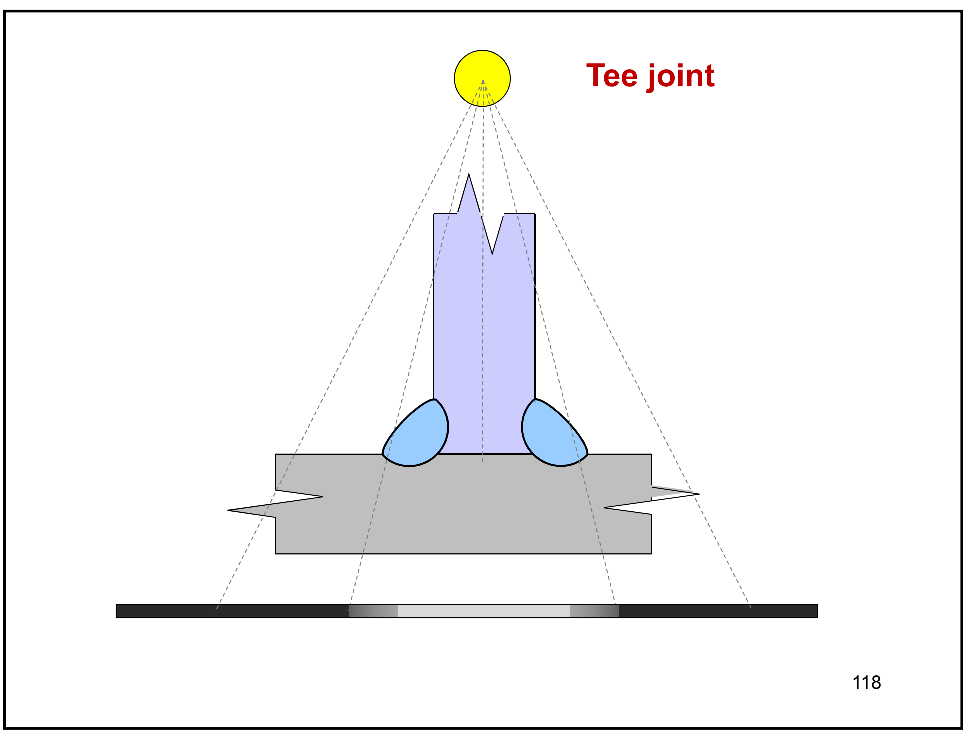

Lap joint
113

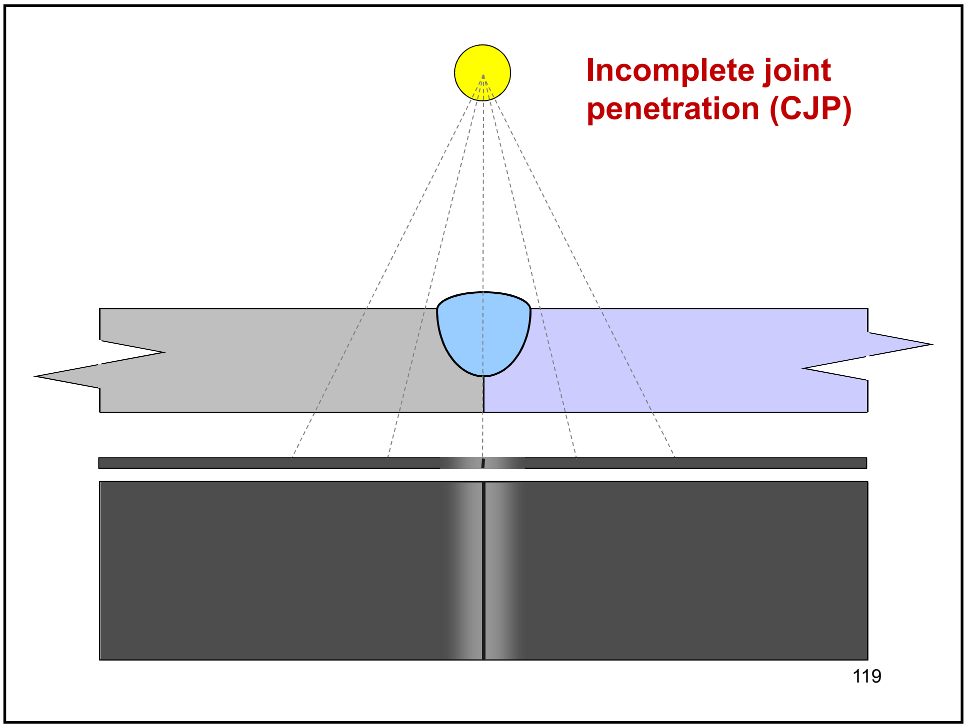

"Hat-shaped" bead with cracks
"Hat-shaped" cracks often missed with RT
114

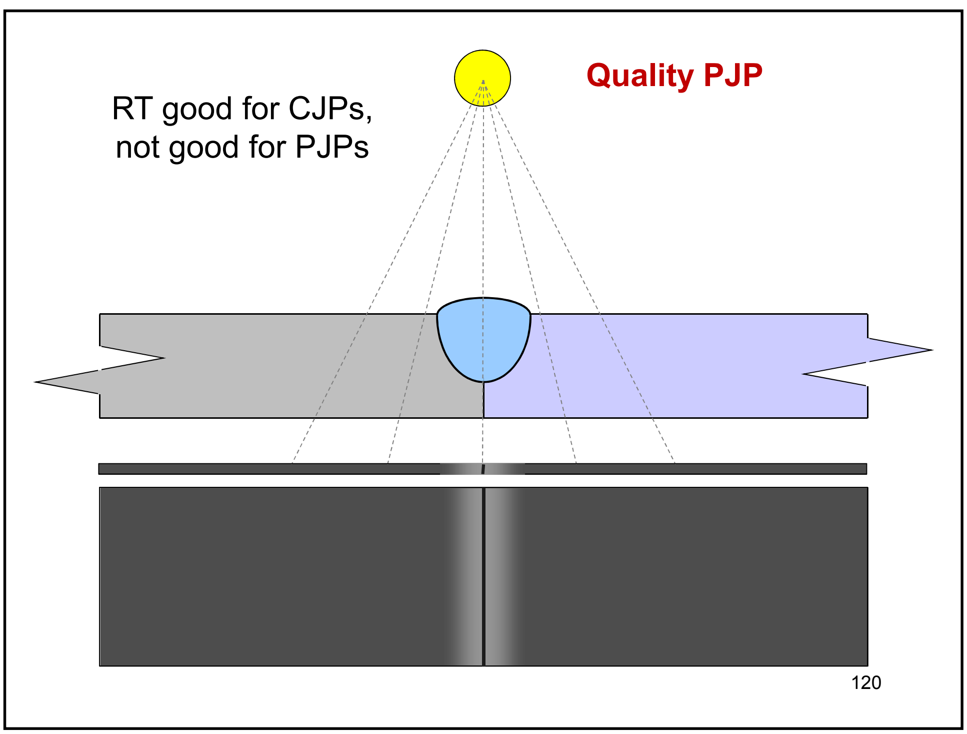

Porosity
Porosity readily detected with RT
115

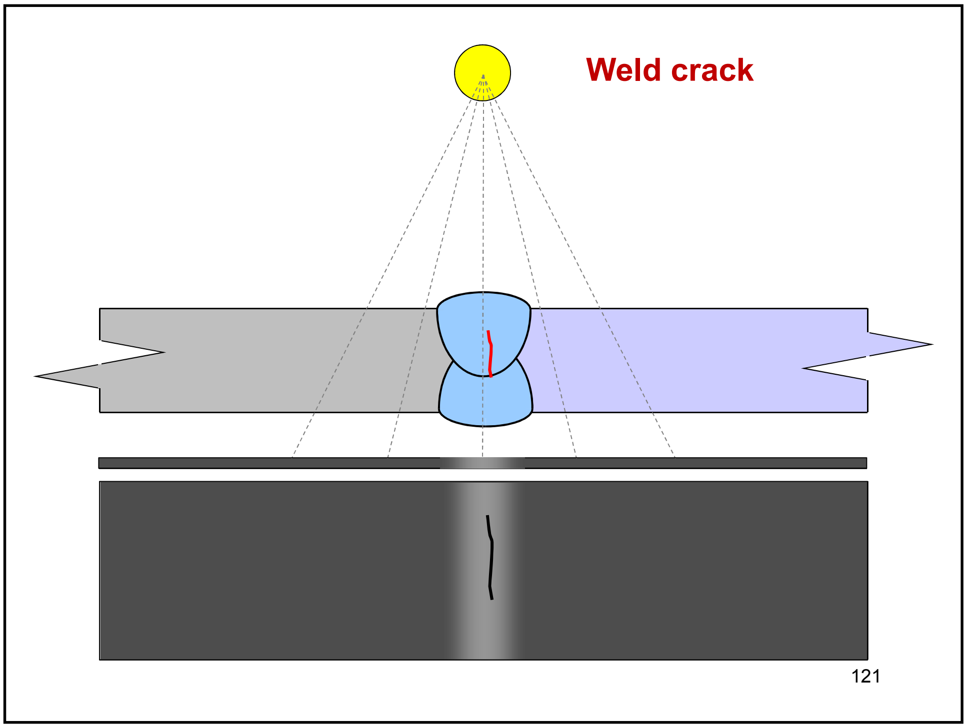

Slag Inclusions
Slag inclusions readily detected with RT
116

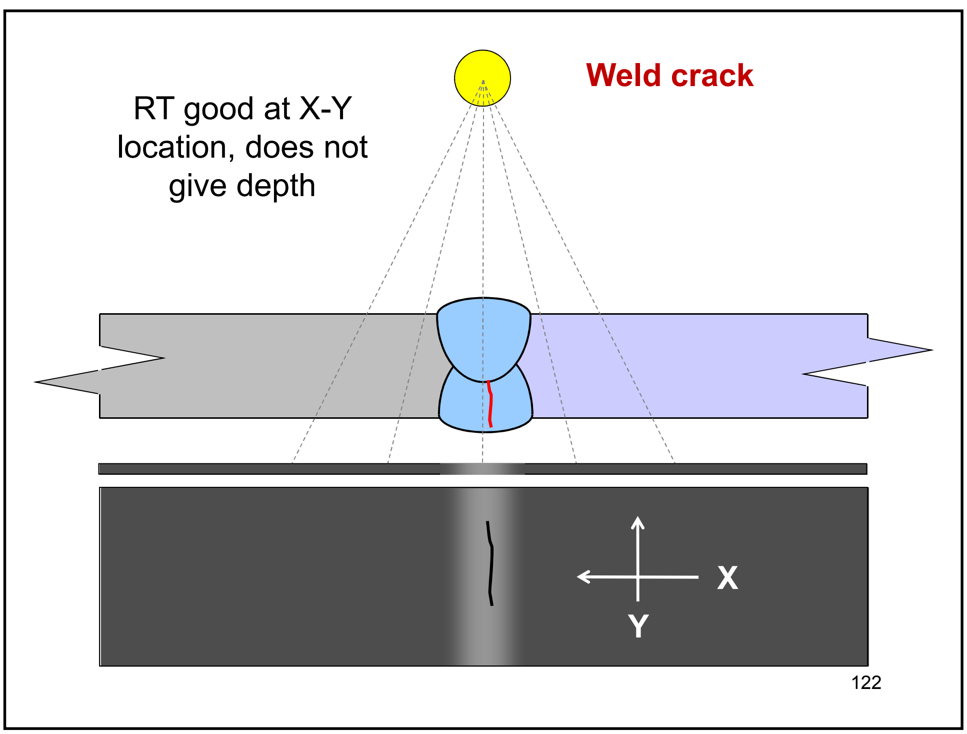

Corner joint
117


Tee joint
118

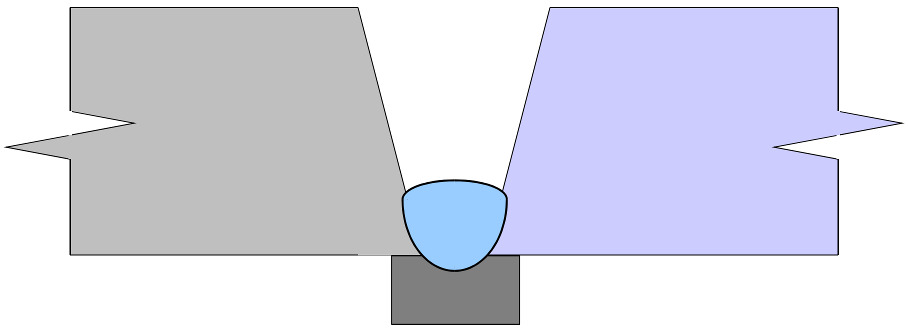

Incomplete joint
penetration (CJP)
119


RT good for CJPs,
not good for PJPs
Quality PJP
120


Weld crack
121


Weld crack
RT good at X-Y location, does not give depth
X
Y
122

RT Anomalies



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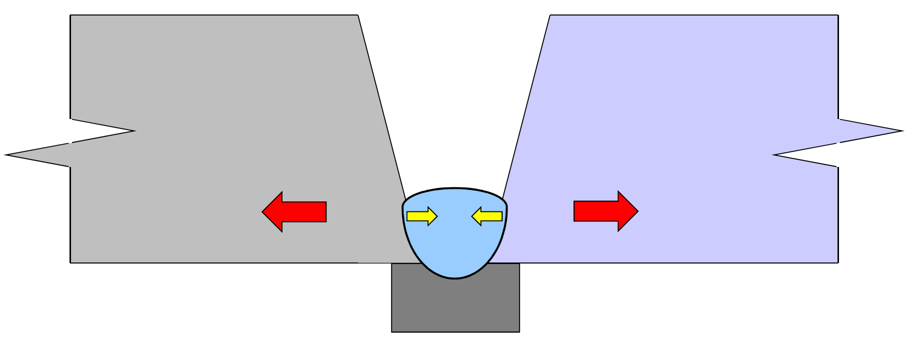
RT Anomalies



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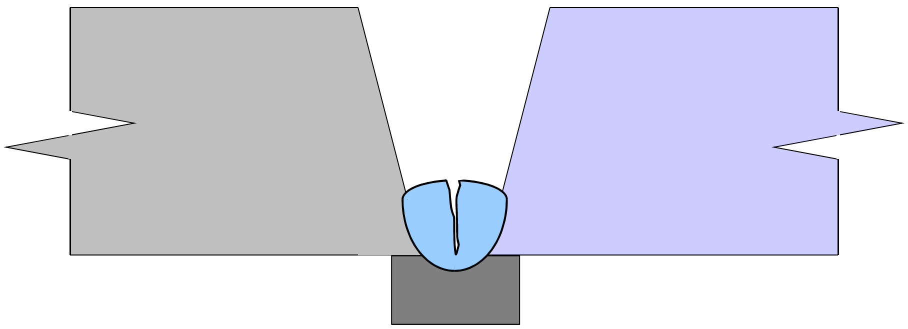
RT Anomalies



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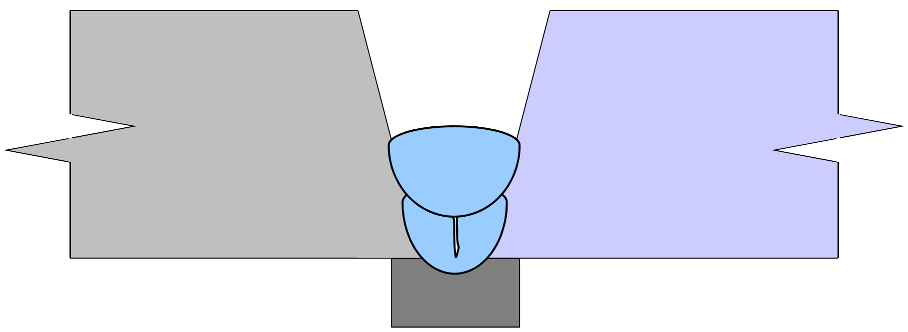
RT Anomalies



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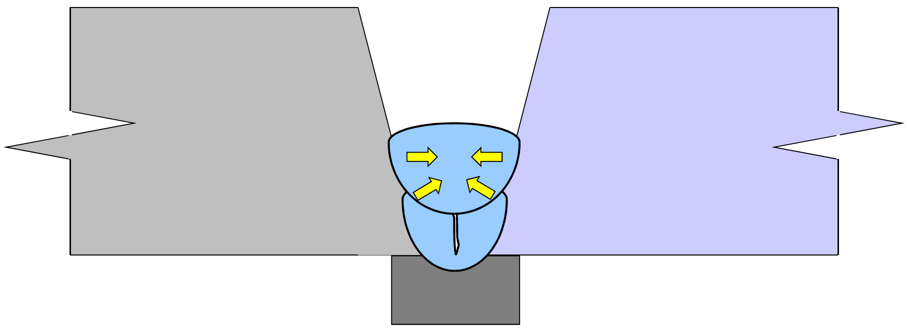
RT Anomalies



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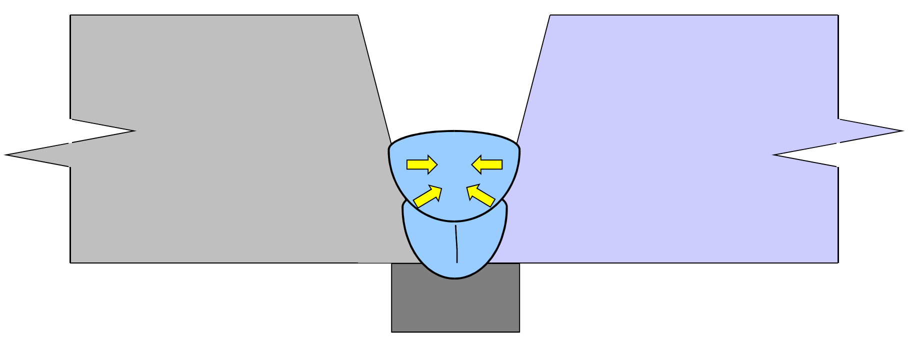
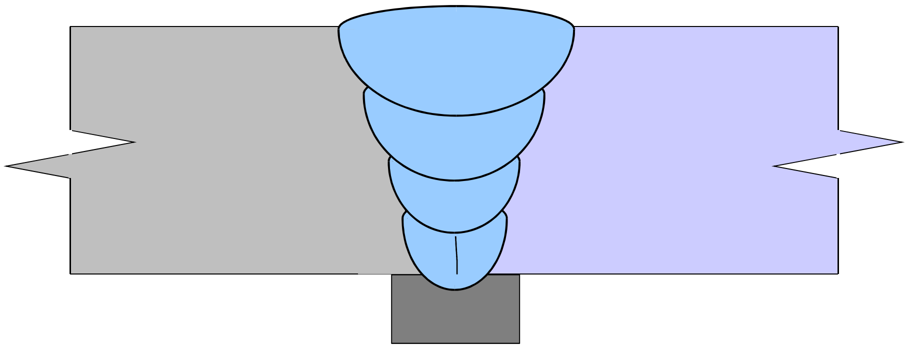
RT Anomalies



128

RT Anomalies

Might miss root pass crack



129

NDT Methods: Radiographic Testing (RT)

Advantages

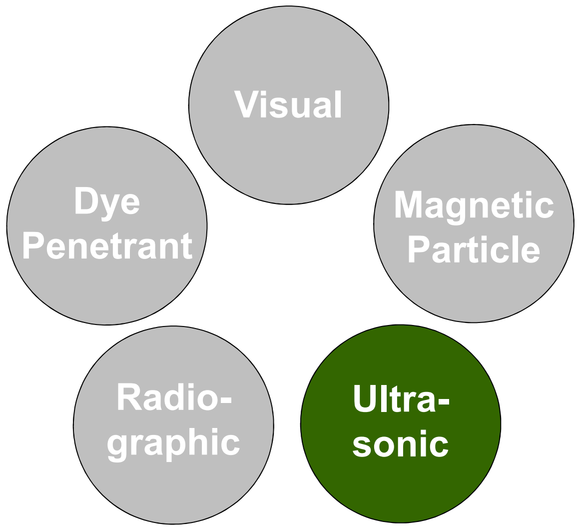
- Performs volumetric assessment
- Good at finding 3D discontinuities (slag, porosity)
- Permanent record
- Provides "picture" of discontinuity location
- Intuitive
- Works well on butts with CJPs

