Q = N + 1

Basic Quality Assurance for Structural Steel

Philip E. Fish & David M. Boldt
Fish & Associates, Inc.
April 27, 2012

Fish & Associates, Inc.

Partners in Structural Solutions

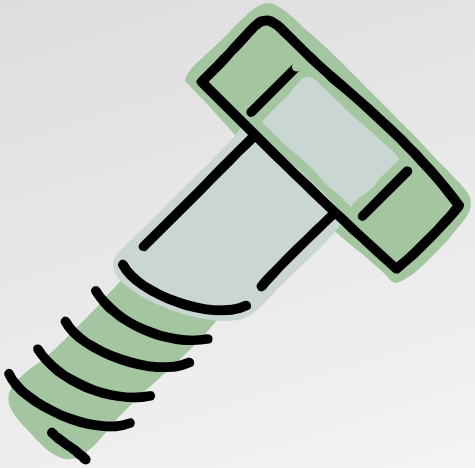
SEND COMMENTS TO:
dboldt@fishassoc.com

Presentation Outline

Philosophy (of Design)

Nuts and Bolts

(and Welds)



What is Design?

"Design is neither solely calculations, nor construction documents; rather it is a synthesis of techniques used to communicate a conception that constructors bring to reality…"

Fischer, James M., "Design!", Proceedings of the North American Steel Construction Conference, 2006

What is Design?

"Design is not a success until construction is complete, and the structure functions properly"

Fischer, James M., "Design!", Proceedings of the North American Steel Construction Conference, 2006

How Do You Achieve Success?

- Intelligent, Economical, and Constructible Designs
- Clear, Concise, Correct, and Complete Documents
- Use of Quality Control and Quality Assurance

  Wait a minute… what… really?

Quality Control / Quality Assurance

Outside of Wisconsin…

1. Look in IBC Chapter 17, “Structural Tests and Special Inspections”
2. Follow instructions
3. Follow local interpretations

Quality Control / Quality Assurance

In Wisconsin…

SPS 362.1700 Structural tests and special inspections. The requirements in IBC chapter 17, except for the requirements in IBC sections 1711 to 1716, are not included as part of this code.

History: CR 00−179: cr. Register December 2001 No. 552, eff. 7−1−02; CR 06−120: am. Register February 2008 No. 626, eff. 3−1−08; CR 10−103: am. Register August 2011 No. 668, eff. 9−1−11.

Quality Control / Quality Assurance

In Wisconsin… what are we excluding?

Administrative Stuff? - YES

Technical Stuff?

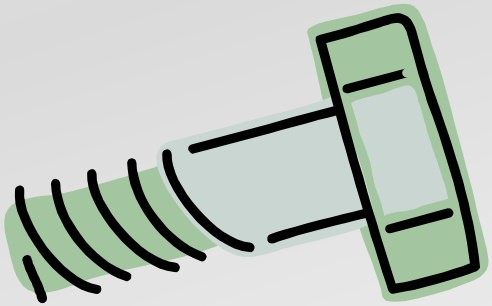
The Technical Stuff in IBC Ch 17

- Testing and inspection requirements for steel, concrete, masonry, soils, etc.
- Increasingly based on reference standards outside the code…

IBC 2009 Chapter 17 for Steel

IBC 2009 Ch. 17 Requirements for Steel Based on:

- AWS D1.1 - Welding Code – Steel



- RCSC Specification for Structural Joints Using High-Strength Bolts

IBC 2012 Chapter 17 for Steel

IBC 2012, Sec.1705.2.1: *Special inspection for structural steel shall be in accordance with quality assurance inspection requirements of AISC 360*

Specifically… AISC Chapter N

AISC 360 Chapter N

AISC's "new" Chapter N guidelines are based on:

- AWS D1.1 - Welding Code – Steel
- RCSC Specification for Structural Joints Using High-Strength Bolts

AISC adds guidance on using these for QC/QA

A Look at Chapter N

QUALITY

This chapter addres
nondestructive testi
for buildings and oth

User Note: This c
crete reinforcing
members. This cha
preparation or coat

User Note: The in
vessels, cables, co
this Specification.

The Chapter is organ

CHAPTER N

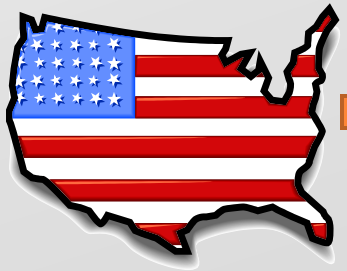
QUALITY CONTROL AND QUALITY ASSURANCE

N1. SCOPE

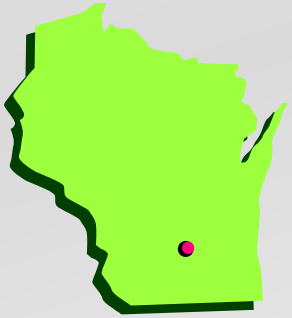
Chapter N of the 2010 AISC Specification provides minimum requirements fo
ity control (QC), quality assurance (QA) and nondestructive testing (ND
structural steel systems and steel elements of composite members for buildi
other structures. Minimum observation and inspection tasks deemed neces
ensure quality structural steel construction are defined.

Chapter N defines a comprehensive system of "Quality Control" requiremen
part of the steel fabricator and erector and similar requirements for
Assurance" on the part of the project owner's representatives when such is
necessary to complement the contractor's quality control function. These
ments exemplify recognized principles of developing involvement of all
the quality control process as the most

Path to QC/QA for Steel - Current



IBC 2009
Ch. 17



(With additional information stated in Section 05 12 00)

AWS D1.1 and RCSC

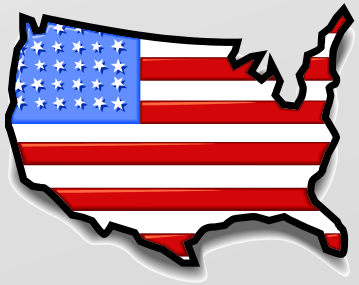
Firm	Visual (VT)	Magnetic Particle (MT)	Ultrasonic Testing (UT)
			of PJP welds of CJP welds
2	“All” welds	100% of hanger-type 100% new to existing 1 ainder	100% of PJP welds 100% of CJP welds
3	Fillet and PJP	MT OR	
4	Field welds	MT, UT, or other methods no specific weld types or percentages given	
5			ion frequency sting methods
6		inspection frequency or testing methods to be used	AISC with no further direction on

QUIZ 1: Which one matches AISC 360 Chapter N?

QUIZ 2: What does your firm’s specification say?

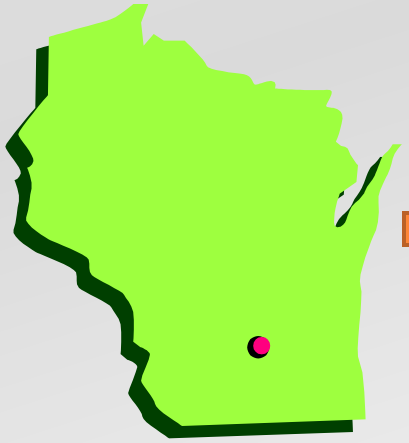
QUIZ 3: What do you want to specify in the future?

Path to QC/QA for Steel - Future



IBC 2012
Ch. 17

AISC 360
Ch. N



AISC 360 Ch. N

(Suggested, with your firm's exceptions and revisions)

AWS D1.1 and RCSC

The Challenge

- AISC 360 is already a common reference
- Chapter N adds “new” QC/QA requirements
  - “Adequate and effective for most structures”
  - ~~“Strongly encouraged without modification”~~

    READ IT IN DETAIL AND MODIFY TO SUIT
    Q = N + 1 , 1 person, 1 hour, 1 page of notes
- Includes administrative stuff intended to fill in some of the gaps for AWS D1.1 and RCSC

The Benefits of Chapter N

- Defines Quality Control vs Quality Assurance
- Outlines Roles, Responsibilities, Submittals
- Gives Minimum Inspector Qualifications
- Recommends Specific Rates of Testing (% UT)
- Establishes Inspection Intervals

The Opportunity

- **Time to revise your 05 12 00 specification**
- **Assuming IBC Chapter 17 will not apply in WI, what do you want done for QC/QA?**
- For projects in Wisconsin citing AISC 360:
  - Either update 05 12 00 to exclude Chapter N (to avoid conflicts w/ your existing requirements)
  - Or include Chapter N and specify any variances

Quality Control vs Quality Assurance

Quality Control

- Performed by contractor, fabricator or erector
- Self-check of conformance with project requirements; a full-time requirement
- AISC Certifications help establish a baseline for fabricator/erector QC

Quality Assurance

- By an inspector or agent on the Owner's behalf
- An audit to verify that the QC is being performed; part-time, as needed
- Third-party typically does non-destructive testing (NDT) to supplement QC

Periodic vs. Continuous

AISC 360 Chapter N
Does NOT Use These Terms
Due to Widespread Confusion
Regarding Their Meaning

Observe vs. Perform

Observe

Observe the items on a random basis.