Limitations

- Not suitable for tee, corner, lap joints
- May miss cracks (if tight)
- Misses laminations
- Radiation issues
- Not good for fillet welds, PJP groove welds

130

The Big Five Of Weld Inspection



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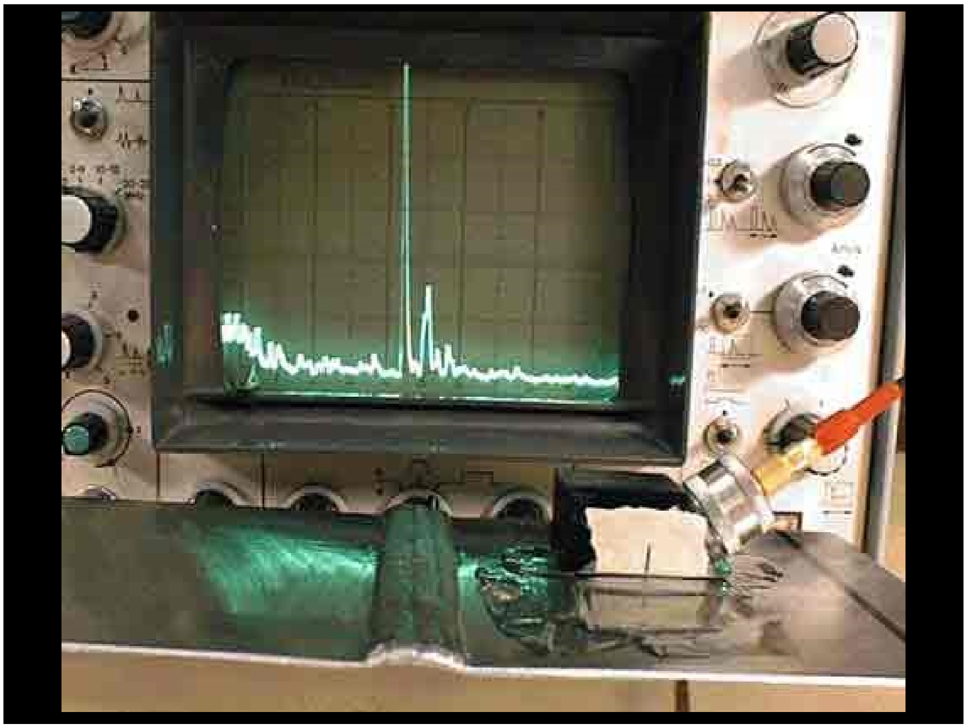

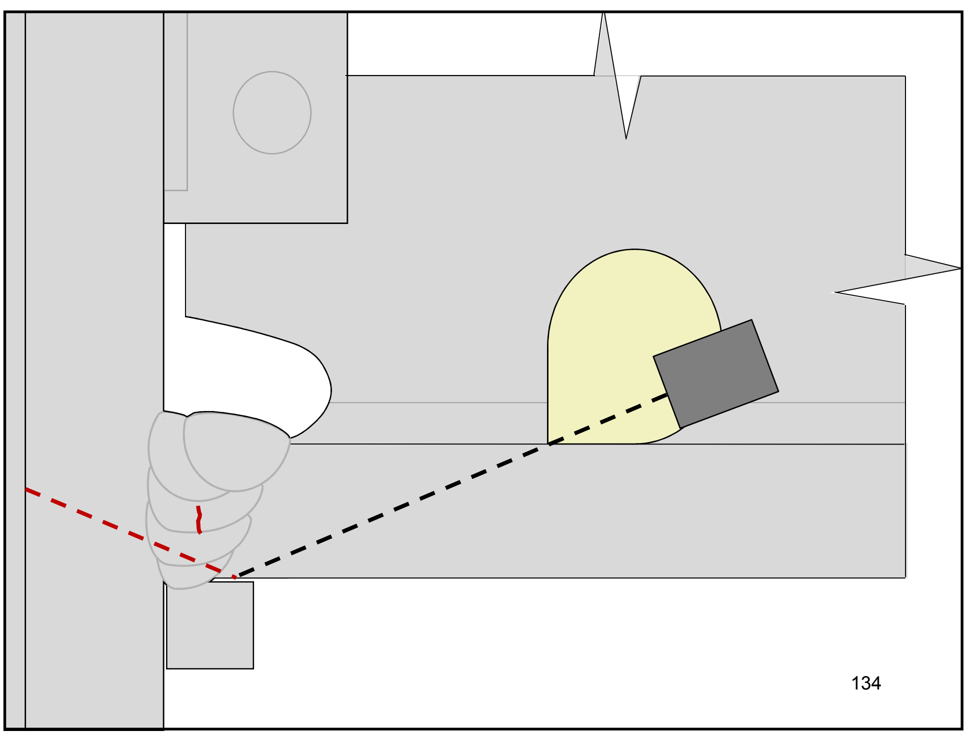
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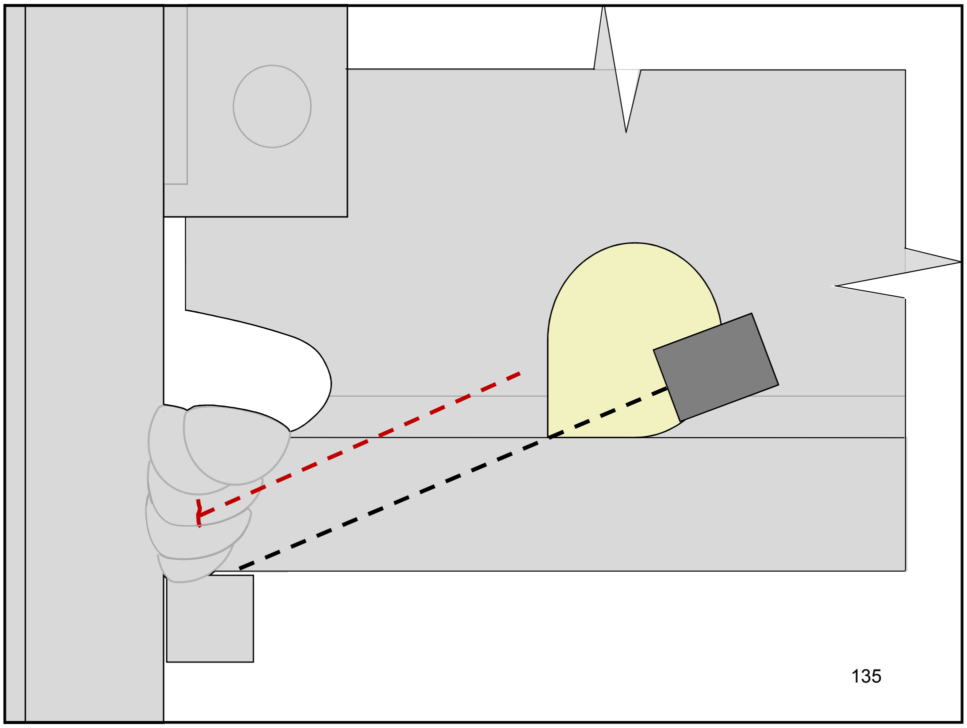
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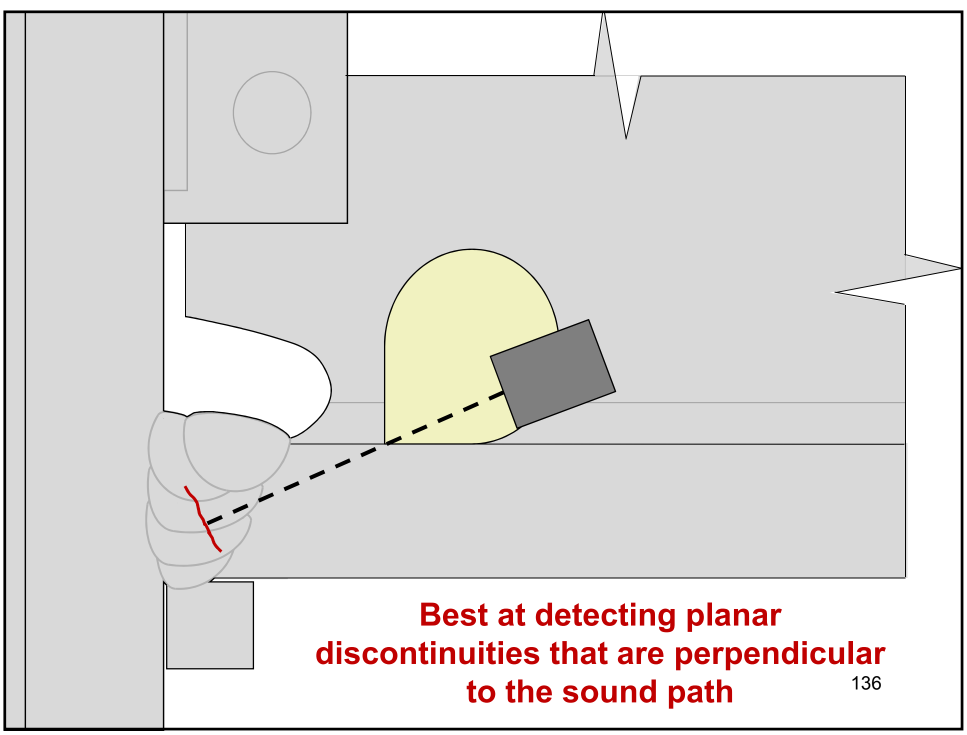
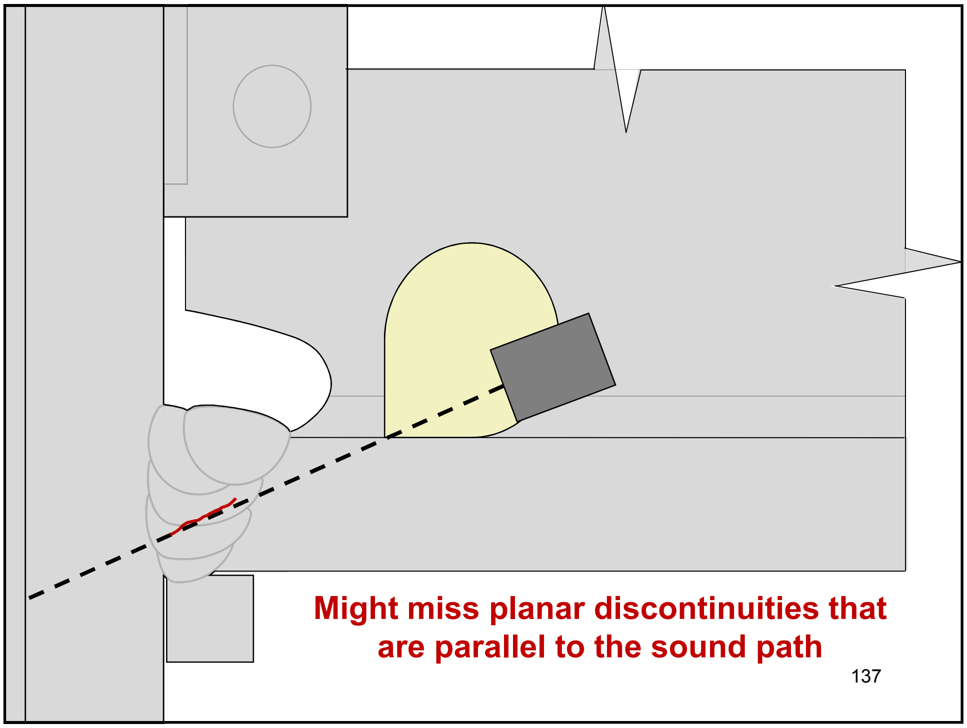
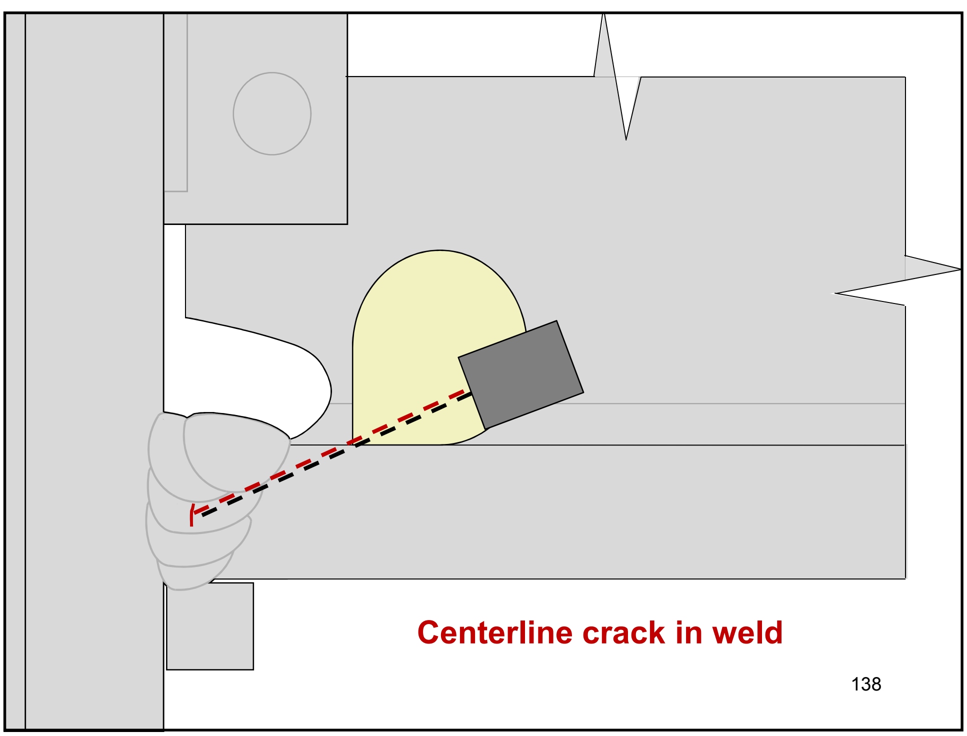
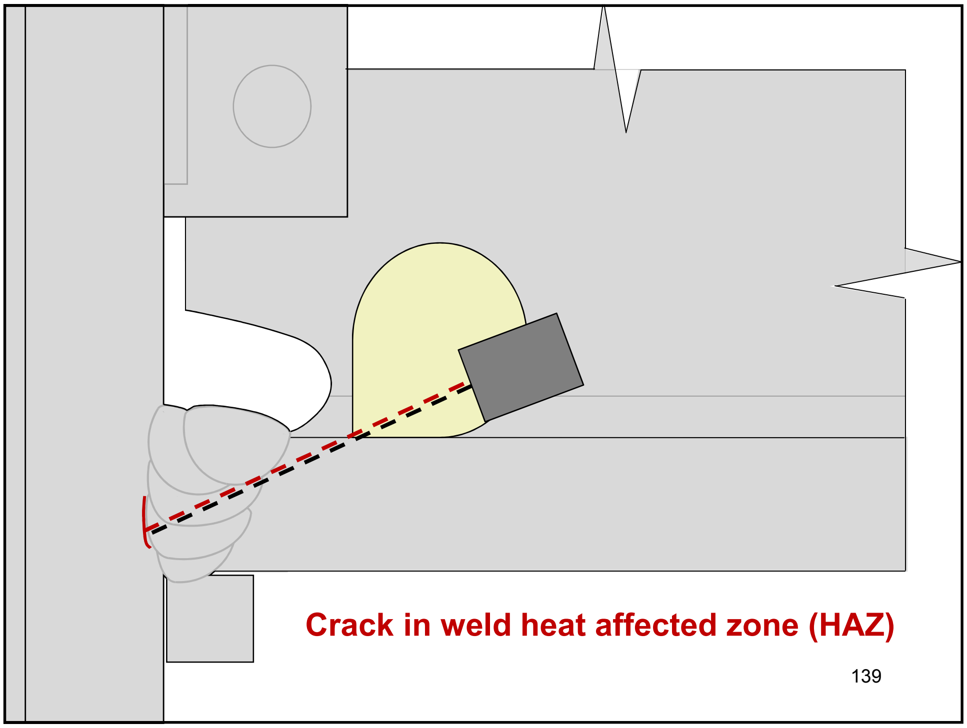
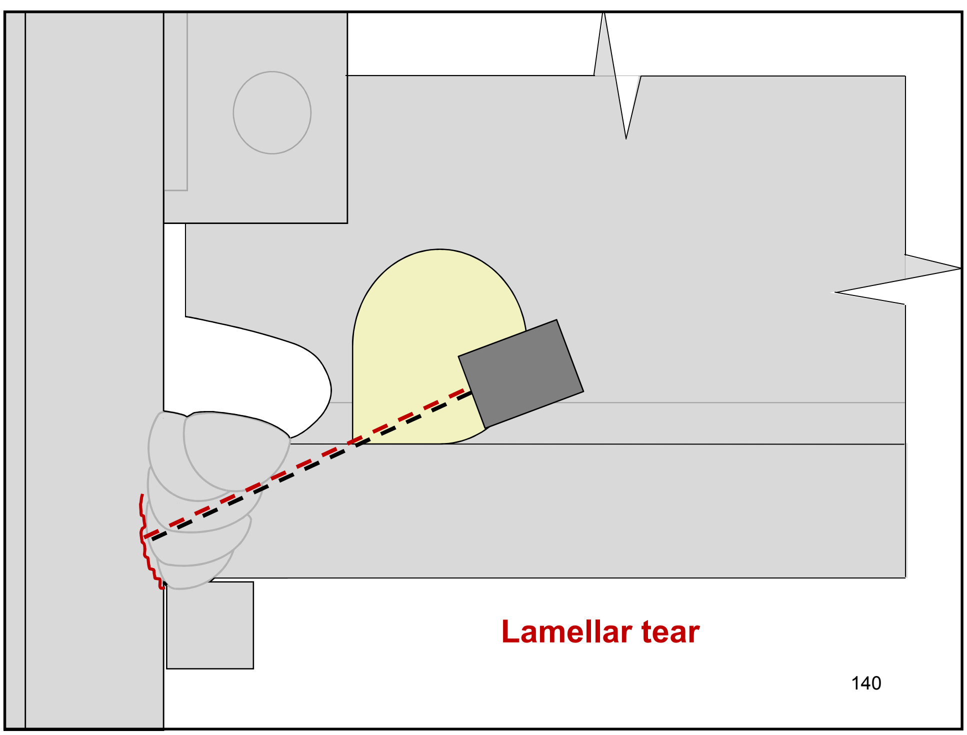
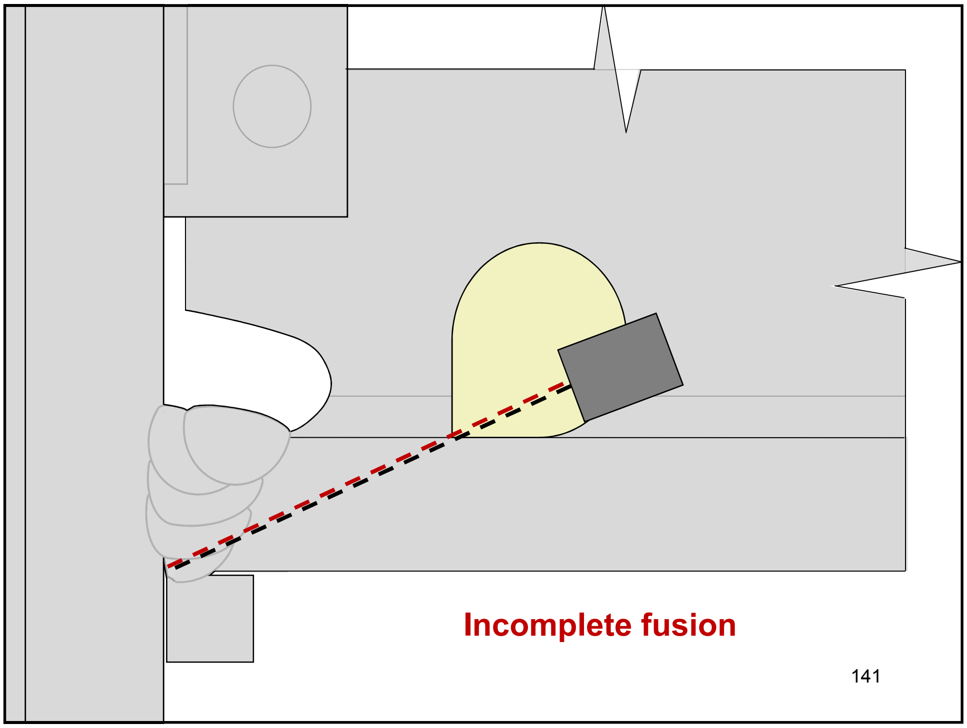