Operations need not be delayed pending these inspections.

Perform

Perform these tasks for each welded joint or bolted connection

How to Provide Quality Assurance

- **Sometimes** = OBSERVE items from time to time, with your eyes
- **Always** = PERFORM an action (such as NDT) for all instances of a specific type of condition, or a percentage of the instances
- **Never** = Anything not required to be observed or performed

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.

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

Keys to Quality Welds

Appropriate Weld Types Specified

Qualified Weld Procedures

Proper Welding Equipment

Proper Welding Environment

Proper Fit-up (Alignment, Gaps)

Proper Access for Welding

Qualification of Welds, Welder

Weld Procedure Spec.

- Process
- Joint Type
- Material Thickness
- Electrodes
- Operating Parameters, Including Positions

Welder Certification

- Process
- Joint Type
- Material Thickness
- Electrodes
- Position
- Duration
- Special Conditions

Weld Procedure Specifications

- Indicate how a welder will perform each type of weld on a project – WPS required per AWS D1.1

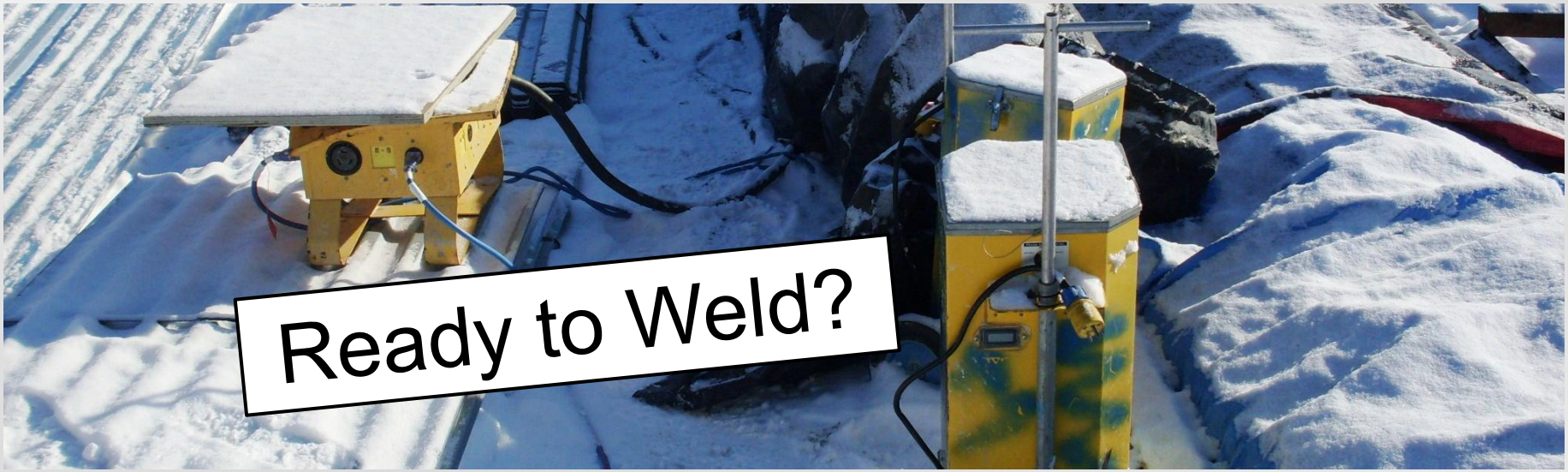
- Assures that the weld metal produced will provide required strength, ductility and toughness.

Welder Qualifications

- Welder qualification requirements are set in *AWS D1.1*

- Qualification of welders is required for each process (i.e. SMAW, FCAW-S, etc.), and for different positions.

Proper Welding Environment



- Joints may require pre-heat in 0° F to 32° F temps
- Welding in temperatures below 0° F not permitted
- Welding in rain or snow not permitted
- Welding over paint or galvanizing not permitted

TABLE N5.4-3
Inspection Tasks After Welding

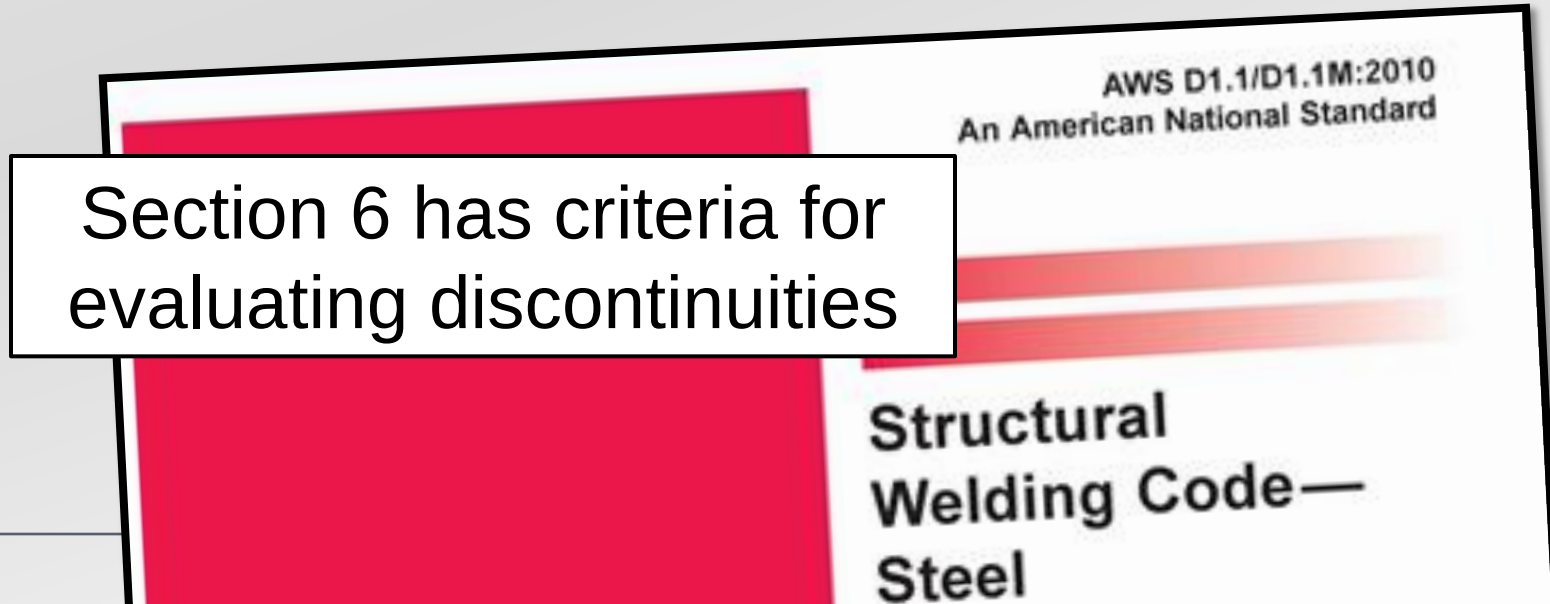
Inspection Tasks After Welding	QC	QA
Welds cleaned	O	O
Size, length and location of welds	P	P
Welds meet visual acceptance criteria • Crack prohibition • Weld/base-metal fusion • Crater cross section • Weld profiles • Weld size • Undercut • Porosity	P	P
Arc strikes	P	P
k-area[1]	P	P
Backing removed and 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.

Discontinuity Evaluation

- All welds contain discontinuities, welds are not required to be “perfect”

- Defects are discontinuities that are unacceptable based on criteria in a standard, typically AWS D1.1



Section 6 has criteria for evaluating discontinuities

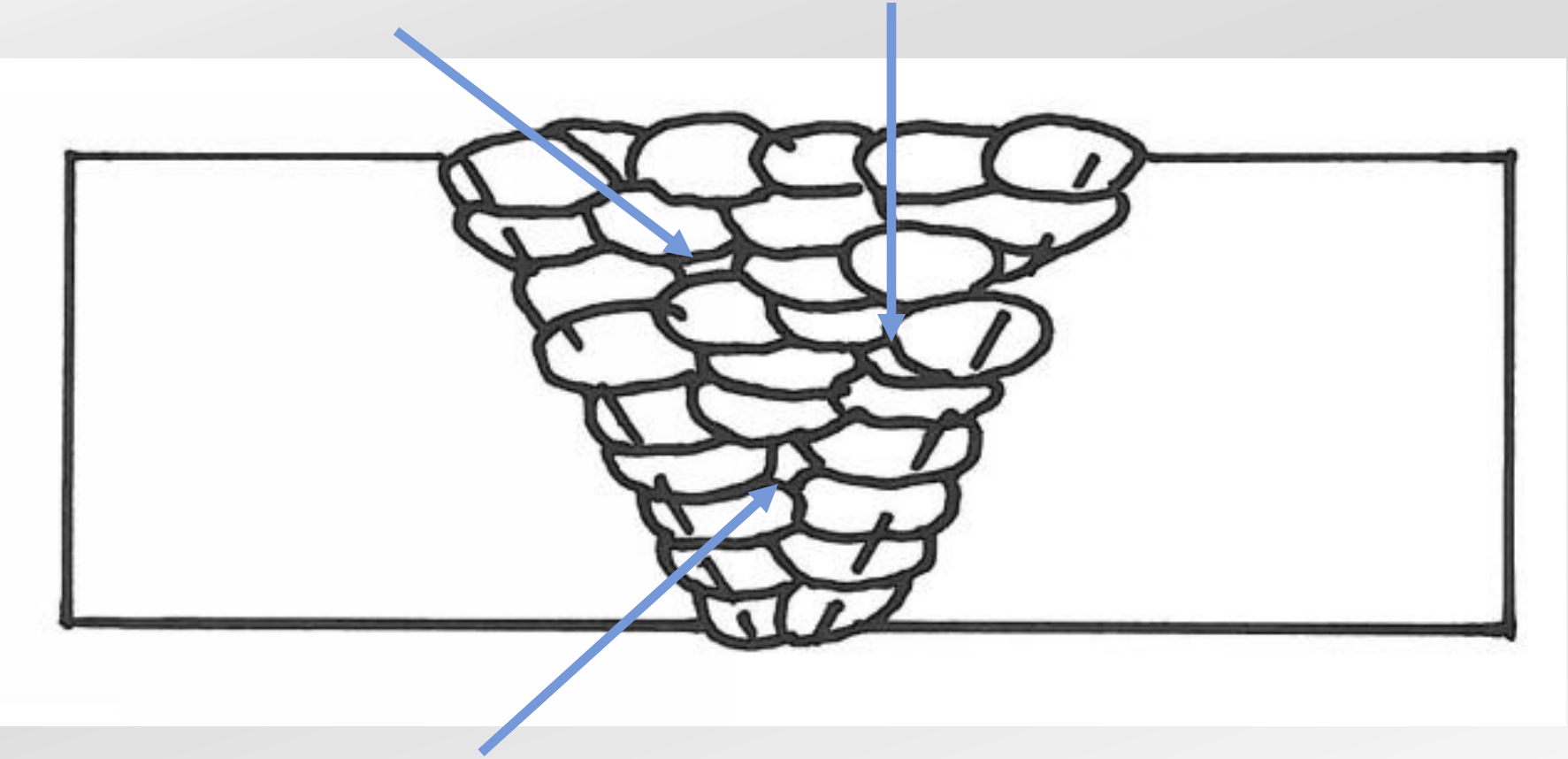
Weld Cracks

- Shrinkage of the weld and surrounding base metal that were heated and expanded by welding

Longitudinal

Transverse

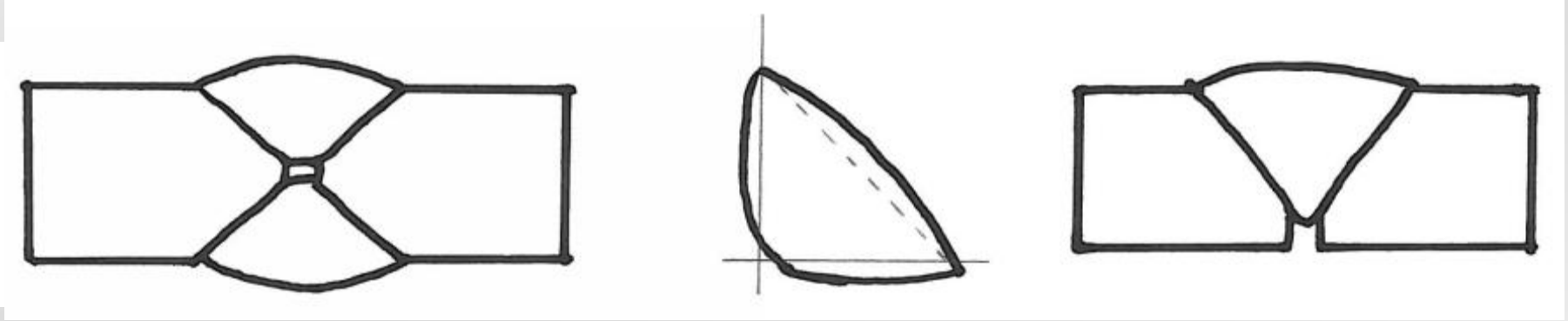
Incomplete Fusion



Lack of fusion between passes may not be visible from the surface

Incomplete Penetration

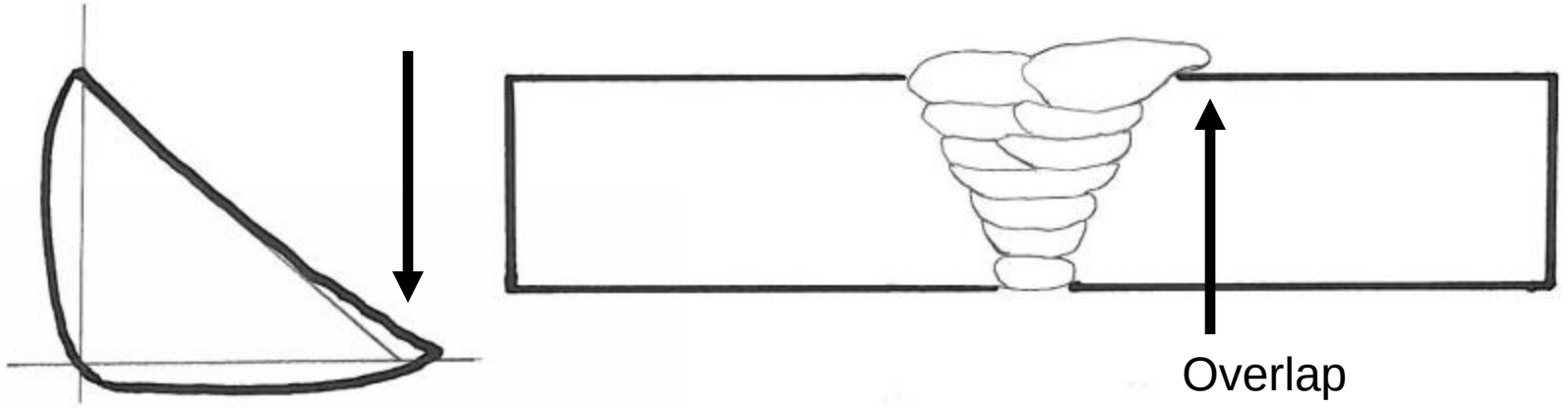
Incomplete fusion occurring at the root of the base metal, or failure to penetrate the root.

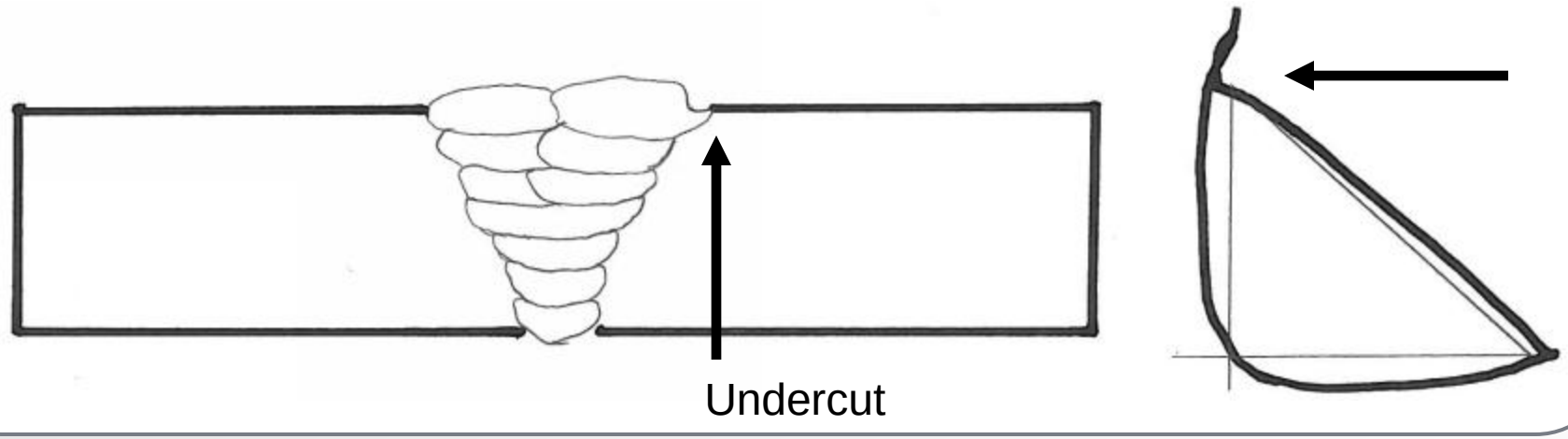


Generally not visible from the surface

Caused by improper backgouging, incorrect electrode placement, improper weld procedure (low current levels), or improperly prepared joint