Best at detecting planar
discontinuities that are perpendicular
to the sound path
136

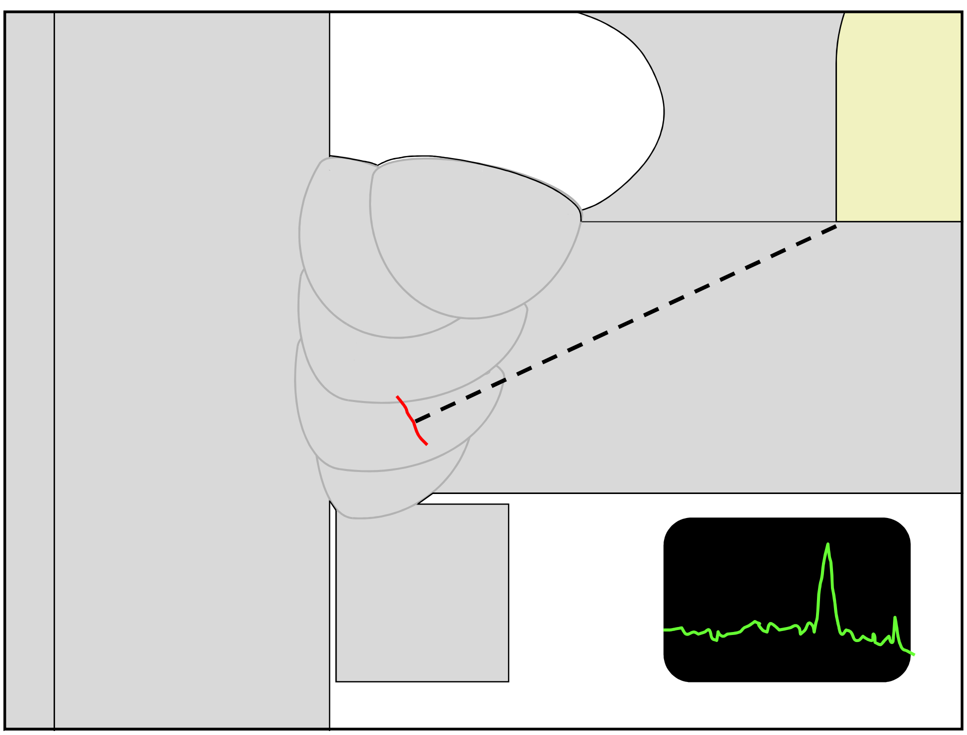

Might miss planar discontinuities that are parallel to the sound path
137

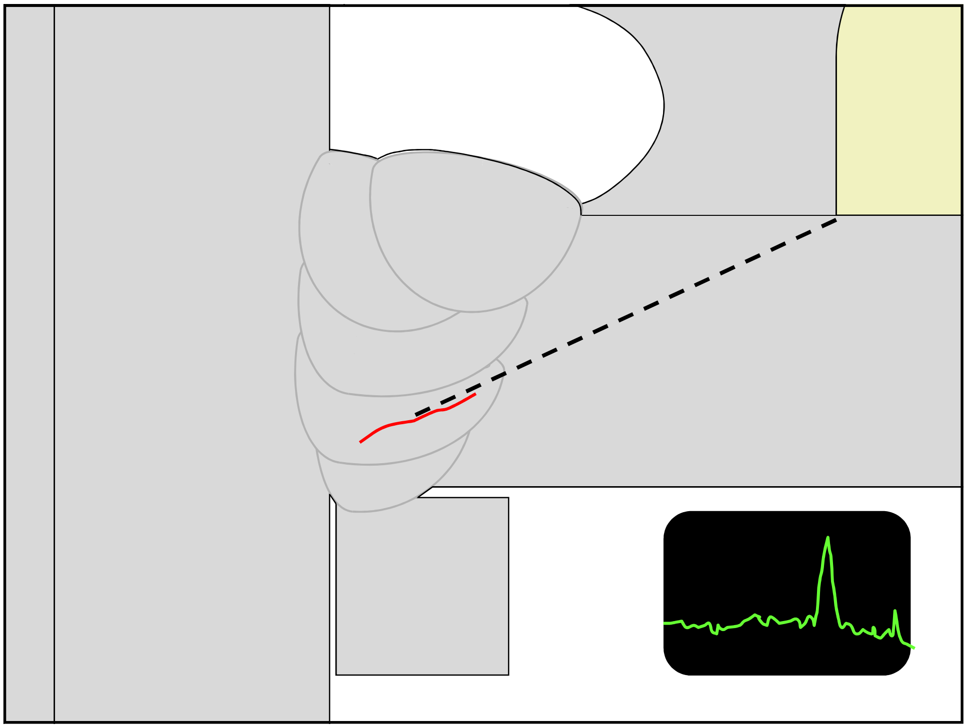

Centerline crack in weld
138

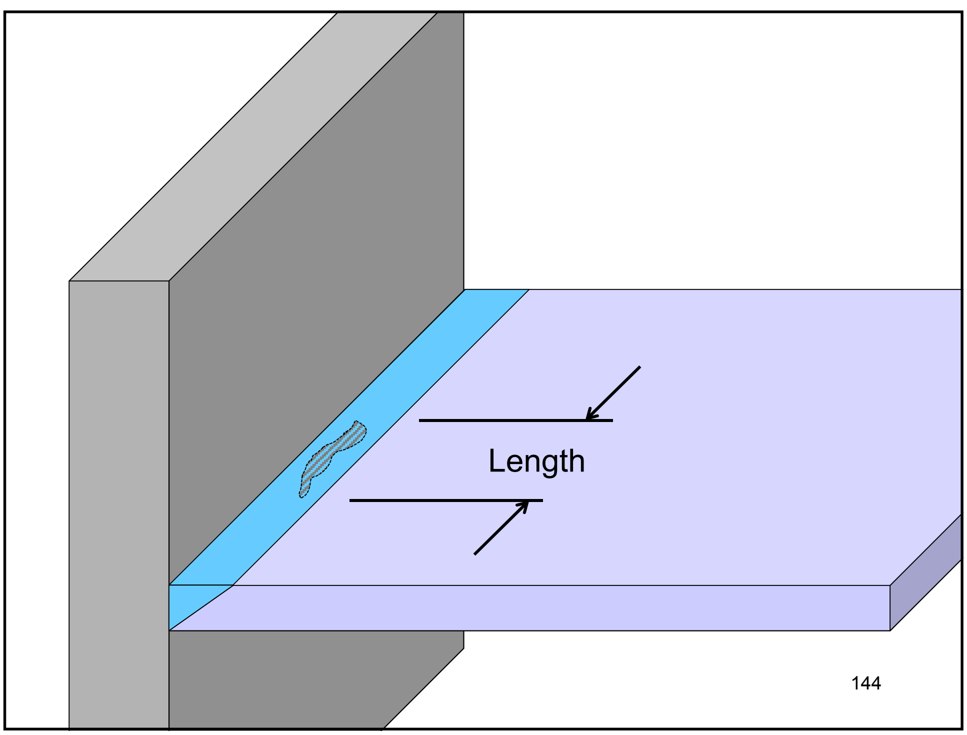

Crack in weld heat affected zone (HAZ)
139


Lamellar tear
140


Incomplete fusion
141






Length
144

AWS D1.1:2010 Structural Welding Code--Steel

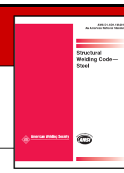


Table 6.2
UT Acceptance-Rejection Criteria (Statically Loaded Nontubular Connections)
(see 6.13.1 and C-6.26.6)

Discontinuity Severity Class	Weld Size[a] in inches [mm] and Search Unit Angle										
	5/16 through 3/4 [8–20]	> 3/4 through 1-1/2 [20–38]	> 1-1/2 through 2-1/2 [38–65]			> 2-1/2 through 4 [65–100]			> 4 through 8 [100–200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	–2 & lower	+1 & lower	+3 & lower	–5 & lower	–2 & lower	0 & lower	–7 & lower	–4 & lower	–1 & lower
Class B	+6	+3	–1 0	+2 +3	+4 +5	–4 –3	–1 0	+1 +2	–6 –5	–3 –2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	–2 to +2	+1 +2	+3 +4	–4 to +2	–1 to +2	+2 +3
Class D	+8 & up	+5 & up	+3 & up	+6 & up	+8 & up	+3 & up	+3 & up	+5 & up	+3 & up	+3 & up	+4 & up

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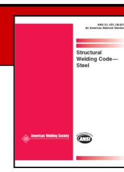
AWS D1.1:2010 Structural Welding Code--Steel



Class A (large discontinuities)
Any indication in this category shall be rejected (regardless of length).

Class B (medium discontinuities)
Any indication in this category having a length greater than 3/4 in [20 mm] shall be rejected.

Class C (small discontinuities)
Any indication in this category having a length greater than 2 in [50 mm] shall be rejected.

Class D (minor discontinuities)
Any indication in this category shall be accepted regardless of length or location in the weld.

146

AWS D1.1:2010 Structural Welding Code--Steel

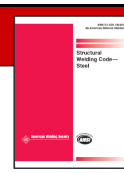


Table 6.2 Statically Loaded Nontubular Connections

> 1-1/2 through 2-1/2 inch with 70°		
Class	**Length**	**dB Rating**
A	Any	-2 and lower
B	> 3/4 inch	-1, 0
C	> 2 inch	+1, +2
D	Unlimited	+3 and up

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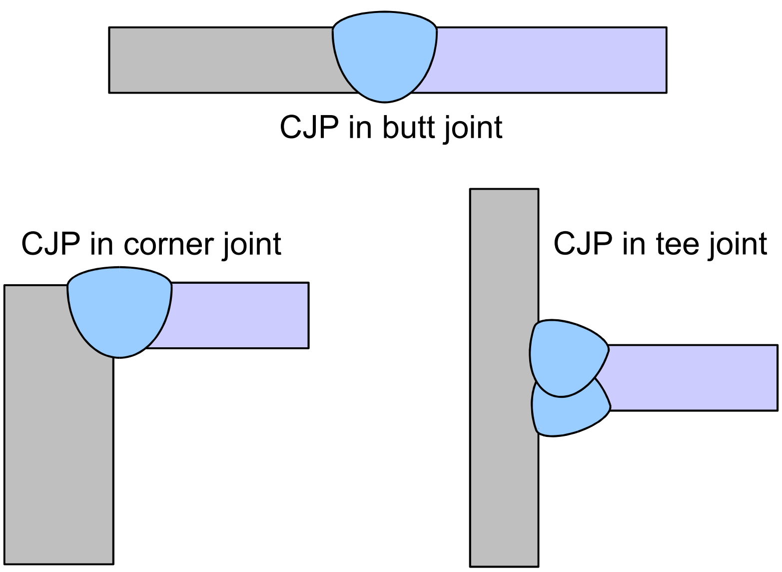
All Inspectable with Ultrasonic Testing



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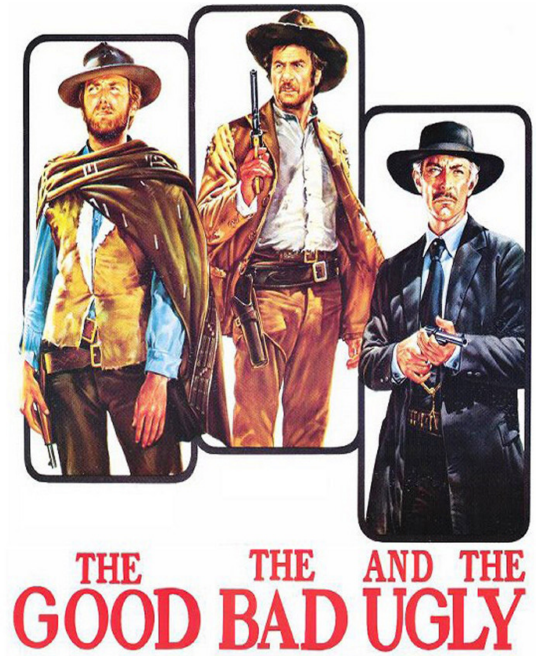

SAC Steel Project

Report No. SAC/BD-00/06 Shaw

Round-Robin Testing of Ultrasonic Testing Technicians

The Study:

- 15 technicians
- 10 agencies
- 5 cities
- "average skill level" (but > average)
- 12 specimens (moment frame)
- Known defects
- Inspected to cyclic criteria
- $1000 prize to winner

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SAC Steel Project

Report No. SAC/BD-00/06 Shaw

Round-Robin Testing of Ultrasonic Testing Technicians

The Conclusions (the good):

- "When detected, discontinuity length measurement was fairly consistent…."
- "Technicians were generally able to indicate the relative position of the discontinuity in relation to the weld throat dimension (height) of the weld."
- "…technicians were generally able to measure the discontinuity along the "x-axis"…."

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SAC Steel Project

Report No. SAC/BD-00/06 Shaw

Round-Robin Testing of Ultrasonic Testing Technicians

The Conclusions (the bad):

- "The scatter in UT results is broad, particularly in the "indication rating" or "db" value used for acceptance criteria under the AWS D1.1 code."
- On average, 16% of the rejectable indications were for locations where no known discontinuities were implanted (false calls)."

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SAC Steel Project

Report No. SAC/BD-00/06 Shaw

Round-Robin Testing of Ultrasonic Testing Technicians

The Conclusions (the ugly):

- "On average, approximately 25% of the known discontinuities were missed."

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UT is not perfect…

but it found 75% of the known discontinuities.

UT is not perfect…

but false positives tend to be self correcting.

UT is not perfect…

but when discontinuities are found, their location is generally accurately predicted.

UT is not perfect…

but UT is only part of a quality management system.

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NDT Methods: Ultrasonic Testing (UT)

Advantages

- Performs volumetric assessment
- Good at finding 2D discontinuities, depending on beam angle
- Evaluates butt, tee, corner joints

Limitations

- Operator sensitive
- Generates "signal" that must be interpreted
- May detect meaningless indications
- Not good for fillet welds, PJP groove welds

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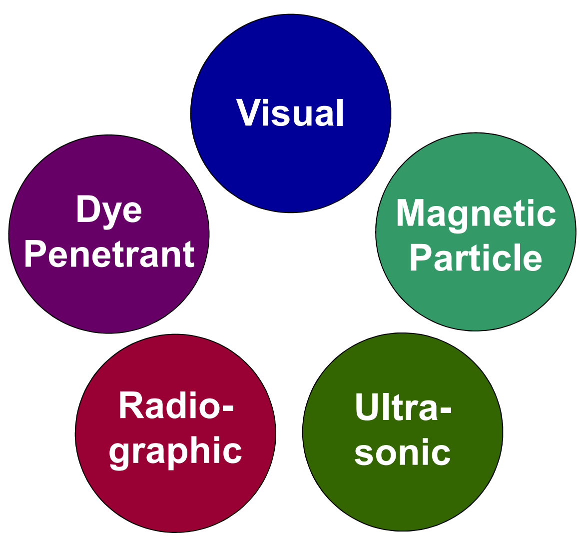
The Big Five Of Weld Inspection



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Welded Connection

~~WELD~~ INSPECTION

Background

NDT Methods and Capabilities

- PT and MT: augment visual
- RT and UT: volumetric
- RT for butt joints, volumetric discontinuities
- UT for most joints, planar discontinuities

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Welded Connection

~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

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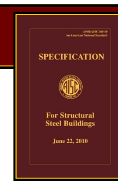
AISC 360-10 SPECIFICATION



APPENDIX 3

DESIGN FOR FATIGUE

This appendix applies to members and connections subject to high cycle loading within the elastic range of stresses of frequency and magnitude sufficient to initiate cracking and progressive failure, which defines the limit state of fatigue.

User Note: See AISC Seismic Provisions for Structural Steel Buildings for structures subject to seismic loads.

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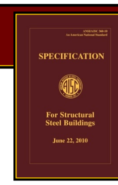
AISC 360-10 SPECIFICATION



APPENDIX 3 Commentary

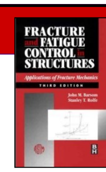
….Issues of fatigue are not normally encountered in building design; however, when encountered and if the severity is great enough, fatigue is of concern and all provisions of Appendix 3 must be satisfied.

162


Crane Supports


Reciprocating Machinery Supports
MINSTER
MINSTER

Fatigue and Fracture Control in Structures



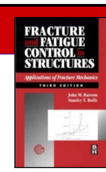
$$\frac{da}{dN} = A\,\Delta K^{m}$$

Where:

- a = crack length
- N = number of cycles
- da/dN = fatigue crack growth per cycle
- ΔK = change in stress intensity factor due to fluctuating stresses
- A and m are constants that are a function of the material

Equation 9.1 from Barsom and Rolfe

Fatigue and Fracture Control in Structures



Procedure

1. Use inspection reports to estimate a_0, the initial flaw size.
2. Calculate a_{cr}, based on K_c or K_{IC}.
3. Find equation for da/dN.
4. Determine ΔK, based on K_I and a_0, and stress range.
5. Integrate the crack-growth-rate expression between the limits of a_0 and a_{cr}.

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Fatigue Crack Growth Rate Calculations

Example

A992 welded with E70

$\sigma_y = 60$ ksi

$K_{IC} = 75\ \text{ksi}\sqrt{\text{in}}$

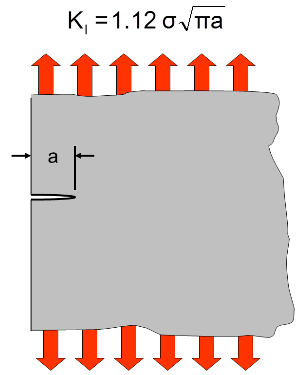
$a_0 = 0.25$ in. (edge crack)

$\sigma_{max} = 25$ ksi

$\sigma_{min} = 10$ ksi

$\Delta\sigma = 15$ ksi

$K_I = 1.12\sigma\sqrt{\pi a}$



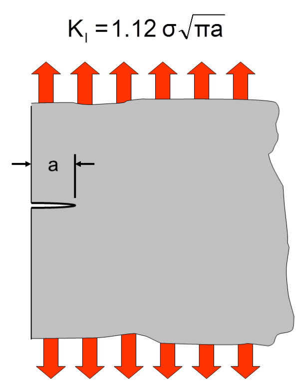
Values were selected to illustrate the methodology and were not selected to represent any specific application.

Fatigue Crack Growth Rate Calculations

Example

1. Use inspection reports to estimate a_0, the initial flaw size.

$a_0 = 0.25$ in. (edge crack)



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Fatigue Crack Growth Rate Calculations

Example

2. Calculate a_{cr}, based on K_c or K_{IC}.

$$K_I = 1.12\sigma\sqrt{\pi a}$$

$$a_{cr} = \left(\frac{K_{IC}}{1.12\ \sigma\sqrt{\pi}}\right)^2$$

$$a_{cr} = \left(\frac{75}{1.12\ (25)\sqrt{\pi}}\right)^2 = 2.28\ \text{in.}$$

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Fatigue Crack Growth Rate Calculations

Example

3. Find equation for da/dN (inch/cycle)

$$\frac{da}{dN} = 3.6 \times 10^{-10}\,\Delta K^{3.0}$$ Ferrite-Pearlite Steels

$$\frac{da}{dN} = 0.66 \times 10^{-8}\,\Delta K^{2.25}$$ Martensitic Steels

$$\frac{da}{dN} = 1 \times 10^{-9}\,\Delta K^{2.2}$$ Steel Weldments

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Fatigue Crack Growth Rate Calculations

Example

4. Determine ΔK, based on K_I and a_0, and stress range.

$$K_I = 1.12\sigma\sqrt{\pi a}$$

$$\Delta K_I = 1.12\ \Delta\sigma\ \sqrt{\pi a}$$

$$\Delta K_I = 1.12\ \ (15\ )\sqrt{\pi\ a}$$

$$\Delta K_I = 29.8\ \sqrt{a}$$

For a_0 = 0.25 inch

$$\Delta K_I = 16.3\,\text{ksi}\ \sqrt{\text{in}}$$

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Fatigue Crack Growth Rate Calculations

Example

5. Integrate the crack-growth-rate expression between the limits of a_0 and a_{cr}.

a_0 = 0.25 inch
a_{cr} = 2.28 inch

Find ΔN for every increment of crack growth of 0.10 inch.

Replace da/dN with $\Delta a/\Delta N$

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Fatigue Crack Growth Rate Calculations

Example

5. Integrate the crack-growth-rate expression between the limits of a_0 and a_{cr}.

$$\frac{da}{dN} = 3.6 \times 10^{-10} \Delta K^{3.0}$$

$$\frac{\Delta a}{\Delta N} = 3.6 \times 10^{-10} \Delta K^{3.0}$$

$$\Delta N = \frac{\Delta a}{3.6 \times 10^{-10} \Delta K^{3.0}}$$

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Fatigue Crack Growth Rate Calculations

Example

$$\Delta N = \frac{\Delta a}{3.6 \times 10^{-10} \Delta K^{3.0}}$$

$$\Delta K_I = 16.3 \text{ ksi} \sqrt{\text{in}}$$

$$\Delta N = \frac{0.10}{3.6 \times 10^{-10} (16.3)^{3.0}}$$

$$\Delta N = 64{,}076 \text{ cycles}$$

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Fatigue Crack Growth Rate Calculations

a_0	a_f	a_{ave}	ΔK_{IC}	ΔN	ΣN
0.25	0.35	0.3	16.31	64076	64076
0.35	0.45	0.4	18.83	41618	105694
0.45	0.55	0.5	21.05	29780	135474
0.55	0.65	0.6	23.06	22654	158128
0.65	0.75	0.7	24.91	17977	176105
0.75	0.85	0.8	26.63	14714	190820
0.85	0.95	0.9	28.24	12331	203151
0.95	1.05	1.0	29.77	10529	213680
1.05	1.15	1.1	31.22	9126	222806
1.15	1.25	1.2	32.61	8009	230815
1.25	1.35	1.3	33.94	7103	237919
1.35	1.45	1.4	35.22	6356	244275
1.45	1.55	1.5	36.46	5731	250006
1.55	1.65	1.6	37.66	5202	255208
1.65	1.75	1.7	38.81	4750	259958
1.75	1.85	1.8	39.94	4360	264318
1.85	1.95	1.9	41.03	4020	268338
1.95	2.05	2.0	42.10	3722	272061
2.05	2.15	2.1	43.14	3460	275520
2.15	2.25	2.2	44.16	3227	278747
2.25	2.35	2.3	45.15	3018	281765

Fatigue Crack Growth Rate Calculations

Example 1

Summary:

For crack to grow from a_0 and a_{cr} (0.25 to 2.25 inch), the model predicts **281,765** cycles will be required.

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Fatigue Crack Growth Rate Calculations

Example 2

Summary:

For crack to grow from a_0 and a_{cr} (**1.0** to 2.25 inch), the model predicts **68,085** cycles will be required.

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Welded Connection

~~WELD~~ INSPECTION

Background

Fatigue

- Caused by cyclic loading
- Not typical in most building structures
- Crack growth is predictable

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Welded Connection

~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality
- Case Studies

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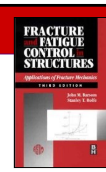
Fatigue and Fracture Control in Structures



FRACTURE MECHANICS is a method of characterizing the fracture and fatigue behavior of sharply notched structural members (cracked or flawed) in terms that can be used by the engineer, namely stress (σ) and flaw size (a).

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Fracture Mechanics

Basic Theory:

Resistance > Demand

$K_C > K_I$

Measured

Calculated

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Fracture Mechanics

Resistance
K_C

- Material
- Temperature
- Loading Rate
- Constraint

Demand
K_I

- Stress
- "Crack" size
- "Crack" location
- Geometry

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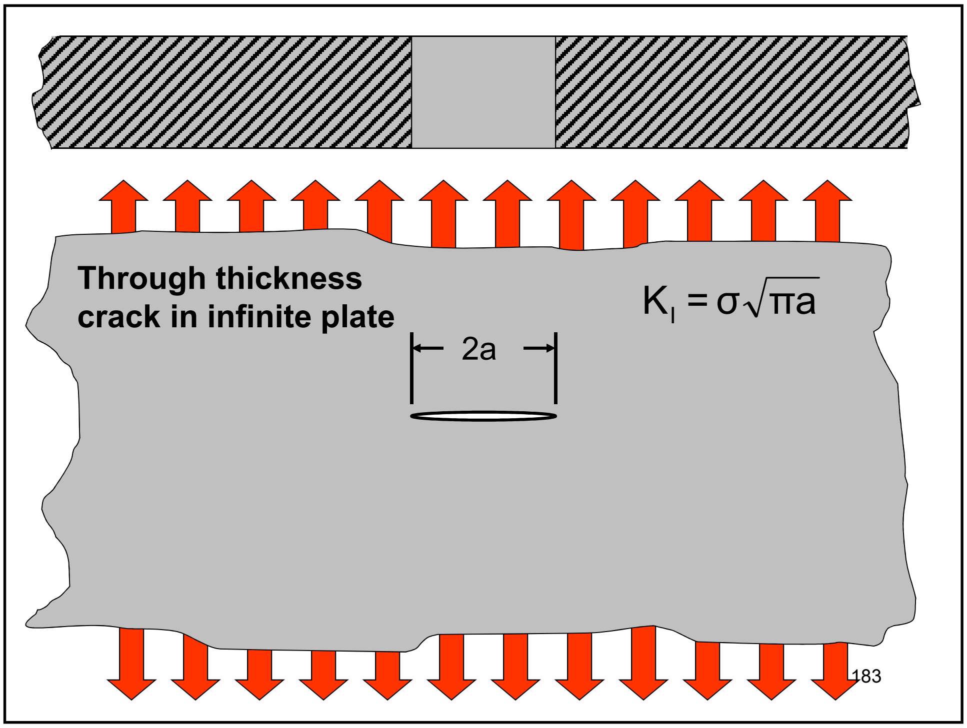
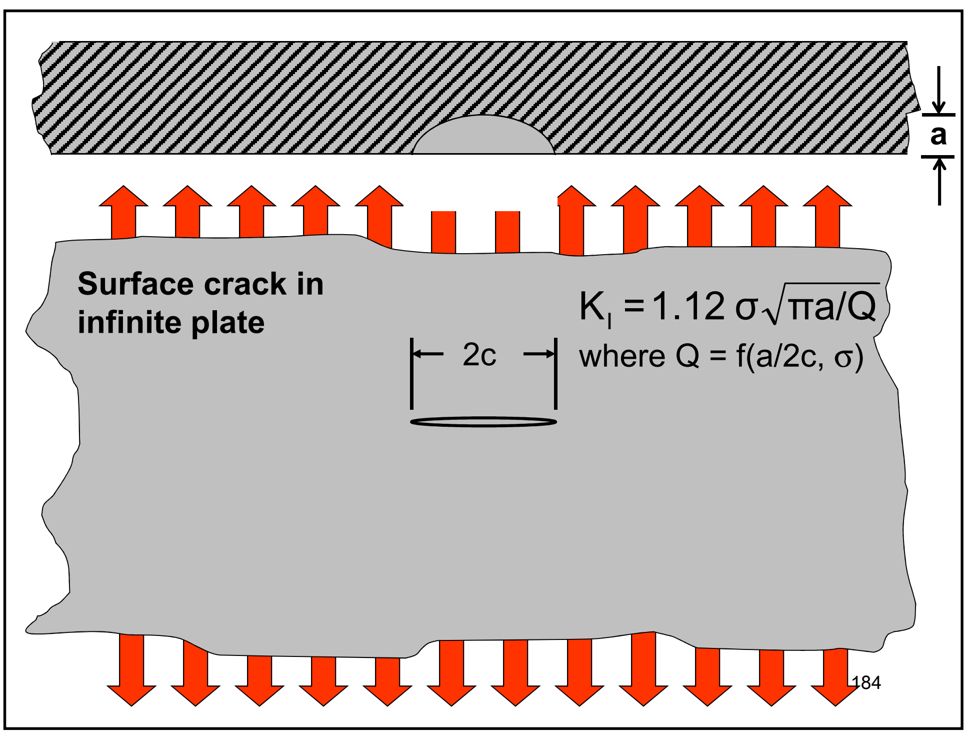
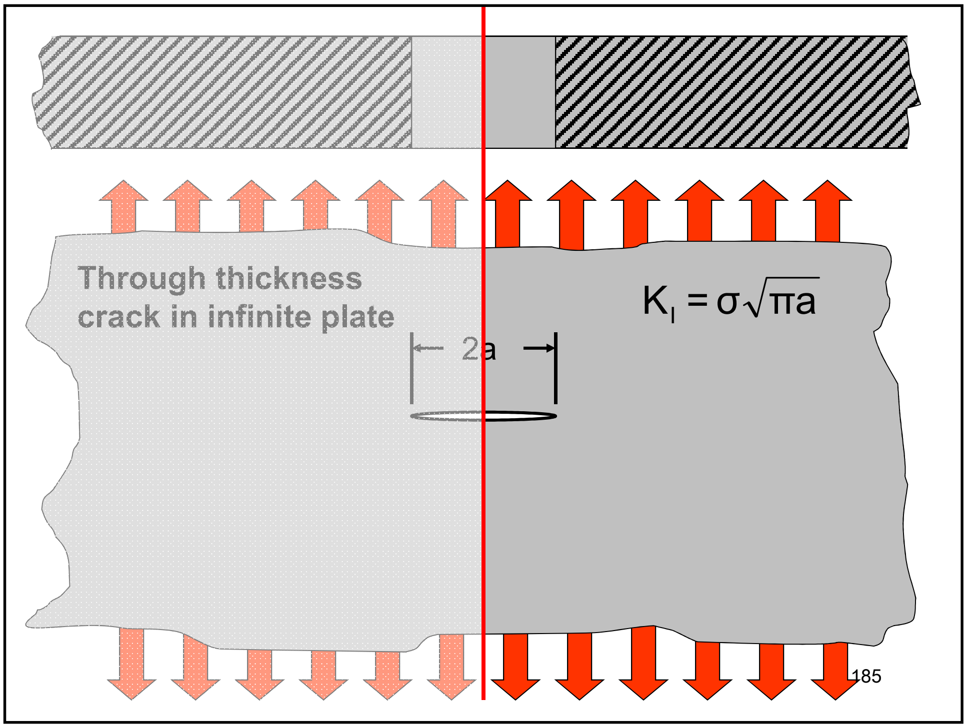
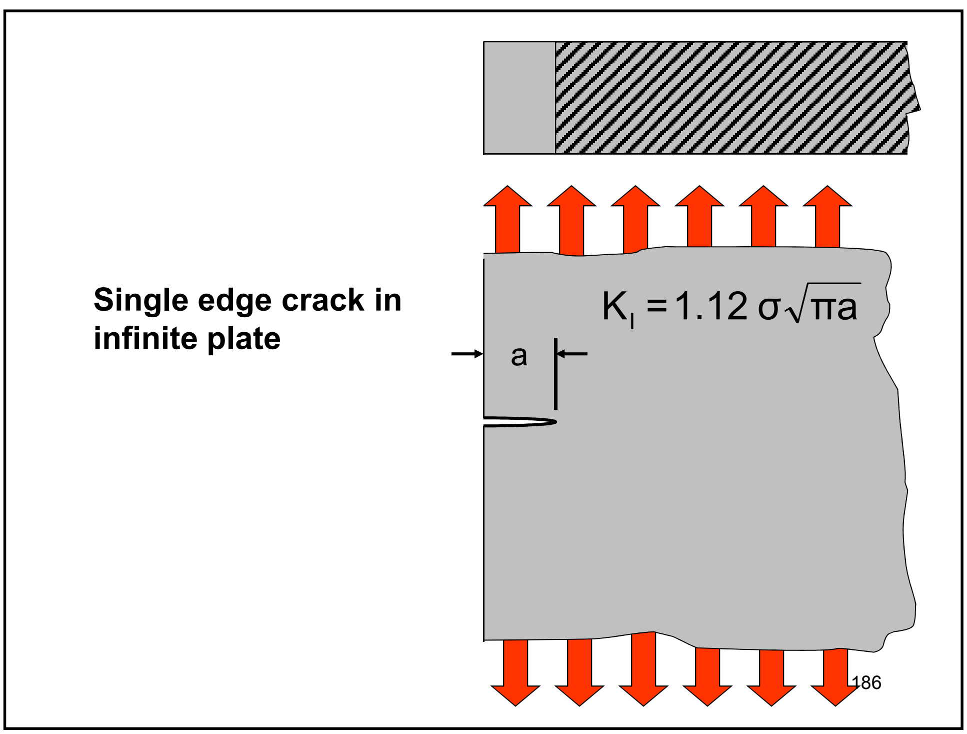
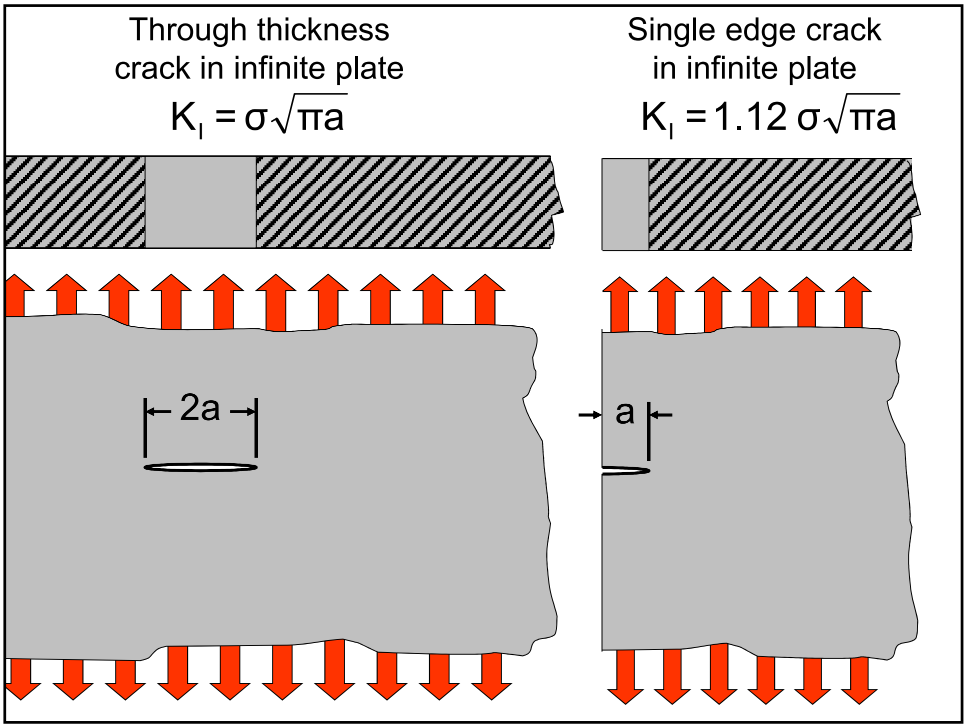
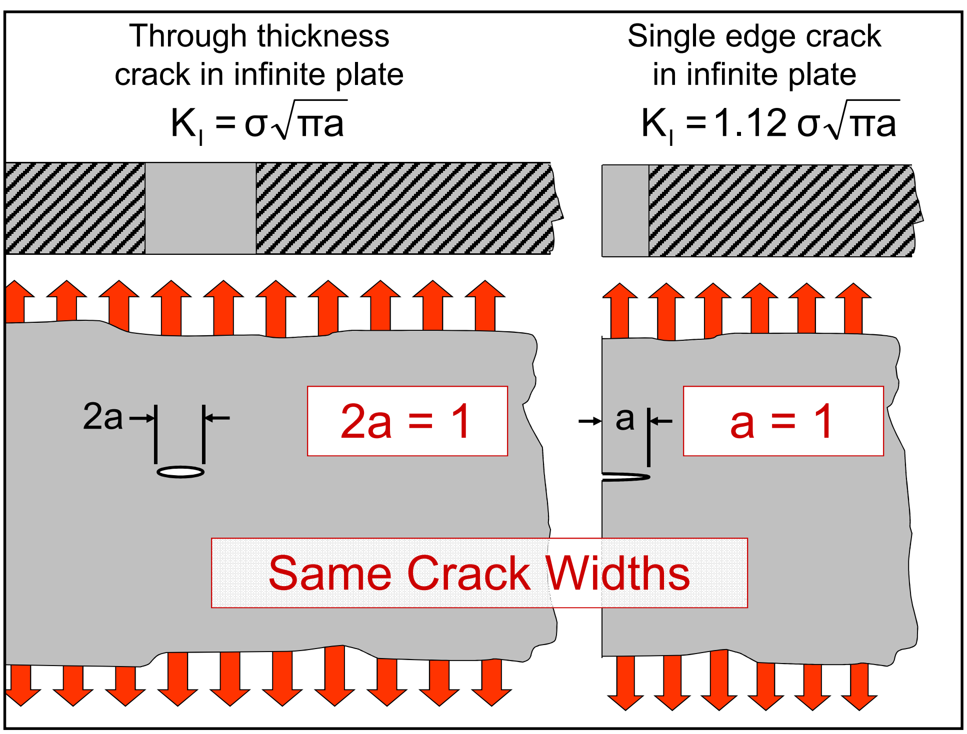

Through thickness
crack in infinite plate
$K_I = \sigma\sqrt{\pi a}$
2a
183


a
Surface crack in
infinite plate
$K_I = 1.12\,\sigma\sqrt{\pi a/Q}$
where Q = f(a/2c, σ)
2c
184


Through thickness
crack in infinite plate
2a
$K_I = \sigma\sqrt{\pi a}$
185

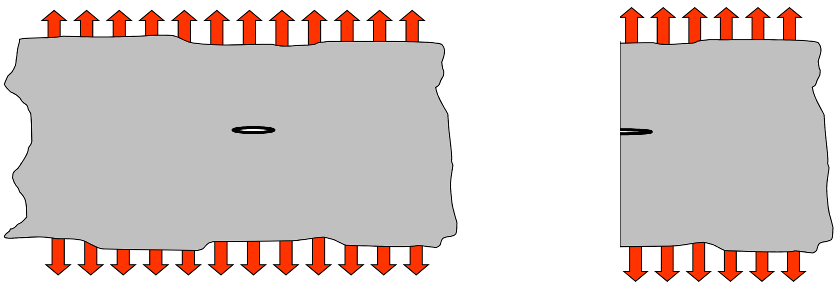

Single edge crack in
infinite plate
a
$K_I = 1.12\,\sigma\sqrt{\pi a}$
186


Through thickness crack in infinite plate
$K_I = \sigma\sqrt{\pi a}$
Single edge crack in infinite plate
$K_I = 1.12\,\sigma\sqrt{\pi a}$
2a
a


Through thickness crack in infinite plate
$K_I = \sigma\sqrt{\pi a}$
Single edge crack in infinite plate
$K_I = 1.12\,\sigma\sqrt{\pi a}$
2a
2a = 1
a
a = 1
Same Crack Widths