Overlap and Undercut

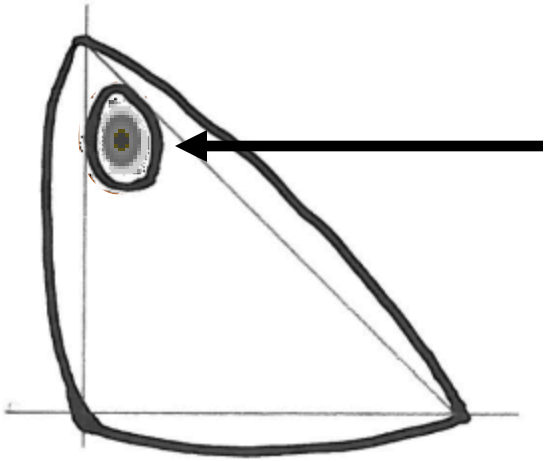




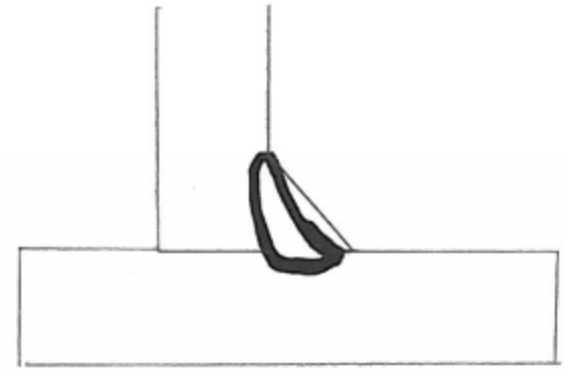
Porosity and Slag Inclusions

Surface Porosity

Slag Inclusions: Entrapped non-metallic “slag” material from previous weld passes

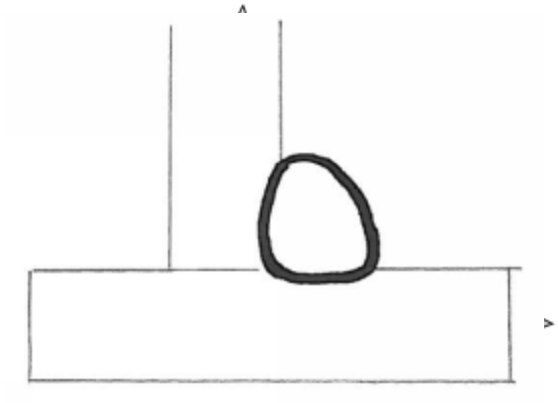


Excessive Concavity / Convexity



Concavity: Inadequate throat, which can lead to cracking

Fix by adding more weld



Convexity: Excessive weld, which may increase stresses at weld toe

Source: AISC Design Guide 21- Welded Connections

Nondestructive Testing (NDT)

- It is critical that NDT requirements be established in advance, under the direction of the engineer
- This allows everyone time to understand and prepare for what is expected during the project
- AISC Chapter N has recommended tests and frequencies (% of welds for UT in certain cases)

Non-Destructive Testing

Visual Inspection (VT)

Magnetic Particle (MT)

Dye Penetrant (PT)

Ultrasonic Testing (UT)

(Conventional or Ultrasonic Phased Array)

Visual Inspection (VT)

- Can actually improve weld quality (e.g. VT of weld joint prep or root opening dimension)
- Everyone involved in the welding project should participate (welders, inspectors, foremen, etc.)
- Must take place before, during, and after welding.
- All welds must be visually inspected per AWS D1.1, even if NDT testing is to be performed.

Source: AISC Design Guide 21- Welded Connections

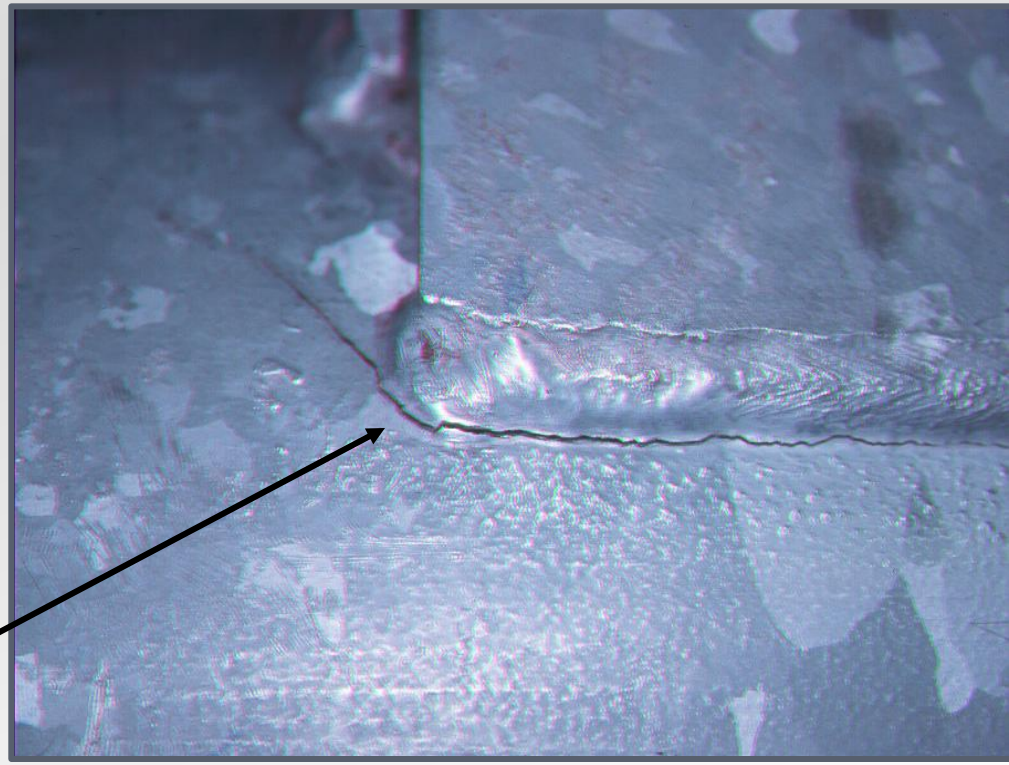
Visual Inspection (VT)

- Know “where to look” and what you’re looking at
- Only obvious surface weld features will be revealed

Weld Size/Length

Profile: Weld Fusion, Undercut, Overlap, Concavity/ Convexity, Porosity, etc.

Cracks



Dye Penetrant (PT)

- Application of a liquid, drawn into discontinuities (i.e. cracks or porosity)
- Developer fluid absorbs penetrant in the discontinuity, results in a stain

Source: AISC Design Guide 21

PT Advantages/Disadvantages

- Simple to use, less costly than other NDT methods
- Can be effective on any non-porous material
- Portable and well suited for field usage
- Sensitive to small defects
- Will reveal surface discontinuities only
- Clean surface a must
- Requires good visual acuity of inspector
- Limited to moderate temperature and humidity

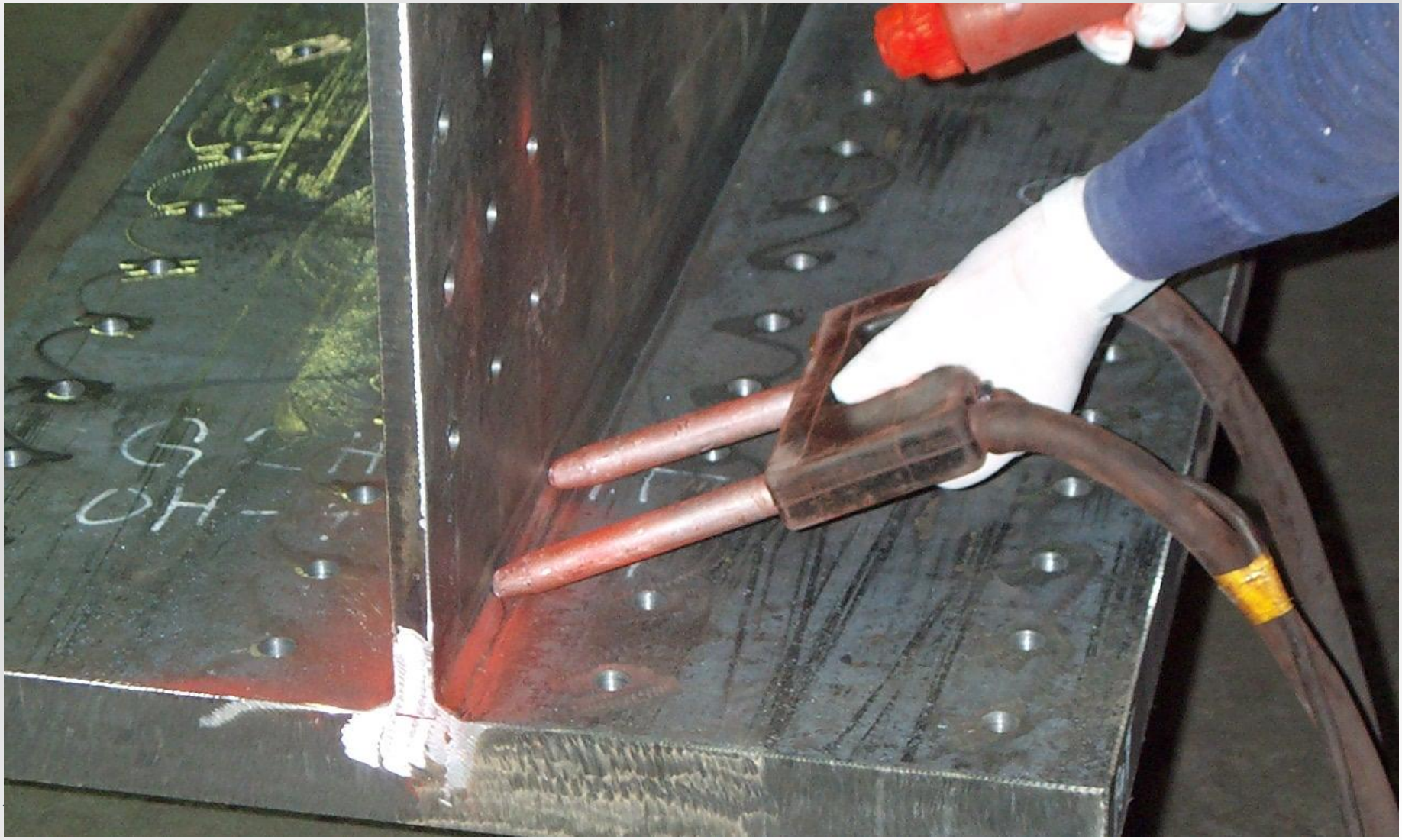
Magnetic Particle (MT)

- Utilizes the change in magnetic flux that occurs in a magnetic field in the vicinity of a discontinuity
- Magnetic particles are dusted on; the change in flux creates a different pattern at a discontinuity
- Effective in locating discontinuities both on the surface as well as slightly below the surface

Source: AISC Design Guide 21- Welded Connections

Magnetic Particle (MT)

Magnetic Particle (MT)



Magnetic Particle - Advantages

- Sensitive to surface or “near” surface cracking
- Fast, inexpensive, portable, minimal pre-cleaning
- Not limited by size or shape of the piece
- Able to determine effectiveness of weld repairs
- Can detect “filled” cracks

Magnetic Particle - Disadvantages

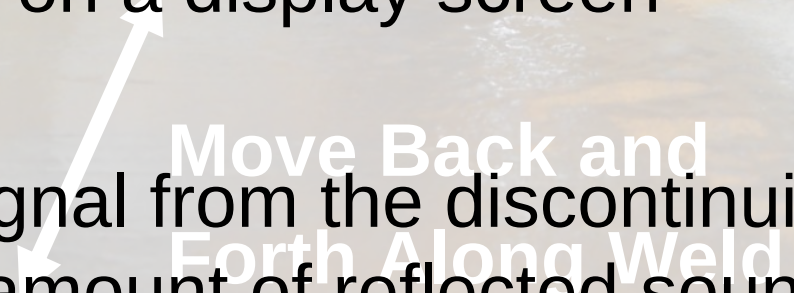
- Works only on ferromagnetic material
- Dependent on defect orientation.
- Only large subsurface defects are readable.
- Dirt and paint reduce sensitivity.

Ultrasonic (UT)

Transmission of sound waves through materials.

Receiver hears any reflected sound

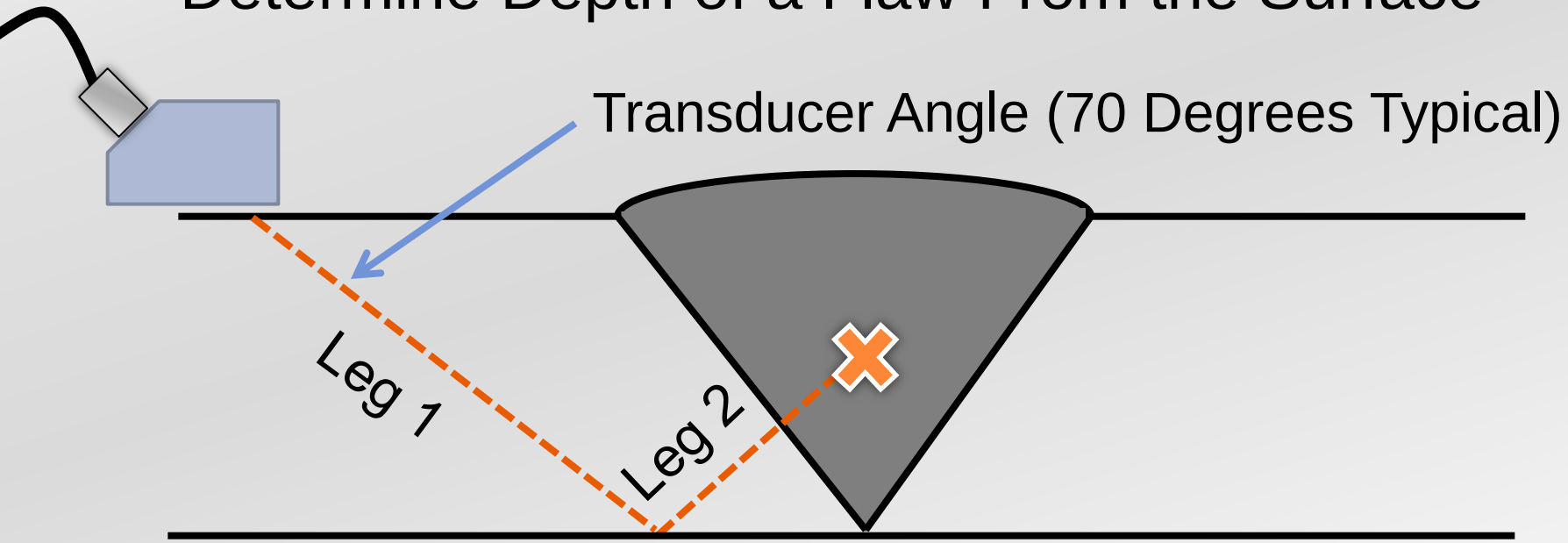
Solid material transmits sound uninterrupted; discontinuities send back a signal to the receiver, and the pulses are read on a display screen



Magnitude of the signal from the discontinuity is proportional to the amount of reflected sound

Ultrasonic Inspection (UT)

- From # of “Legs” and Length of Soundpath, Can Determine Depth of a Flaw From the Surface



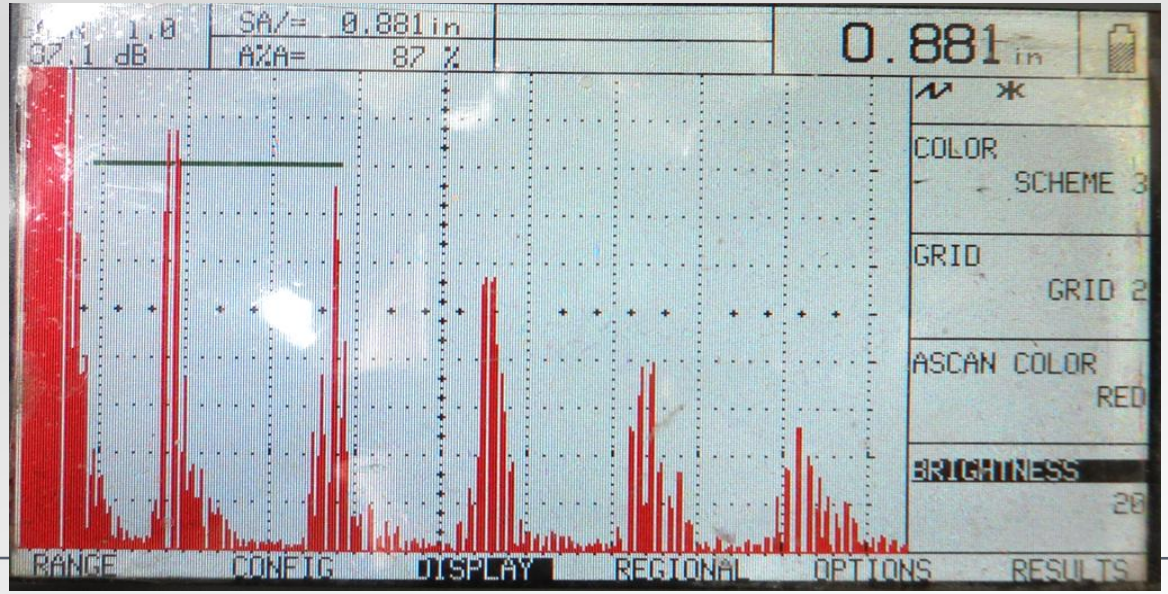
Ultrasonic - Advantages

- Can examine internal structure of a material
- Only one side needs to be accessible
- Thick specimens can be inspected
- Portable units available for field use