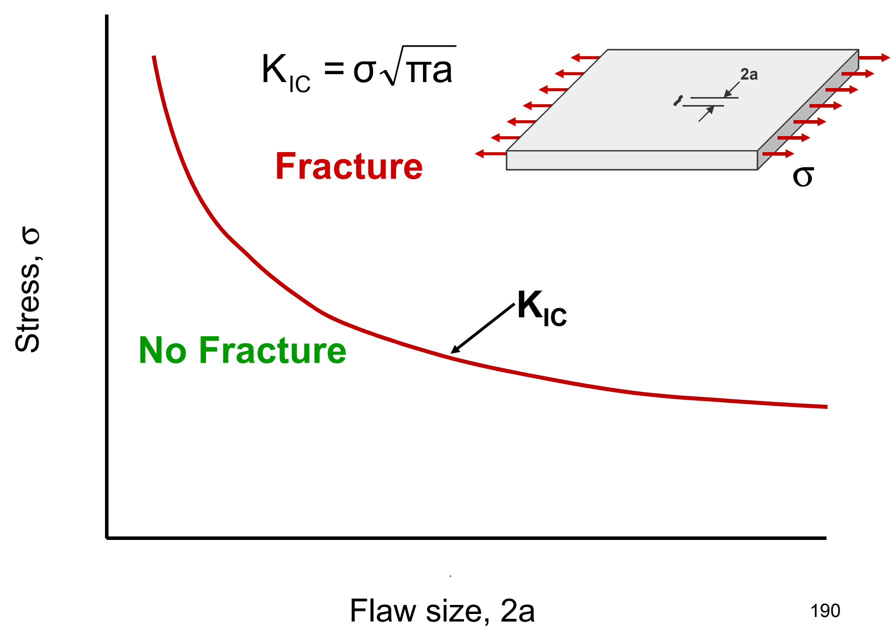
Through thickness crack in infinite plate	Single edge crack in infinite plate
$K_I = \sigma\sqrt{\pi a}$	$K_I = 1.12\,\sigma\sqrt{\pi a}$
$2a = 1$	$a = 1$
$K_I = \sigma\sqrt{\pi\,(0.5)}$	$K_I = 1.12\,\sigma\sqrt{\pi\,(1)}$
$= 1.253\,\sigma$	**$= 1.985\,\sigma$**

For cracks of equal length, an edge crack has a K_I that is 1.58 times that of a through thickness crack



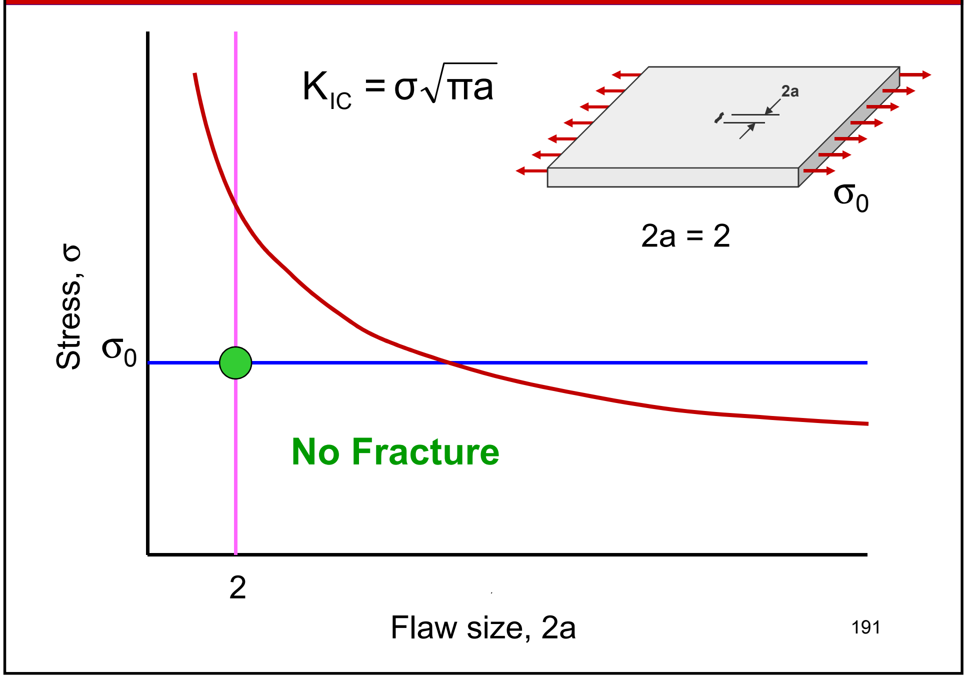
189

Fracture Mechanics

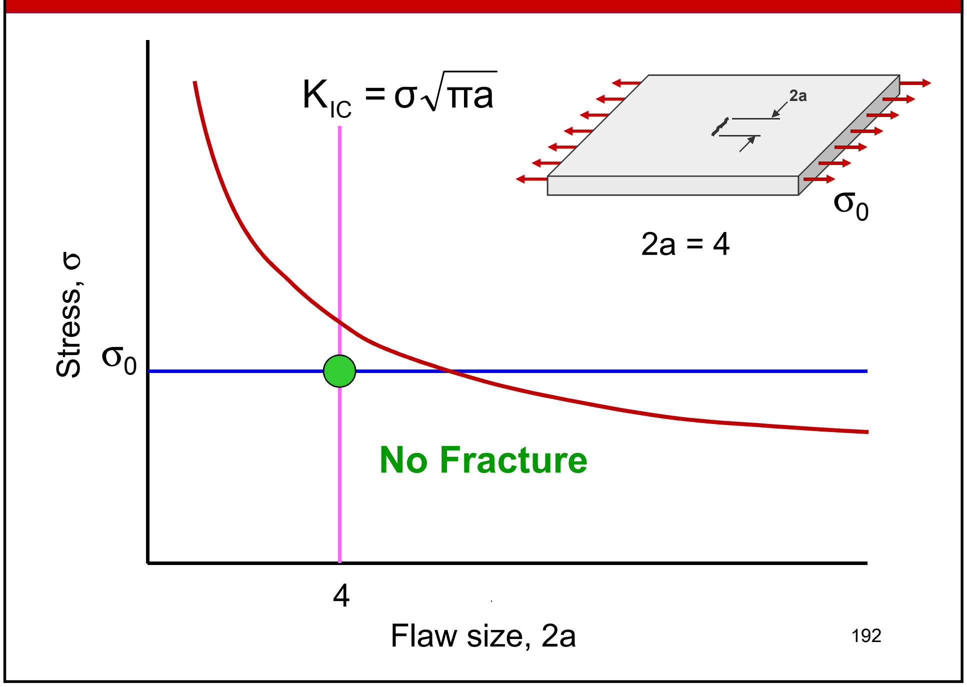


190

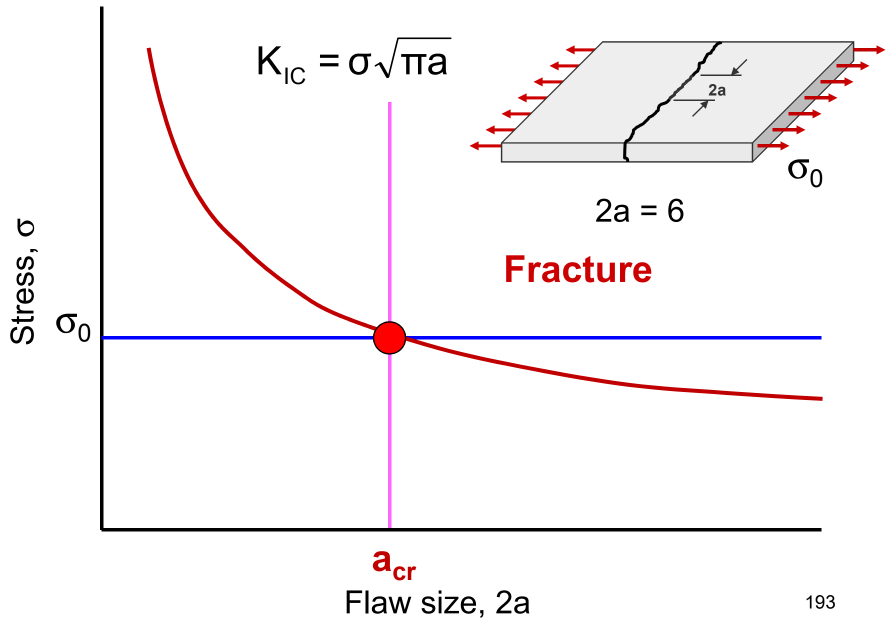
Fracture Mechanics



Fracture Mechanics

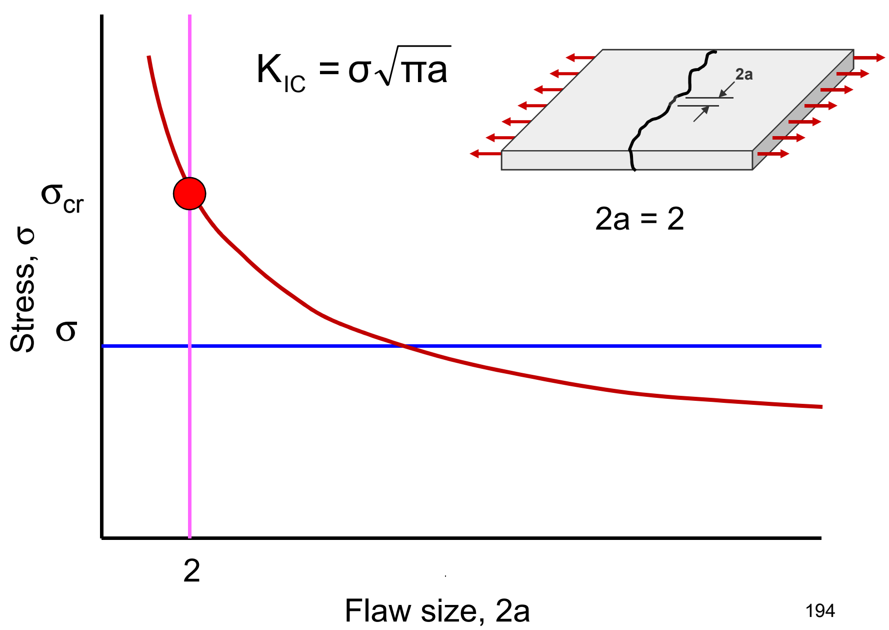


Fracture Mechanics

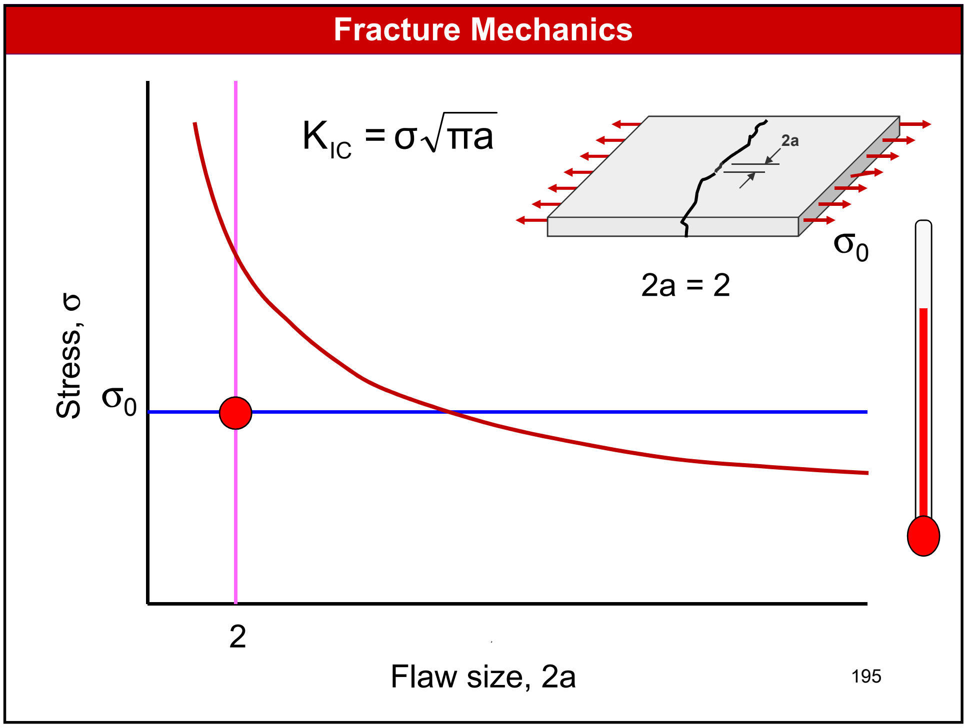


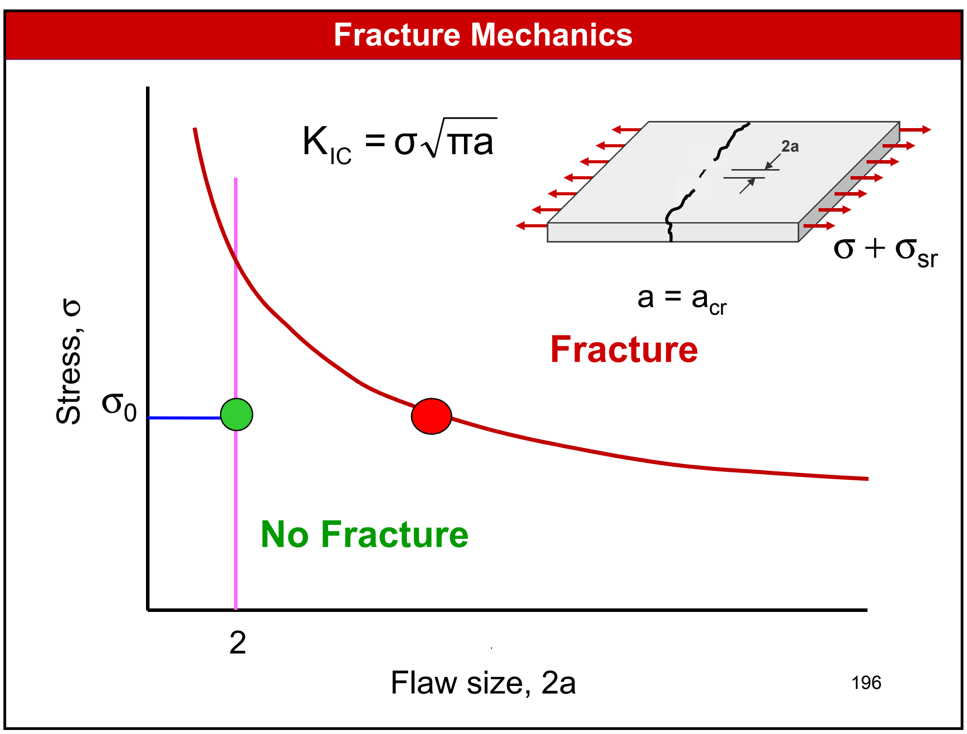
193

Fracture Mechanics



194


Fracture Mechanics
$K_{IC} = \sigma\sqrt{\pi a}$
2a
σ_0
2a = 2
Stress, σ
σ_0
2
Flaw size, 2a
195


Fracture Mechanics
$K_{IC} = \sigma\sqrt{\pi a}$
2a
$\sigma + \sigma_{sr}$
$a = a_{cr}$
Fracture
Stress, σ
σ_0
No Fracture
2
Flaw size, 2a
196

Welded Connection

~~WELD~~ INSPECTION

Background

Fracture Mechanics

- Stress
- Flaws ("crack" size and orientation)
- Material Toughness

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Welded Connection

~~WELD~~ INSPECTION

Background

- Quality Theory
- NDT & Quality Programs
- Weld Discontinuities
- NDT Methods & Capabilities
- Fatigue
- Fracture Mechanics
- AWS D1.1 & Quality

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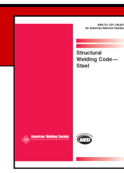
AWS D1.1:2010 Structural Welding Code--Steel



C-6.8 Engineer's Approval for Alternate Acceptance Criteria

The criteria provided in Clause 5, Fabrication, are based upon knowledgeable judgment of what is achievable by a qualified welder. The criteria in Clause 5 should not be considered a boundary of suitability for service. Suitability for service analysis would lead to widely varying workmanship criteria unsuitable for a standard code. Furthermore, in some cases, the criteria would be more liberal than what is desirable and producible by a qualified welder.

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AWS D1.1:2010 Structural Welding Code--Steel

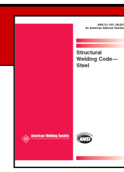

Table 6.1
Visual Inspection Acceptance Criteria (see 6.9)

Discontinuity Category and Inspection Criteria	Statically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections	Tubular Connections (All Loads)
(1) Crack Prohibition Any crack shall be unacceptable, regardless of size or location.	X	X	X
(2) Weld/Base-Metal Fusion Complete fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 5.24.	X	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A 514, A 517, and A 709 Grade 100 and 100 W steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in [mm] — U, allowable decrease from L, in [mm] ≤ 3/16 [5] — ≤ 1/16 [2] 1/4 [6] — ≤ 3/32 [2.5] ≥ 5/16 [8] — ≤ 1/8 [3] In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, underrun shall be prohibited at the ends for a length equal to twice the width of the flange.	X	X	X
(7) Undercut (A) For material less than 1 in [25 mm] thick, undercut shall not exceed 1/32 in [1 mm], with the following exception: undercut shall not exceed 1/16 in [2 mm] for any accumulated length up to 2 in [50 mm] in any 12 in [300 mm]. For material equal to or greater than 1 in [25 mm] thick, undercut shall not exceed 1/16 in [2 mm] for any length of weld.	X		
(B) In primary members, undercut shall be no more than 0.01 in [0.25 mm] deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in [1 mm] deep for all other cases.		X	X
(8) Porosity (A) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in [1 mm] or greater in diameter shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.	X		
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.		X	X
(C) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in [100 mm] of length and the maximum diameter shall not exceed 3/32 in [2.5 mm].		X	X

Note: An "X" indicates applicability for the connection type; a shaded area indicates non-applicability.

200

AWS D1.1:2010 Structural Welding Code--Steel

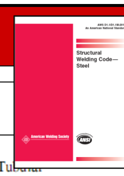

Table 6.1
Visual Inspection Acceptance Criteria (see 6.9)

Discontinuity Category and Inspection Criteria	Statically Loaded Nontubular Connections	Cyclically Loaded Nontubular Connections	Tubular Connections (All Loads)
(1) Crack Prohibition Any crack shall be unacceptable, regardless of size or location.	X	X	X
(2) Weld/Base-Metal Fusion Complete fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.	X	X	X
(3) Crater Cross Section All craters shall be filled to provide the specified weld size, except for the ends of intermittent fillet welds outside of their effective length.	X	X	X
(4) Weld Profiles Weld profiles shall be in conformance with 5.24.	X	X	X
(5) Time of Inspection Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature. Acceptance criteria for ASTM A 514, A 517, and A 709 Grade 100 and 100 W steels shall be based on visual inspection performed not less than 48 hours after completion of the weld.	X	X	X
(6) Undersized Welds The size of a fillet weld in any continuous weld may be less than the specified nominal size (L) without correction by the following amounts (U): L, specified nominal weld size, in [mm] — U, allowable decrease from L, in [mm] ≤ 3/16 [5] — ≤ 1/16 [2] 1/4 [6] — ≤ 3/32 [2.5] ≥ 5/16 [8] — ≤ 1/8 [3] In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, underrun shall be prohibited at the ends for a length equal to twice the width of the flange.	X	X	X

201

AWS D1.1:2010 Structural Welding Code--Steel

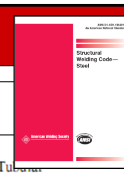

Table 6.1
Visual Inspection Acceptance Criteria (see 6.9)

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(B) In primary members, undercut shall be no more than 0.01 in [0.25 mm] deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1/32 in [1 mm] deep for all other cases.		X	X
(8) Porosity (A) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds and for fillet welds, the sum of the visible piping porosity 1/32 in [1 mm] or greater in diameter shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.	X		
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.		X	X
(C) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in [100 mm] of length and the maximum diameter shall not exceed 3/32 in [2.5 mm].		X	X

202

AWS D1.1:2010 Structural Welding Code--Steel

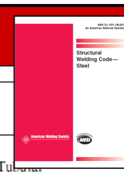

Table 6.1
Visual Inspection Acceptance Criteria (see 6.9)

Discontinuity Category and Insp...	Statically Loaded N...	Cyclically Loaded Nontubular Connections	Tubular Connections (All Loads)
(1) Crack Prohibition Any crack shall be unacceptable...		X	X
(2) Weld/Base-Metal Fusion Complete fusion shall exist betw... and base metal.		X	X
(3) Crater Cross Section All craters shall be filled to prov... intermittent fillet welds outside...		X	X
(4) Weld Profiles Weld profiles shall be in confor...		X	X
(5) Time of Inspection Visual inspection of welds in all... have cooled to ambient tempera... A 709 Grade 100 and 100 W ste... than 48 hours after completion...		X	X
(6) Undersized Welds The size of a fillet weld in any ... size (L) without correction by the following amounts (U): L, specified nominal weld size, in [mm] / U, allowable decrease from L, in [mm] ≤ 3/16 [5] / ≤ 1/16 [2] 1/4 [6] / ≤ 3/32 [2.5] ≥ 5/16 [8] / ≤ 1/8 [3] In all cases, the undersize portion of the weld shall not exceed 10% of the weld length. On web-to-flange welds on girders, underrun shall be prohibited at the ends for a length equal to twice the width of the flange.	X	X	X

Independent of loading

- Crack prohibition
- Weld/base-metal fusion
- Crater cross section
- Weld profiles
- Weld size

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TABLE N5.4-3
Inspection Tasks After Welding

Welds meet visual acceptance criteria

- Crack prohibition
- Weld/base-metal fusion
- Crater cross section
- Weld profiles
- Weld size
- Undercut
- Porosity

Document acceptance or rejection of welded joint or member	P	P

[1] When welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, visually inspect the web *k*-area for cracks within 3 in. (75 mm) of the weld.