Ultrasonic - Disadvantages

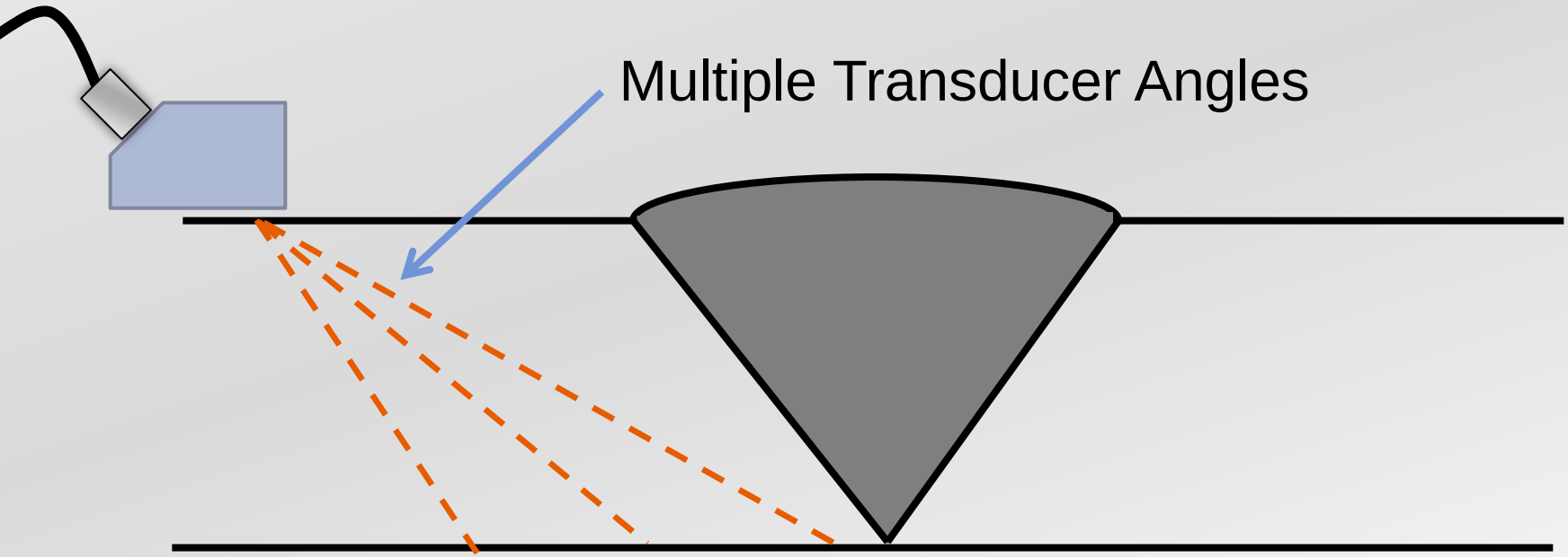
- No rough surfaces or complex geometry (ineffective with corner and T-joints)

- Limited by ability / experience of operator

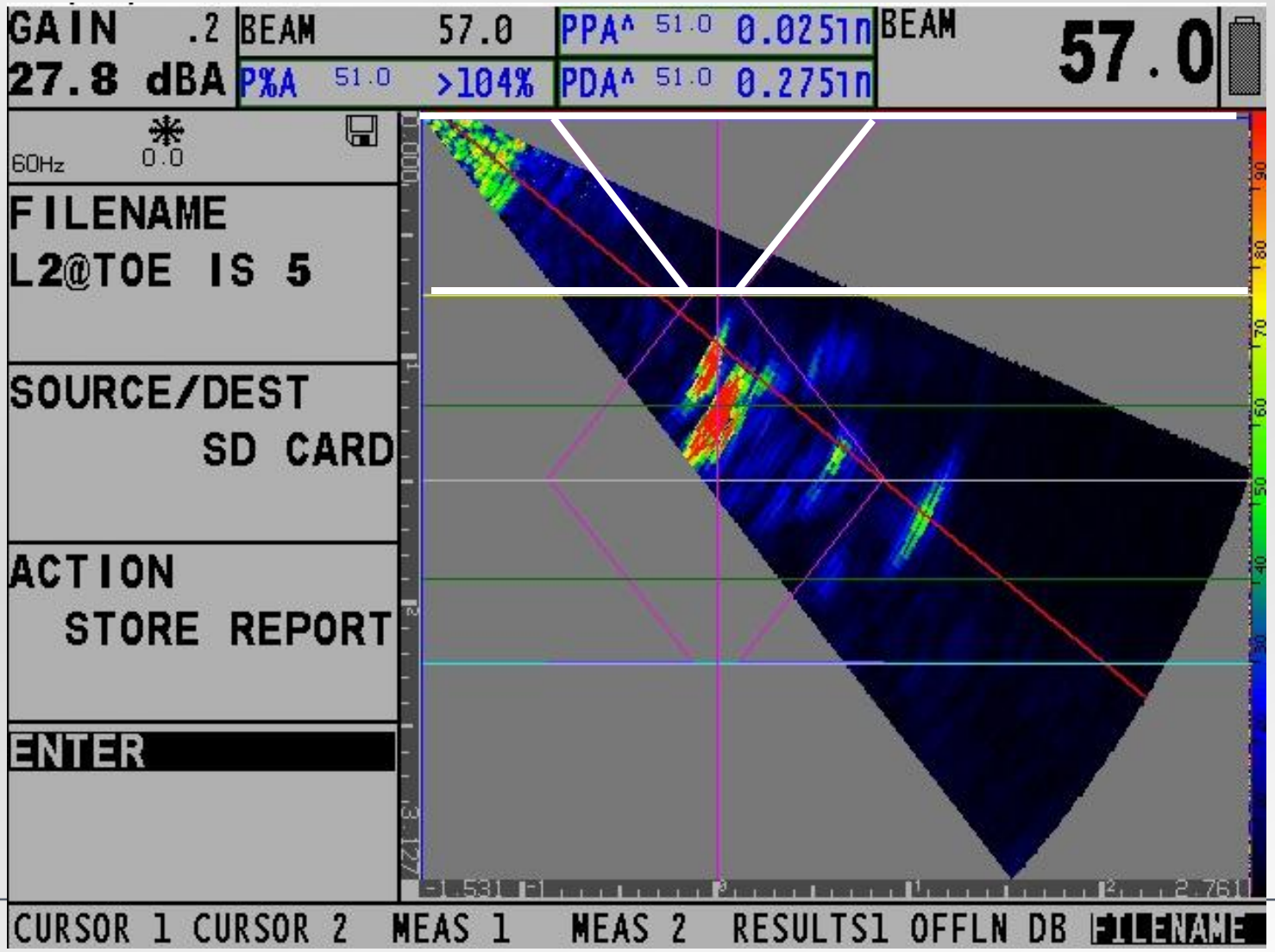


Ultrasonic Phased Array

- Sends out an “Array” of Soundpaths to Get 2-D image



Ultrasonic Phased Array

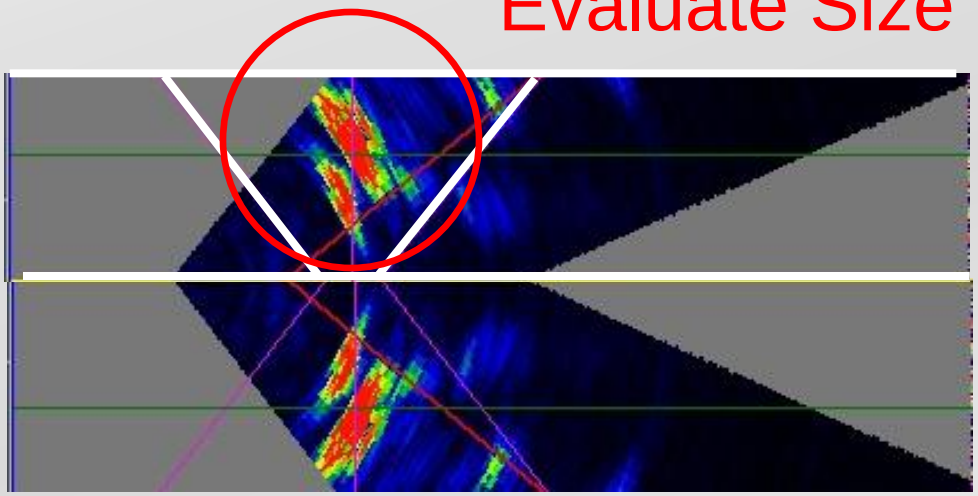


1st Leg

2nd Leg

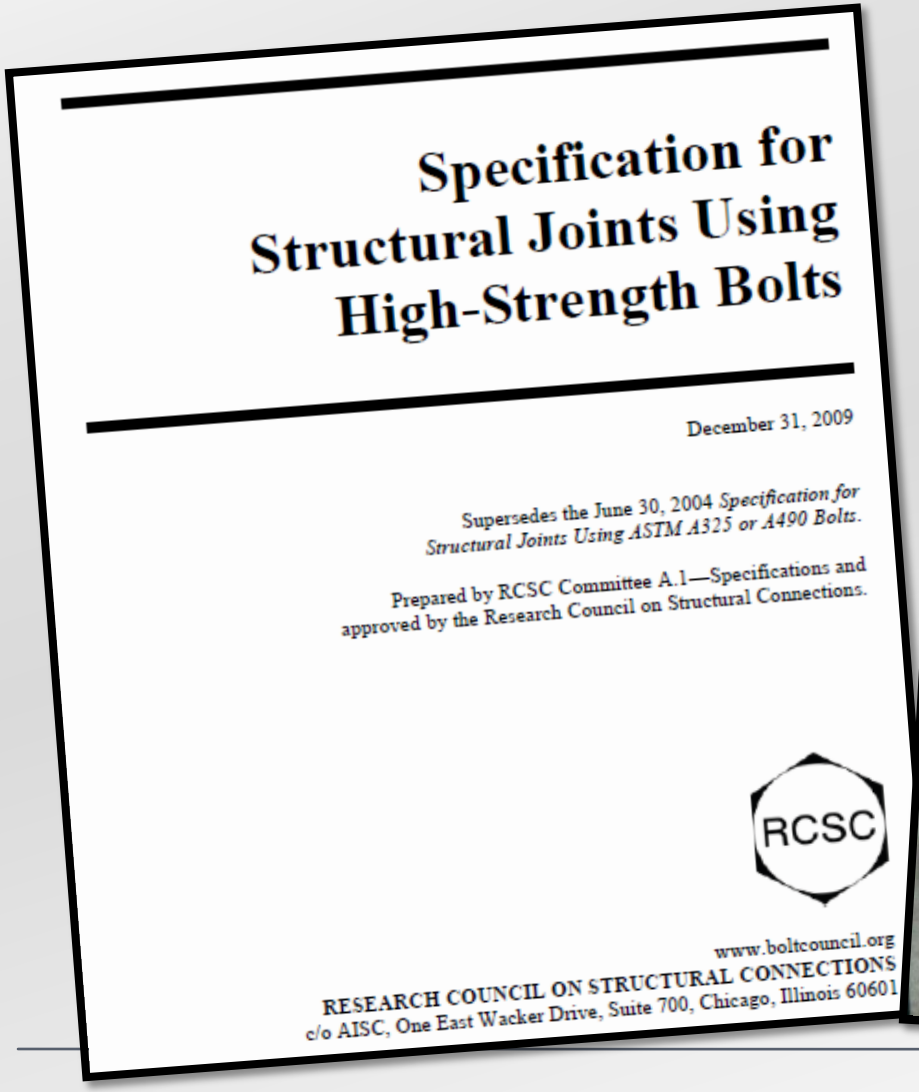
3rd Leg

Ultrasonic Phased Array



- In the sample scan shown, several indications appear in the second leg readings

Ready for Bolting?



Specification for Structural Joints Using High-Strength Bolts

December 31, 2009

Supersedes the June 30, 2004 *Specification for Structural Joints Using ASTM A325 or A490 Bolts.*

Prepared by RCSC Committee A.1—Specifications and approved by the Research Council on Structural Connections.

RCSC

www.boltcouncil.org

RESEARCH COUNCIL ON STRUCTURAL CONNECTIONS
c/o AISC, One East Wacker Drive, Suite 700, Chicago, Illinois 60601

TABLE N5.6-1
Inspection Tasks Prior to Bolting

Inspection Tasks Prior to Bolting	QC	QA
Manufacturer's certifications available for fastener materials	O	P
Fasteners marked in accordance with ASTM requirements	O	O
Proper fasteners selected for the joint detail (grade, type, bolt length if threads are to be excluded from shear plane)	O	O
Proper bolting procedure selected for joint detail	O	O
Connecting elements, including the appropriate faying surface condition and hole preparation, if specified, meet applicable requirements	O	O
Pre-installation verification testing by installation personnel observed and documented for fastener assemblies and methods used	P	O
Proper storage provided for bolts, nuts, washers and other fastener components	O	O

Proper Storage Methods

Sealed containers, properly labeled with lot numbers

Protected from the elements

Bolts returned to proper containers at end of workday

Types of Joints (RCSC)

Snug-Tight

Formerly known as shear/bearing

Pretensioned

Formerly known as direct tension

Slip-Critical

Formerly known as friction-type

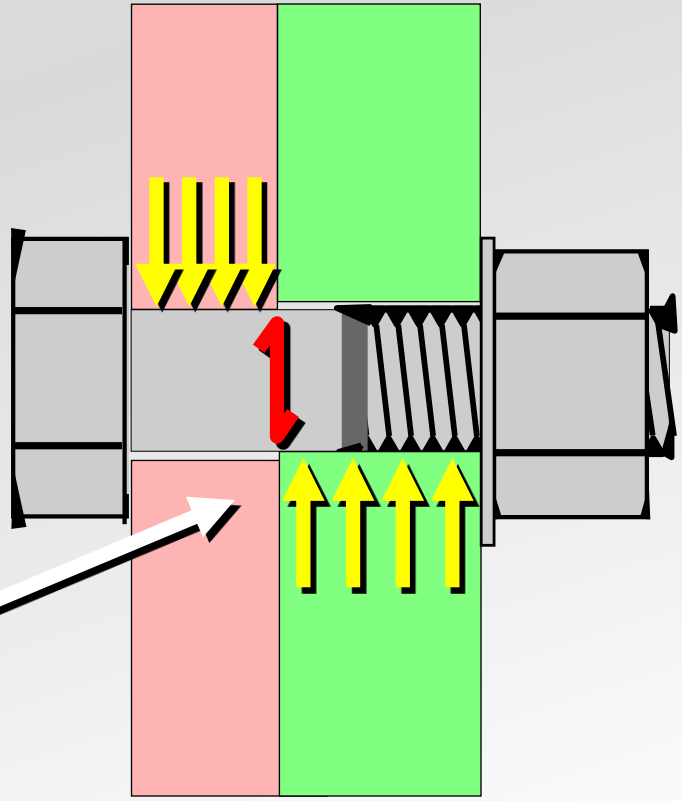
Source: RCSC Specification, 2009 Edition

Snug Tight

"Snug Tight" ensures all parts are in firm contact, which is sufficient for most applications

Equal to the effort of a worker with an ordinary spud wrench

Bolt is in Shear ONLY

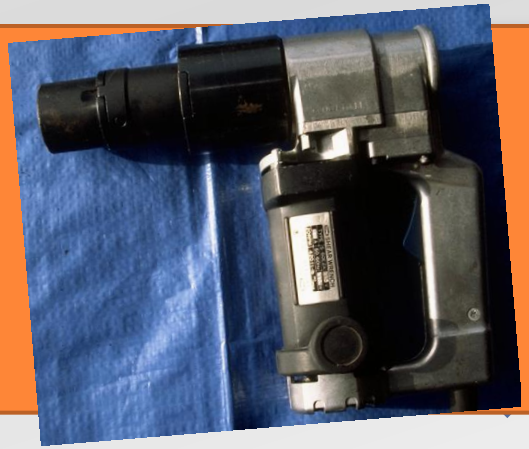


Bolting Requirements

Snug-Tight =

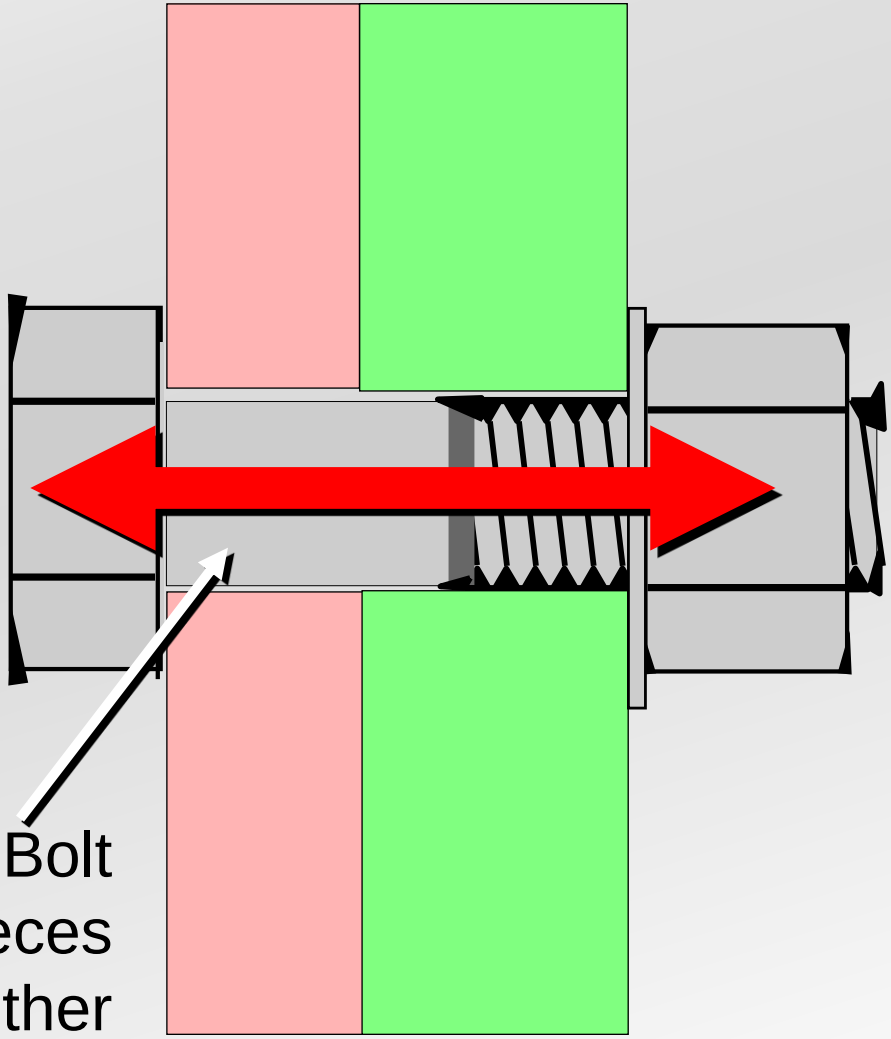
Pretensioned (PT)