204

AWS D1.1:2010 Structural Welding Code--Steel

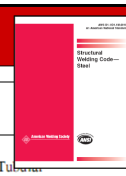

Table 6.1
Visual Inspection Acceptance Criteria (see 6.9)

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(B) In primary members, underc the weld is transverse to tensile be no more than 1/32 in [1 mm]		X	X
(8) Porosity (A) CJP groove welds in butt joi shall have no visible piping porc sum of the visible piping porosit 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.			
(B) The frequency of piping porosity in fillet welds shall not exceed one in each 4 in [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in [10 mm] in any linear inch of weld and shall not exceed 3/4 in [20 mm] in any 12 in [300 mm] length of weld.		X	X
(C) CJP groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in [100 mm] of length and the maximum diameter shall not exceed 3/32 in [2.5 mm].		X	X

Dependent of loading

- **Undercut**
- **Porosity**

205

AWS D1.1:2010 Structural Welding Code--Steel

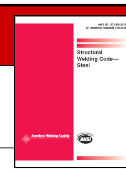

Table 6.2
UT Acceptance-Rejection Criteria (Statically Loaded Nontubular Connections)
(see 6.13.1 and C-6.26.6)

Discontinuity Severity Class	Weld Size[a] in inches [mm] and Search Unit Angle										
	5/16 through 3/4 [8–20]	> 3/4 through 1-1/2 [20–38]	> 1-1/2 through 2-1/2 [38–65]			> 2-1/2 through 4 [65–100]			> 4 through 8 [100–200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+5 & lower	+2 & lower	−2 & lower	+1 & lower	+3 & lower	−5 & lower	−2 & lower	0 & lower	−7 & lower	−4 & lower	−1 & lower
Class B	+6	+3	−1 0	+2 +3	+4 +5	−4 −3	−1 0	+1 +2	−6 −5	−3 −2	0 +1
Class C	+7	+4	+1 +2	+4 +5	+6 +7	−2 to +2	+1 +2	+3 +4	−4 to +2	−1 to +2	+2 +3
Class D	+8 & up	+5 & up	+3 & up	+6 & up	+8 & up	+3 & up	+3 & up	+5 & up	+3 & up	+3 & up	+4 & up

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AWS D1.1:2010 Structural Welding Code--Steel

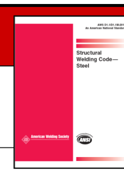

Table 6.3
UT Acceptance-Rejection Criteria (Cyclically Loaded Nontubular Connections)
(see 6.13.2 and C-6.26.6)

Discontinuity Severity Class	Weld Size[a] in inches [mm] and Search Unit Angle													
	5/16 through 3/4 [8–20]	> 3/4 through 1-1/2 [20–38]	> 1-1/2 through 2-1/2 [38–65]			> 2-1/2 through 4 [65–100]			> 4 through 8 [100–200]					
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°			
Class A	+10 & lower	+8 & lower	+4 & lower	+7 & lower	+9 & lower	+1 & lower	+4 & lower	+6 & lower	–2 & lower	+1 & lower	+3 & lower			
Class B	+11	+9	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	–1 0	+2 +3	+4 +5			
Class C	+12	+10	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7			
Class D	+13 & up	+11 & up	+9 & up	+12 & up	+14 & up	+6 & up	+9 & up	+11 & up	+3 & up	+6 & up	+8 & up			

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Welded Connection

~~WELD~~ INSPECTION

Background

AWS D1.1 and Quality

- Visual is primarily workmanship-based
- NDT criteria for static and cyclic
- Acceptance criteria is not lower bound of serviceability

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Welded Connection

~~WELD~~ INSPECTION

NOW

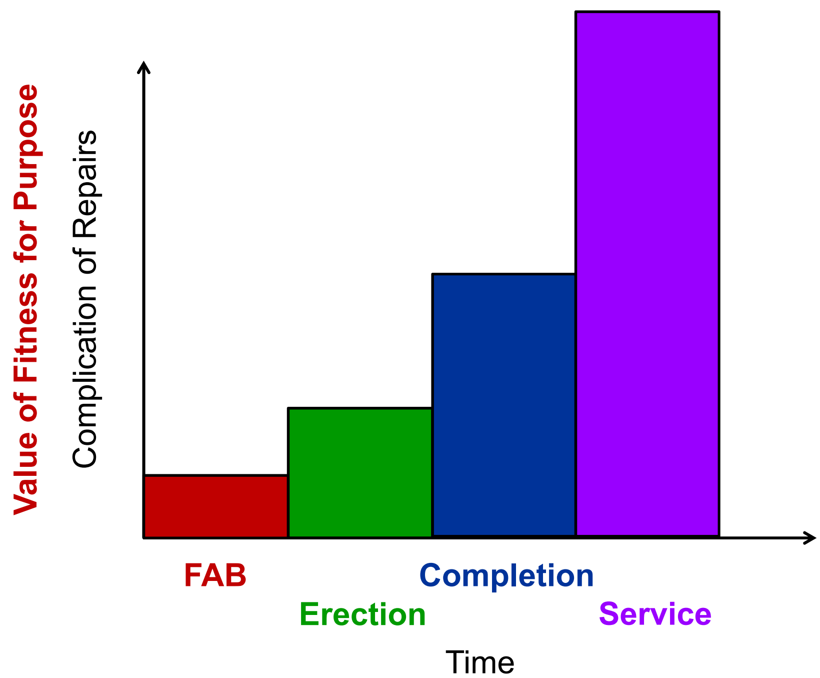
What Matters? And What Don't?

209

Time to get down to brass tacks…….

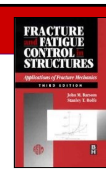
- 90+% of the time, use AISC/AWS acceptance criteria
- When repairs will be difficult or expensive to perform, consider Fitness for Purpose analysis
- For existing structures, Fitness of Purpose Analysis may justify additional loading, longer life

210



211

Fatigue and Fracture Control in Structures

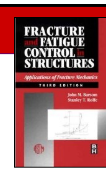


Chapter 14

Fitness for Service

212

Fatigue and Fracture Control in Structures



(quoting Alan Wells)

"**Fitness for purpose** is deemed to be that which is consciously chosen to be the right level of material…and fabrication quality…for each application…, having regard to the risks and consequences of failure; it may be contrasted with the best quality that can be achieved within a given set of circumstances, which may be inadequate for some exacting requirements and needlessly uneconomic for other which are less demanding."

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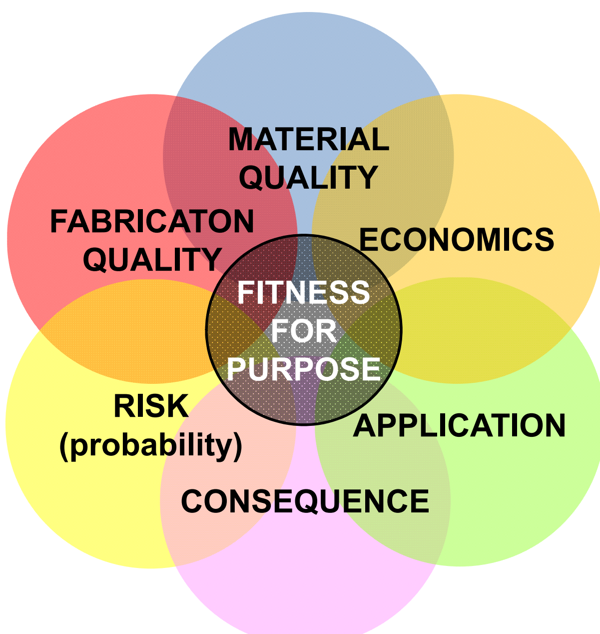
FITNESS FOR PURPOSE



214

COMMON SENSE ENGINEERING

"The Art and Science of Structural Engineering"
Symposium Proceedings, April 1993

Chapter 6
Fitness for Service—Common Sense Engineering
By Stanley T. Rolfe

"The present state of the art is such that fitness-for-service is really an attempt to quantify what has often been referred to as common-sense engineering based on engineering research."

215

COMMON SENSE ENGINEERING

"The Art and Science of Structural Engineering"
Symposium Proceedings, April 1993

Chapter 6
Fitness for Service—Common Sense Engineering
By Stanley T. Rolfe

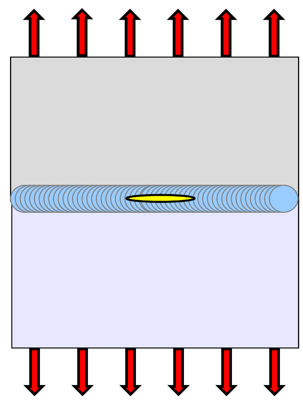
"(fitness for service) is a blend of both the art and science of engineering and is very valuable in helping engineers use new research information to solve the engineering problems of properly assessing the remaining life of existing structures."

216

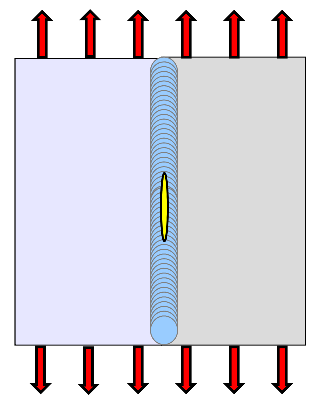
COMMON SENSE ENGINEERING

Stress Transferred Across Joint

Tension Perpendicular



Tension Parallel



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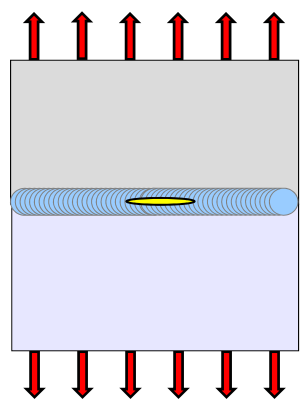
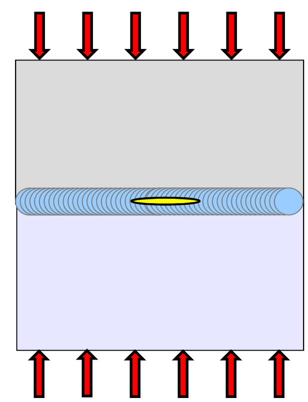
COMMON SENSE ENGINEERING

Nature of Loading

Tension



Compression



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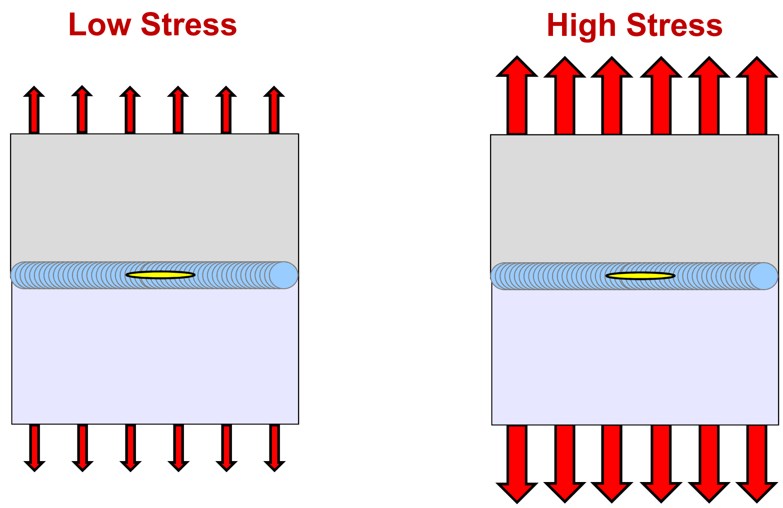
COMMON SENSE ENGINEERING

Magnitude Stress (applied or residual)



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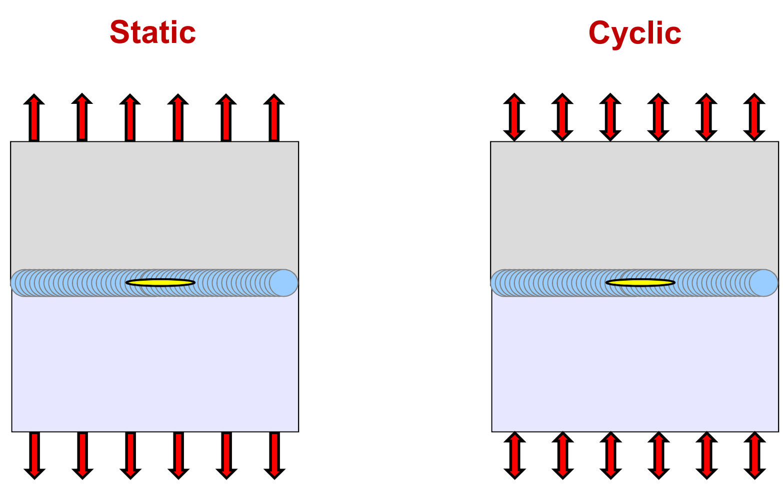
COMMON SENSE ENGINEERING

Nature of Loading

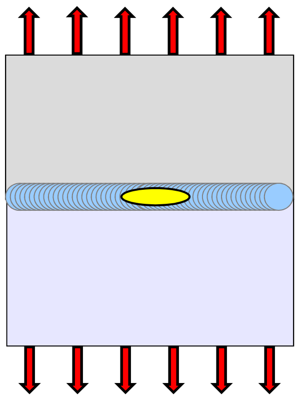


220

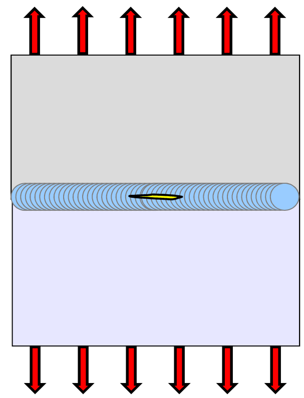
COMMON SENSE ENGINEERING

Acuity (or sharpness) of Discontinuity

Rounded Ends



Sharp Ends

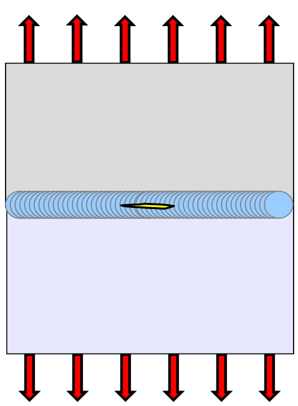


221

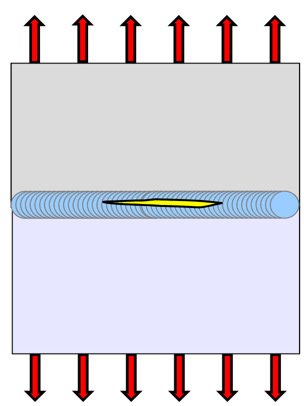
COMMON SENSE ENGINEERING

Size of Discontinuity

Small



Large

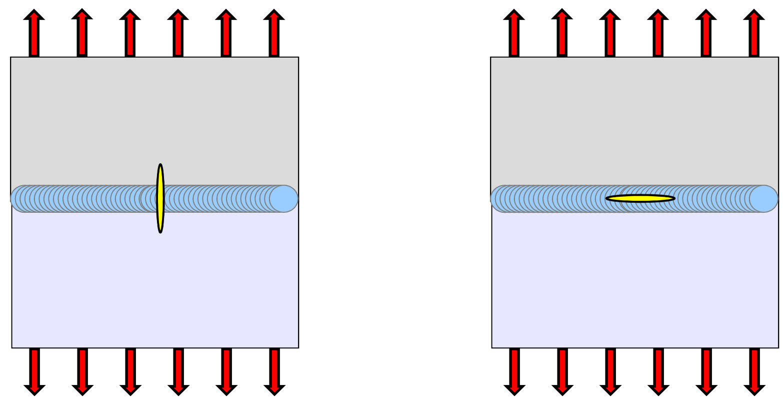


222

COMMON SENSE ENGINEERING

Orientation With Respect to Stress (applied or residual)

Parallel **Perpendicular**



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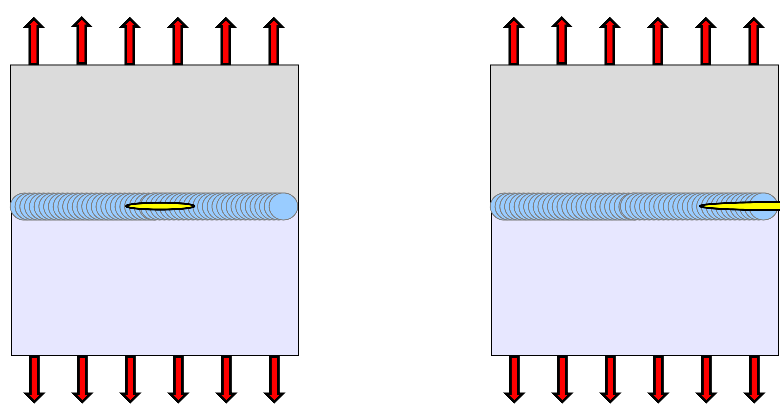
COMMON SENSE ENGINEERING

Location of Discontinuity

Buried Crack **Edge Crack**

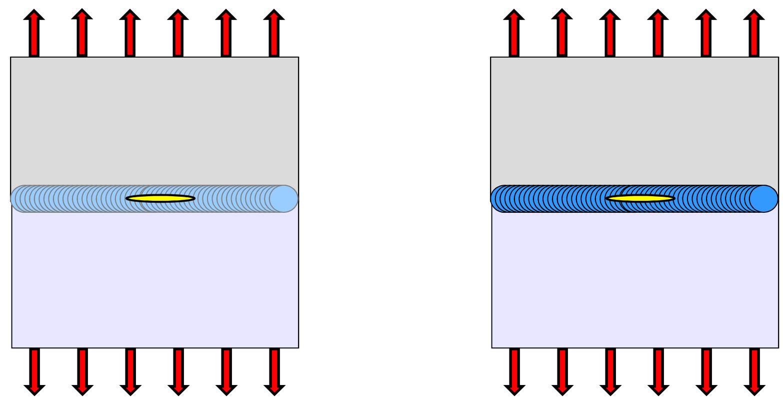


224

COMMON SENSE ENGINEERING

Material Toughness

Low Toughness | **High Toughness**

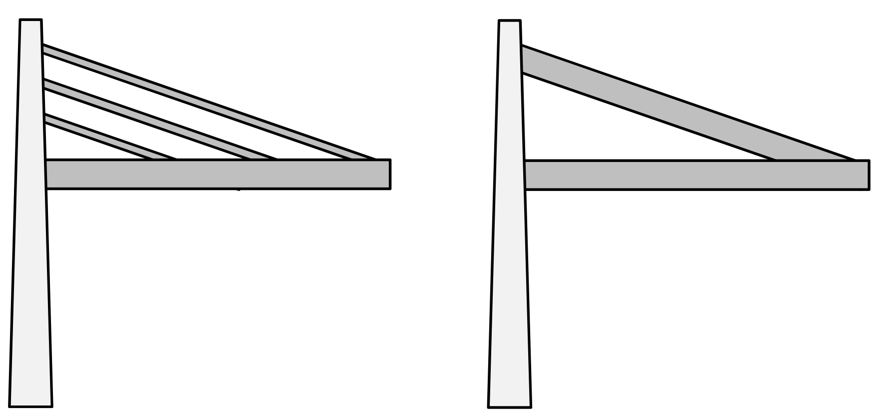


225

COMMON SENSE ENGINEERING

Redundancy

Highly Redundant | **Limited Redundancy**

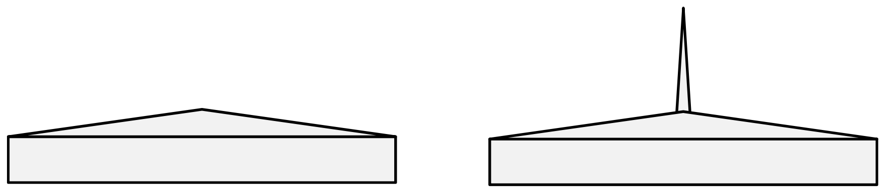


226

COMMON SENSE ENGINEERING

Consequences of Failure

Warehouse #1 | **First Baptist Church**

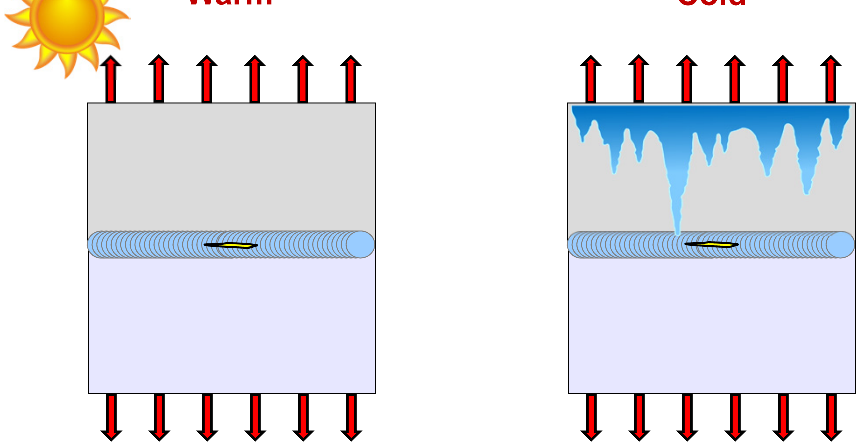


227

COMMON SENSE ENGINEERING

Temperature

Warm | **Cold**



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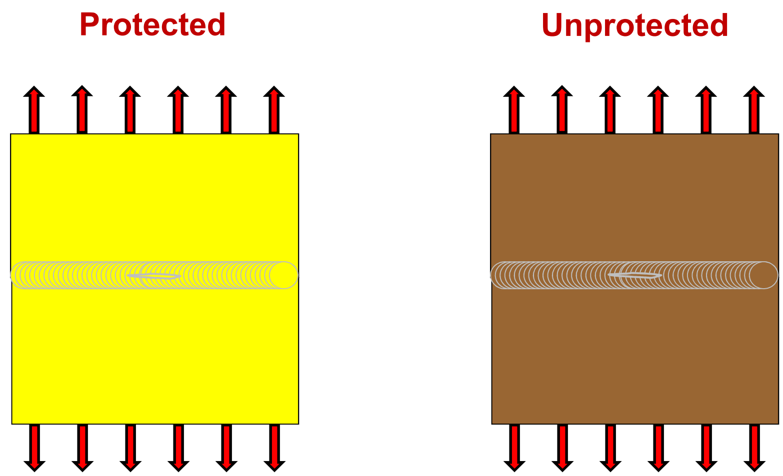
COMMON SENSE ENGINEERING

Subject to Corrosion



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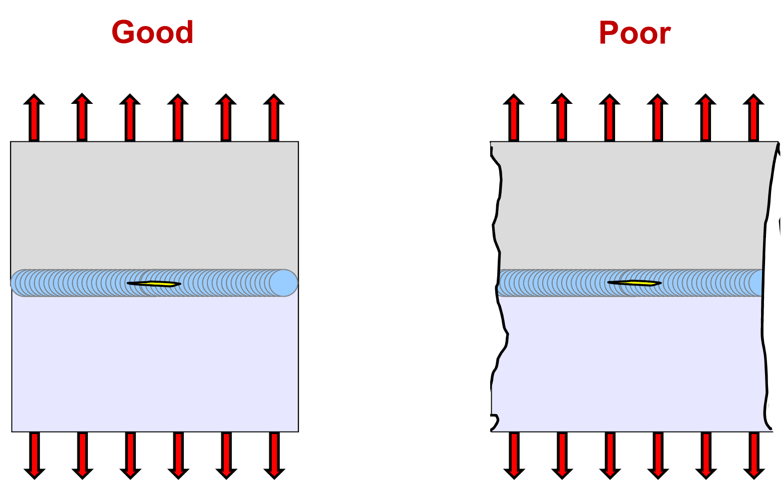
COMMON SENSE ENGINEERING

Quality of Original Construction



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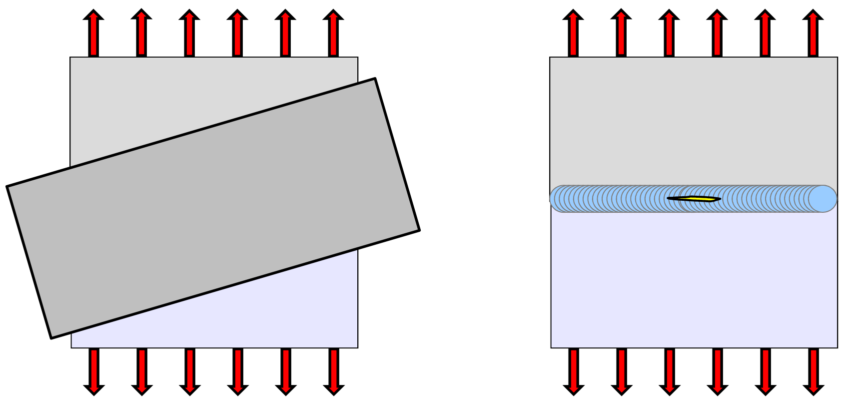
COMMON SENSE ENGINEERING

Quality/Degree of Original Inspection

None/Poor **Extensive/Well Done**



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Welded Connection

~~WELD~~ INSPECTION

Case Studies

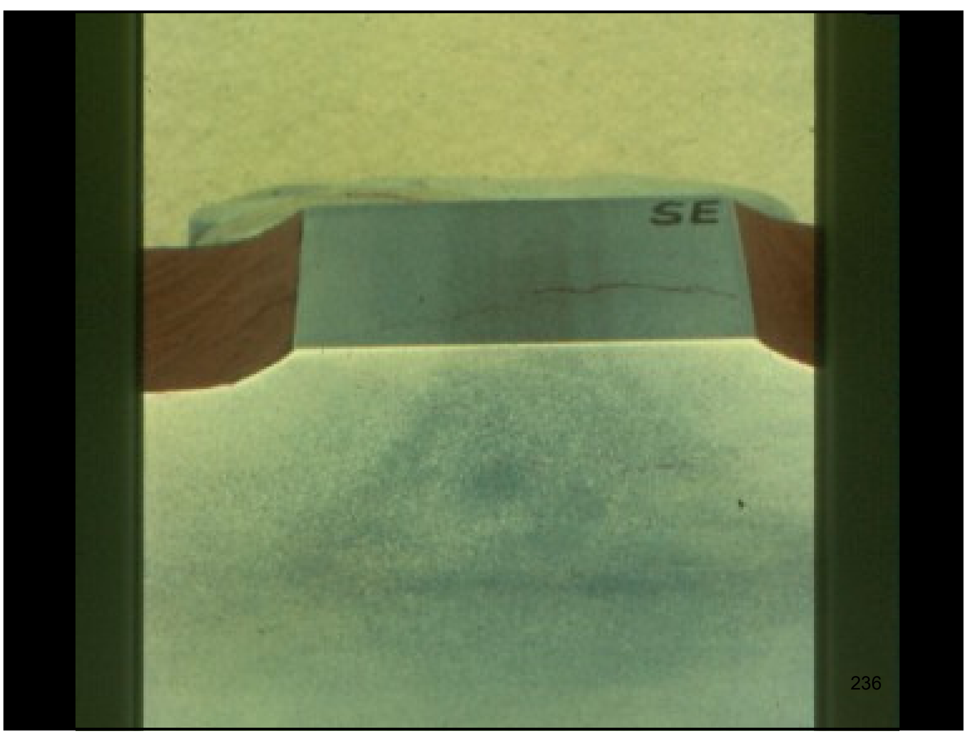
- Jumbo Sections
- Fatigue
- k-area
- Tub Girder

232


EEL.PALATKA.FLA.
233


PALATK
234


PAI
ATK
235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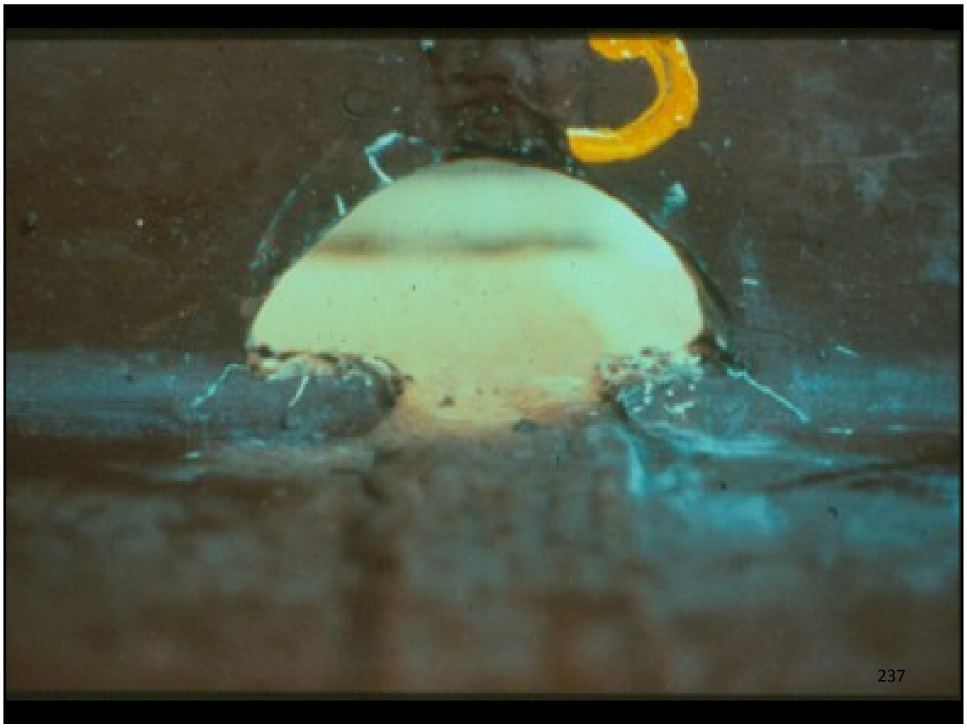
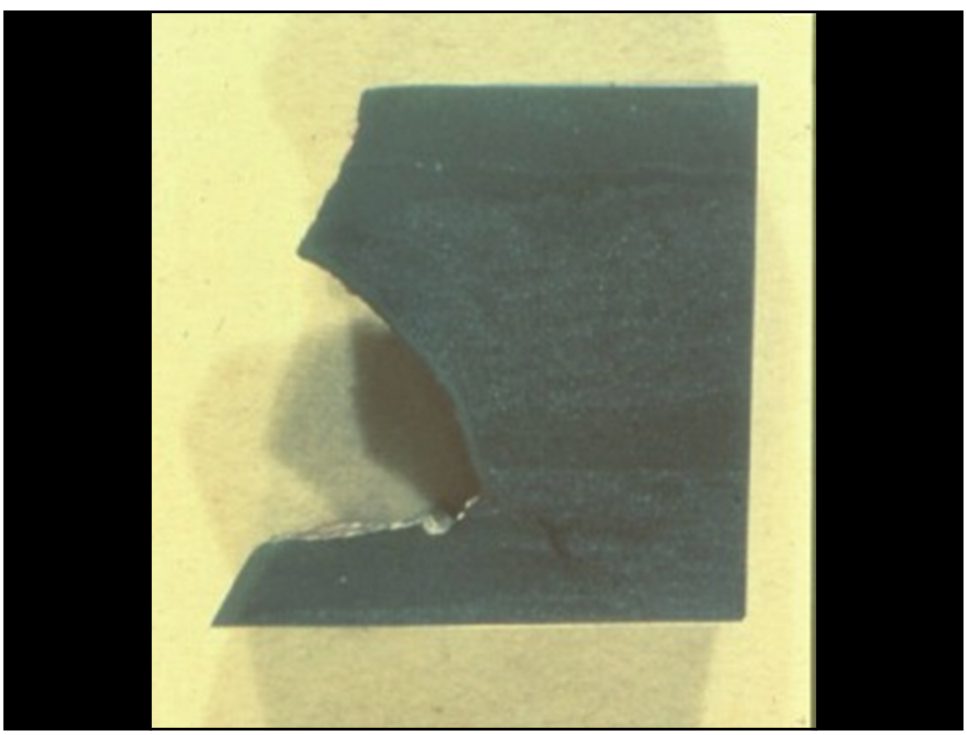

237

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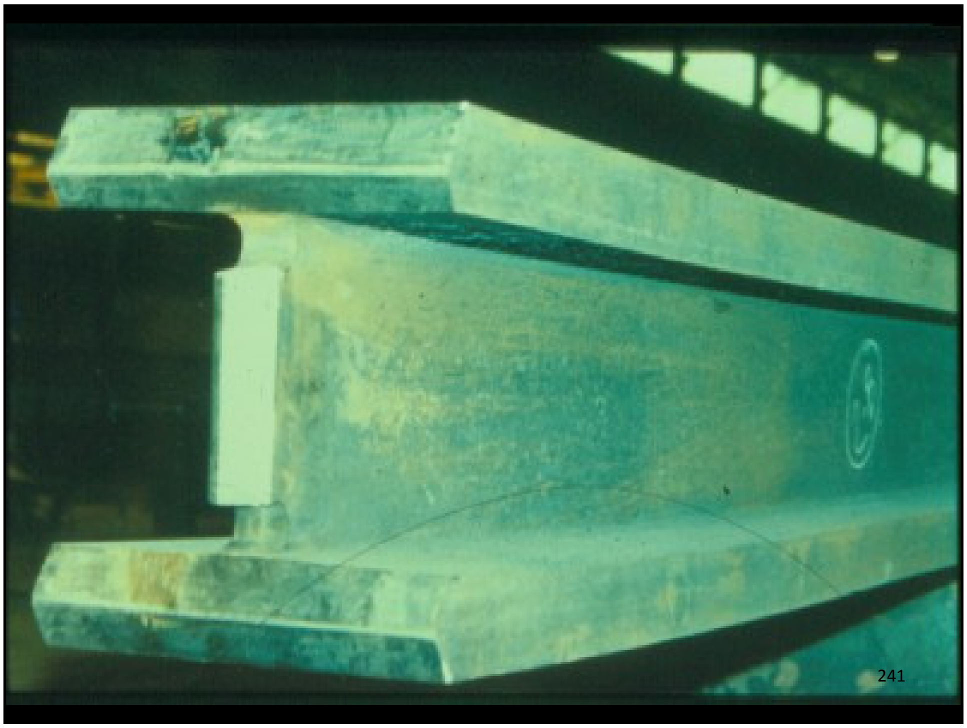
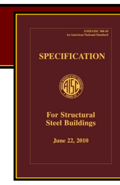
240



241

AISC 360-10 SPECIFICATION



N5.5. Nondestructive Testing of Welded Joints

5c. Access Hole NDT

Thermally cut surfaces of access holes shall be tested by QA using MT or PT, when the flange thickness exceeds 2 in. (50 mm) for rolled shapes, or when the web thickness exceeds 2 in. (50 mm) for *built-up shapes*. Any crack shall be deemed unacceptable regardless of size or location.

242

JUMBO SECTIONS

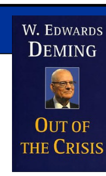
Justification for extra inspection

- Low Toughness
- Thermal Cutting
- Richer Composition Steel
- Workmanship Challenge
- High Restraint
- High Residual Stresses
- Reduced Redundancy (typically)
- Critical Function (typically)

100% Inspection of weld access hole surface with MT or PT

243

Deming: Out of the Crisis



Quality comes not from inspection, but from improvement of the production process.

244

JUMBO SECTIONS

Other provisions to mitigate cracking

- Toughness requirements
- Preheat before thermal cutting
- Minimum access hole dimensions
- Grinding of weld access holes
- Weld tab removal

All part of the "process" changes that were implemented to solve the "jumbo problem"

245

JUMBO SECTIONS

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

Detecting cracks on thermally cut surfaces of weld access holes in jumbo sections.

246

JUMBO SECTIONS

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

NDT of mechanically cut surfaces of weld access holes in jumbo sections.

247

JUMBO SECTIONS

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

NDT of thermally cut surfaces of weld access holes in regular sections.

248

Welded Connection

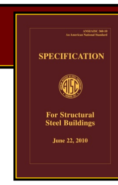
~~WELD~~ INSPECTION

Case Studies

- Jumbo Sections
- Fatigue
- k-area
- Tub Girder

249

AISC 360-10 SPECIFICATION



N5.5. Nondestructive Testing of Welded Joints

5d. Welded Joints Subjected to Fatigue

When required by Appendix 3, Table A-3.1, welded joints requiring weld soundness to be established by radiographic or ultrasonic inspection shall be tested by QA as prescribed. Reduction in the rate of UT is prohibited.

250

AISC 360-10 SPECIFICATION

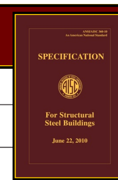
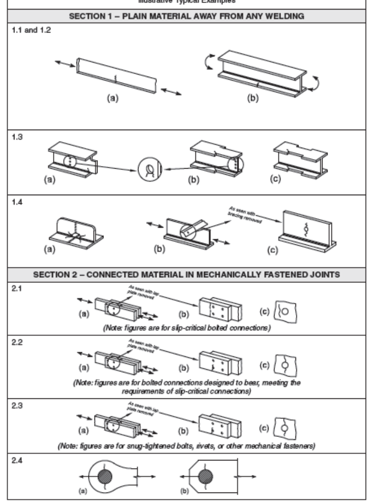


TABLE A-3.1
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (MPa)	Potential Crack Initiation Point
SECTION 1 – PLAIN MATERIAL AWAY FROM ANY WELDING				
1.1 Base metal, except noncoated weathering steel, with rolled or cleaned surface. Flame-cut edges with surface roughness value of 1,000 µin. (25 µm) or less, but without reentrant corners.	A	250×10^8	24 (165)	Away from all welds or structural connections
1.2 Noncoated weathering steel base metal with rolled or cleaned surface. Flame-cut edges with surface roughness value of 1,000 µin. (25 µm) or less, but without reentrant corners.	B	120×10^8	16 (110)	Away from all welds or structural connections
1.3 Member with drilled or reamed holes. Member with re-entrant corners at copes, cuts, block-outs or other geometrical discontinuities made to requirements of Appendix 3, Section 3.5, except weld access holes.	B	120×10^8	16 (110)	At any external edge or at hole perimeter
1.4 Rolled cross sections with weld access holes made to requirements of Section J1.6 and Appendix 3, Section 3.5. Members with drilled or reamed holes containing bolts for attachment of light bracing where there is a small longitudinal component of brace force.	C	44×10^8	10 (69)	At reentrant corner of weld access hole or at any small hole (may contain bolt for minor connections)
SECTION 2 – CONNECTED MATERIAL IN MECHANICALLY FASTENED JOINTS				
2.1 Gross area of base metal in lap joints connected by high-strength bolts in joints satisfying all requirements for slip-critical connections.	B	120×10^8	16 (110)	Through gross section near hole
2.2 Base metal at net section of high-strength bolted joints, designed on the basis of bearing resistance, but fabricated and installed to all requirements for slip-critical connections.	B	120×10^8	16 (110)	In net section originating at side of hole
2.3 Base metal at the net section of other mechanically fastened joints except eye bars and pin plates.	D	22×10^8	7 (48)	In net section originating at side of hole
2.4 Base metal at net section of *eyebar* head or pin plate.	E	11×10^8	4.5 (31)	In net section originating at side of hole

TABLE A-3.1 (continued)
Fatigue Design Parameters

Illustrative Typical Examples



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AISC 360-10 SPECIFICATION

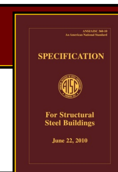
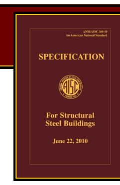


TABLE A-3.1 (continued)
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (MPa)	Potential Crack Initiation Point
SECTION 5 – WELDED JOINTS TRANSVERSE TO DIRECTION OF STRESS				
5.1 Weld metal and base metal in or adjacent to complete-joint-penetration groove welded splices in rolled or welded cross sections with welds ground essentially parallel to the direction of stress and with soundness established by radiographic or ultrasonic inspection in accordance with the requirements of subclauses 6.12 or 6.13 of AWS D1.1/D1.1M.	B	120×10^8	16 (110)	From internal discontinuities in weld metal or along the fusion boundary

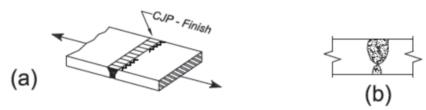
252

AISC 360-10 SPECIFICATION



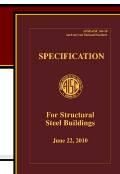
SECTION 5 – WELDED JOINTS TRANSVERSE TO DIRECTION OF STRESS

5.1



253

AISC 360-10 SPECIFICATION



5.1 Weld metal and base metal in or adjacent to complete-joint-penetration groove welded splices in rolled or welded cross sections with welds ground essentially parallel to the direction of stress and with soundness established by radiographic or ultrasonic inspection in accordance with the requirements of subclauses 6.12 or 6.13 of AWS D1.1/D1.1M.

254

AISC 360-10 SPECIFICATION

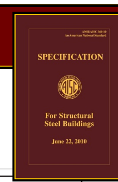
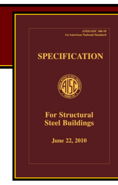


TABLE A-3.1 (continued)
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (MPa)	Potential Crack Initiation Point
SECTION 3 – WELDED JOINTS JOINING COMPONENTS OF BUILT-UP MEMBERS				
3.1 Base metal and weld metal in members without attachments built up of plates or shapes connected by continuous longitudinal complete-joint-penetration groove welds, back gouged and welded from second side, or by continuous fillet welds.	B	120 x 10^8	16 (110)	From surface or internal discontinuities in weld away from end of weld

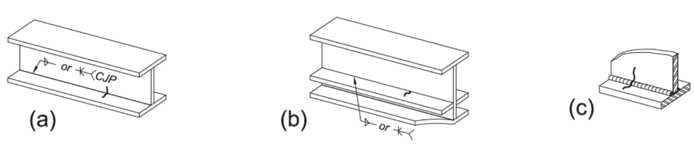
255

AISC 360-10 SPECIFICATION



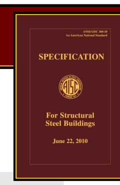
SECTION 3 – WELDED JOINTS JOINING COMPONENTS OF BUILT-UP MEMBERS

3.1



256

AISC 360-10 SPECIFICATION



3.1 Base metal and weld metal in members without attachments built up of plates or shapes connected by continuous longitudinal complete-joint-penetration groove welds, back gouged and welded from second side, or by continuous fillet welds.

No NDT specified

257

FATIGUE

Justification for extra inspection

- Cyclic Loading
- Transverse Tension
- CJP Groove Welds
- Critical Function

100% volumetric inspection with RT or UT

258

FATIGUE

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

Detecting defects in Category B, transverse tension CJP groove welds, subject to cyclic loading.

259

FATIGUE

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

NDT of Category B, longitudinal shear loaded CJP groove welds, subject to cyclic loading.

260

Welded Connection

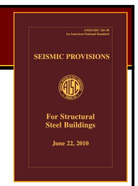
~~WELD~~ INSPECTION

Case Studies

- Jumbo Sections
- Fatigue
- k-area
- Tub Girder

261

AISC 341-10 SEISMIC PROVISIONS



CHAPTER J
QUALITY CONTROL AND QUALITY ASSURANCE

J5. INSPECTION TASKS

2a. *k*-Area NDT
Where welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, the web shall be tested for cracks using magnetic particle testing (MT)…..

for seismic applications

262

AISC 360-10 SPECIFICATION

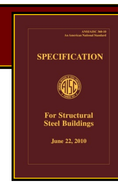


TABLE N5.4-3
Inspection Tasks After Welding

Inspection Tasks After Welding	QC	QA
Welds cleaned	O	O
Size, length and location of welds	P	P
Welds meet visual acceptance criteria • Crack prohibition • Weld/base-metal fusion • Crater cross section • Weld profiles • Weld size • Undercut • Porosity	P	P
Arc strikes	P	P
k-area[1]	P	P
Backing removed and weld tabs removed (if required)	P	P
Repair activities	P	P
Document acceptance or rejection of welded joint or member	P	P

[1] When welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, visually inspect the web *k*-area for cracks within 3 in. (75 mm) of the weld.

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AISC 360-10 SPECIFICATION

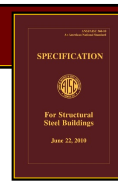


TABLE N5.4-3
Inspection Tasks After Welding

Inspection Tasks After Welding	QC	QA
Welds cleaned	O	O

[1] When welding on doubler plates, continuity plates or stiffeners has been performed in the k-area, visually inspect the web k-area for cracks within 2 in. (75 mm) of the weld.

• Porosity		
Arc strikes	P	P
k-area[1]	P	P
Backing removed and weld tabs removed (if required)	P	P
Repair activities	P	P
Document acceptance or rejection of welded joint or member	P	P

[1] When welding of doubler plates, continuity plates or stiffeners has been performed in the *k*-area, visually inspect the web *k*-area for cracks within 3 in. (75 mm) of the weld.

264

k-area

Justification for extra inspection for seismic

- Low Toughness Region
- Residual Stresses from Welding
- In Panel Zone (that might be severely stained in earthquake)

100% inspection with visual and MT

265

k-area

Justification for extra inspection for static

- Low Toughness Region
- Residual Stresses from Welding

100% inspection with visual

266

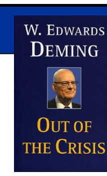
k-area

Alternate detailing to eliminate inspection

- Large snipes for continuity plates
- Doublers that are not flush with web
- Doublers with large snipes, welded in radius (not in k-area)
- Eliminate doublers with heavier columns

267

Deming: Out of the Crisis



Quality comes not from inspection, but from improvement of the production process.

268

k-area

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

Detection of cracking in the low toughness k-area, when subject to seismic loading: visual and MT required.

269

k-area

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

The extra assurance of crack detection that is provided by MT for connections that are subject to static loading only.

270

Welded Connection

~~WELD~~ INSPECTION

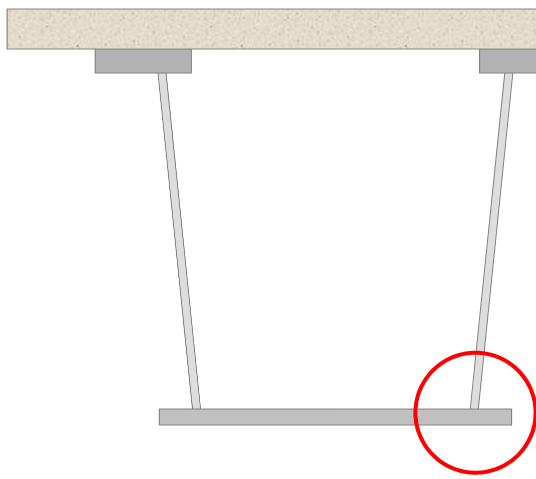
Case Studies

- Jumbo Sections
- Fatigue
- k-area
- Tub Girder

271

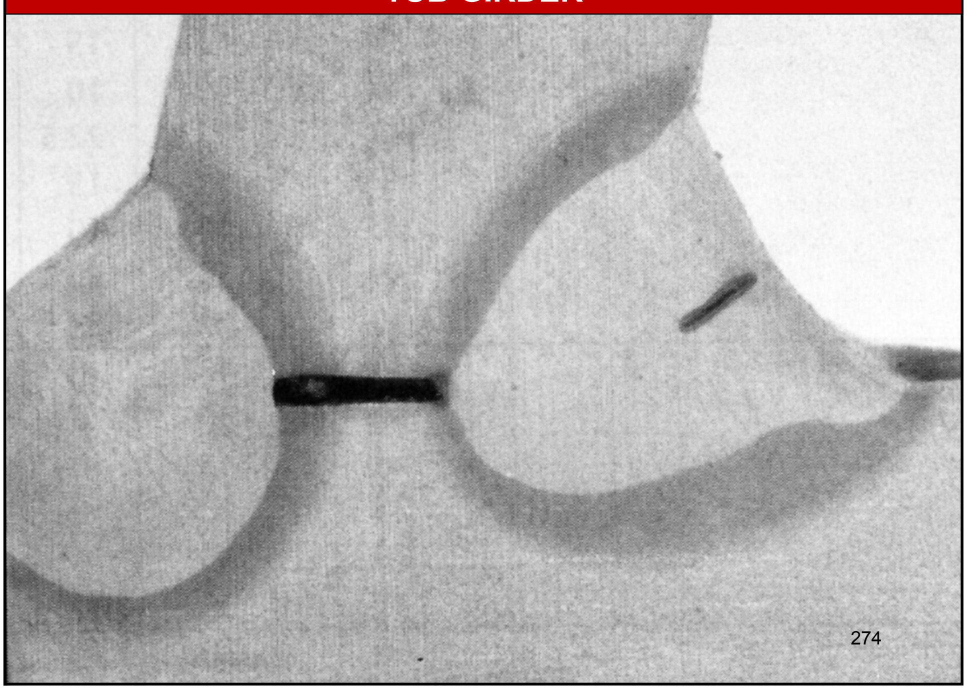
TUB GIRDER

TUB GIRDER



273

TUB GIRDER



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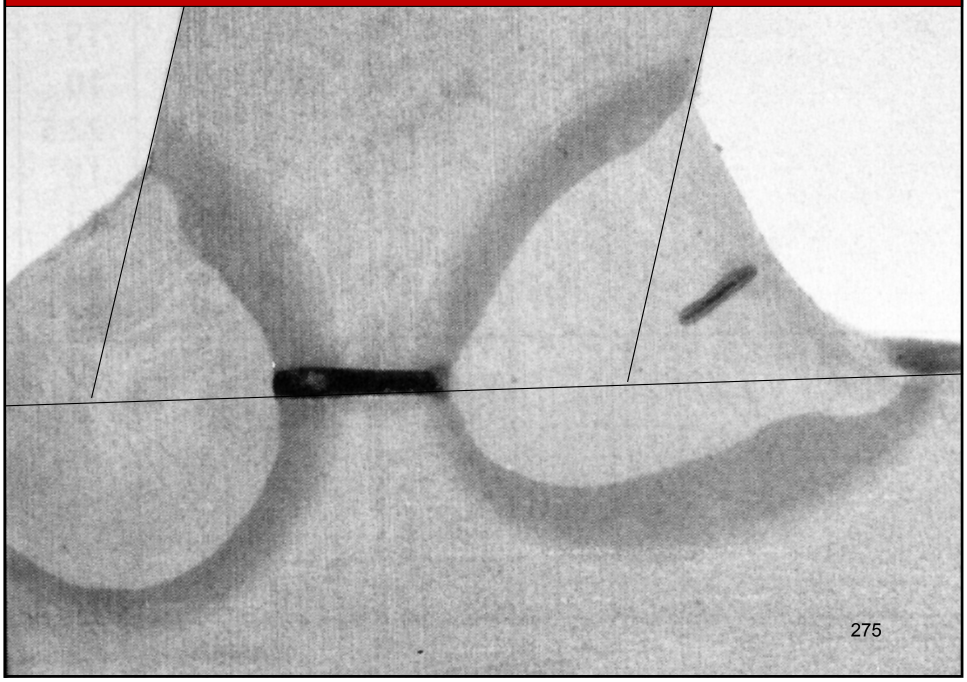
TUB GIRDER



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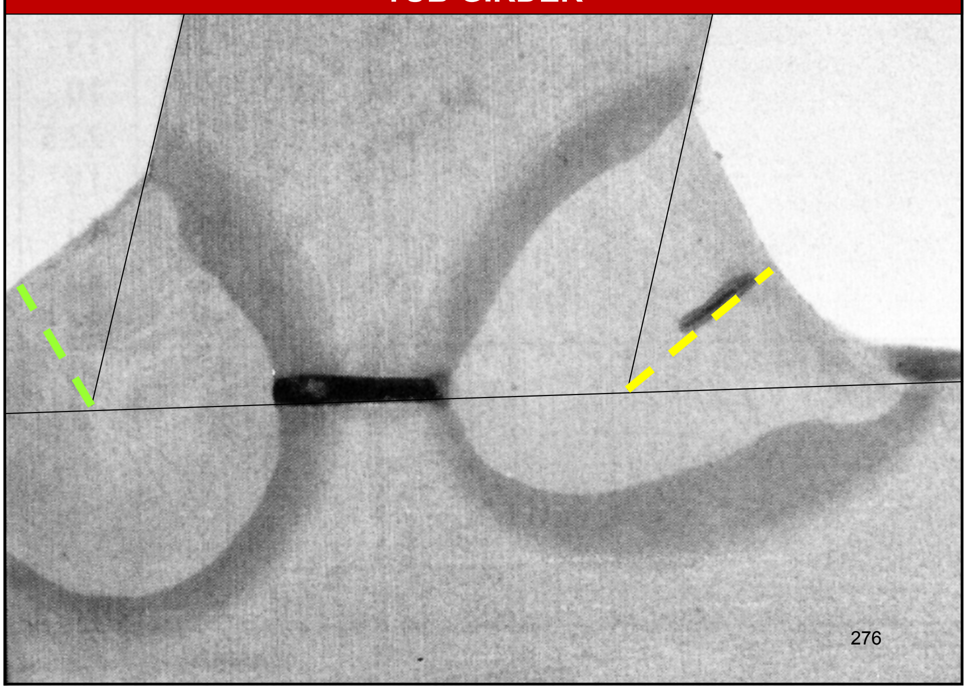
TUB GIRDER



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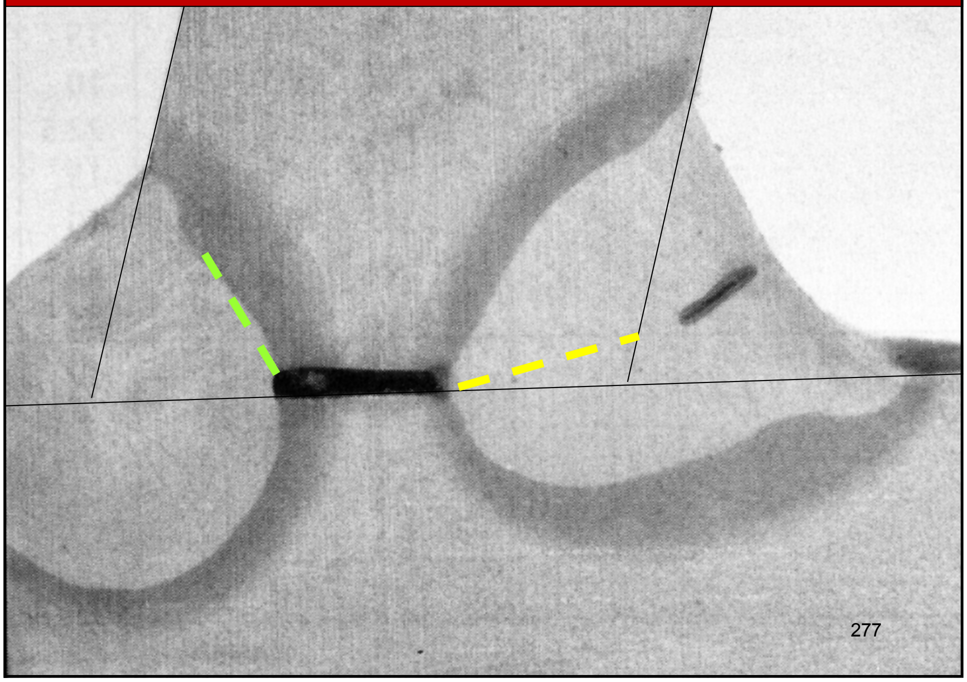
TUB GIRDER



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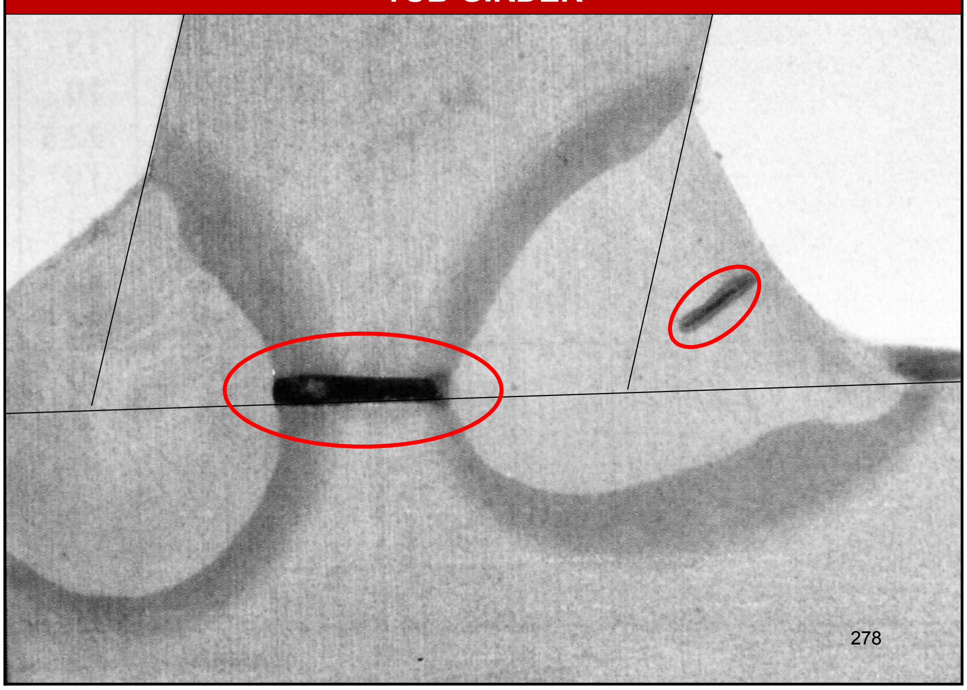
TUB GIRDER



278

TUB GIRDER

- Cyclic, Shear Loading
- Low Stress Range (size based on minimum fillet sizes)
- Deep Penetration--Larger Throats
- Defined Toughness

Unrepaired weld is in service

279

TUB GIRDER

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

The weld has an adequate throat dimension, the stress range is low, and the stress concentration created by the crack is parallel to the stress field.

280

TUB GIRDER

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

That the weld is cracked.

281

Welded Connection

~~WELD~~ INSPECTION

What Matters?

- 2D (planar)
- Perpendicular to stress field
- Conditions that may cause cracks to grow (cyclic loading)
- Unexpected high loading
- Low or unknown toughness
- Low (no) redundancy
- Cold

And What Don't?
(or, not as much)

- 3D (volumetric)
- Parallel to stress field
- Conditions where cracks do not grow (static loading)
- Known, controlled loading
- Defined toughness
- Redundancy
- Warm

282

Welded Connection

~~WELD~~ INSPECTION

What Matters? And What Don't?

COMMON SENSE ENGINEERING

283

There's always a solution in steel.

WELD INSPECTION

What Matters? And What Don't?

structural STEEL

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