Additional Bolt Tightening Induces Tension, More Testing and Inspection Requirements



Source: RCSC Specification, 2009 Edition

Pretensioned (PT)



Rely on Tension in Bolt
to **CLAMP** Pieces
Tightly Together

Bolting Requirements

Snug-Tight =

Pretensioned (PT)

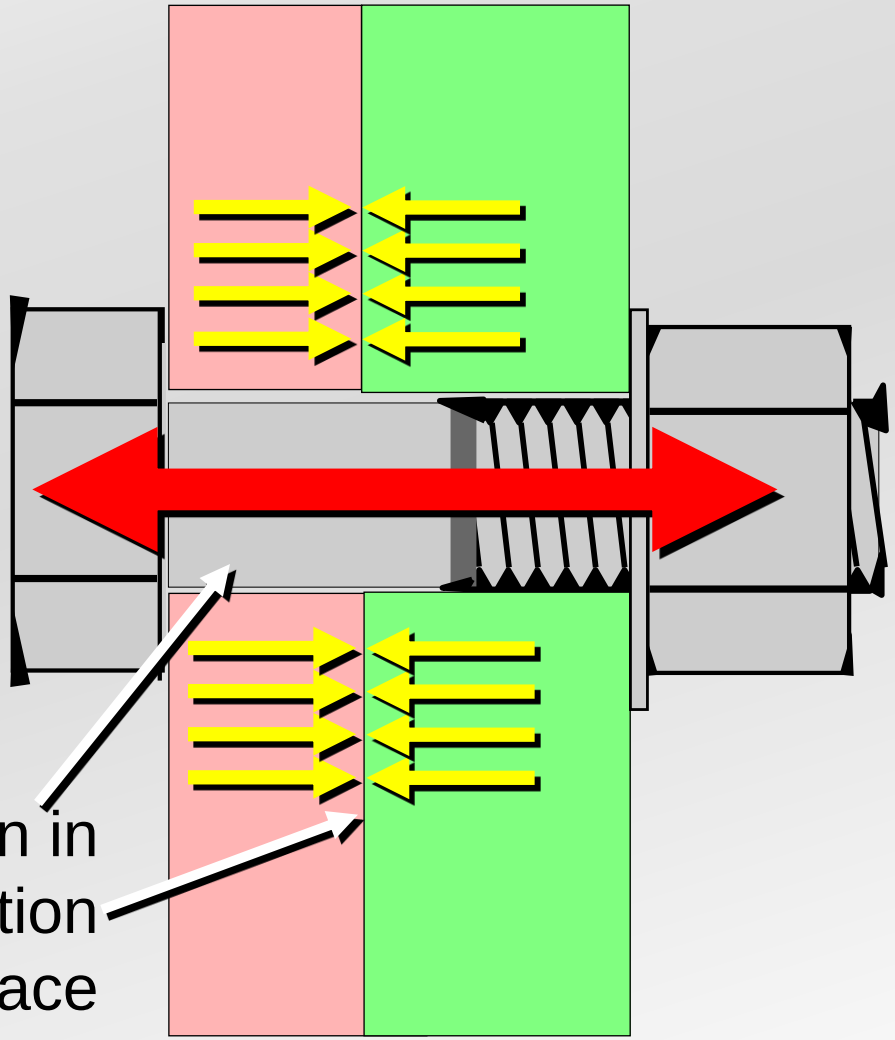
Additional Bolt Tightening Induces Tension,
More Testing and Inspection Requirements

Slip-Critical (SC)

Utilization of Friction, Thus…
Emphasis on Surface Conditions

Source: RCSC Specification, 2009 Edition

Slip Critical (SC)



Rely on Tension in Bolt AND Friction at Contact Surface

Bolt Tension Calibration

- Required for pretensioned or slip-critical joints
- Confirms that bolts can achieve required tension
- Helps to establish torque-tension relationships
- Tests equipment and methods used in the field

Pre Installation Verification

Test not less than 3 assemblies per lot

- same diameter, length, production process
- submitted for inspection at the same time

Bring bolt to snug-tight condition in calibrator, then tighten further according to specific method used

Minimum Bolt Pretension for Pre-Installation Verification

Inspector must observe testing.

Inspector can also perform testing.

Testing must be done at the job site

If conditions change, perform new tests

Nominal Bolt Diameter, d_b, in.	Minimum Bolt Pretension for Pre-Installation Verification, kips [a]	
	ASTM A325 and F1852	ASTM A490 and F2280
½	13	16
⅝	20	25
¾	29	37
⅞	41	51
1	54	67
1⅛	59	84
1¼	75	107
1⅜	89	127
1½	108	155

[a] Equal to 1.05 times the specified minimum bolt pretension required in Table 8.1, rounded to the nearest kip.

Source: RCSC Specification, 2009 Edition – Table 7.1

Pre-Installation Verification

After Tensioning, Examine Bolt and Nut

- Stripping
- Thread Shear Failure
- Torsional Failure

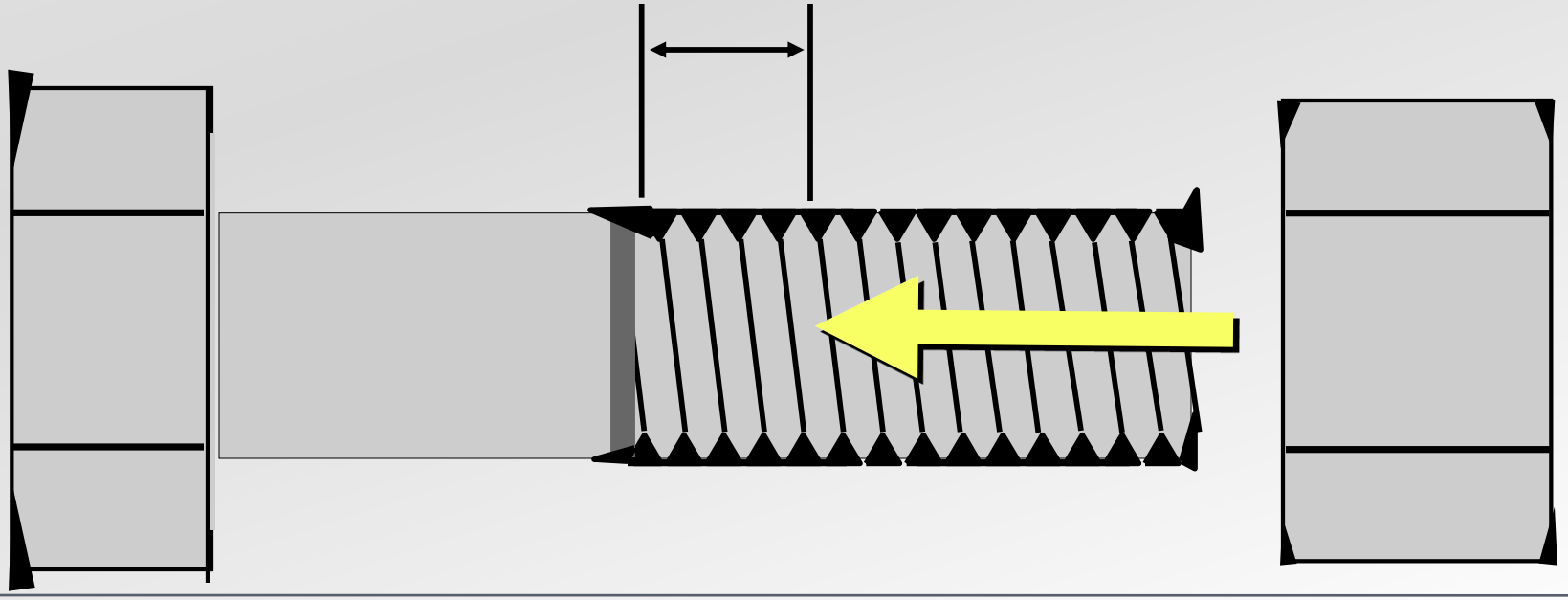


TABLE N5.6-2
Inspection Tasks During Bolting

Inspection Tasks During Bolting	QC	QA
Fastener assemblies, of suitable condition, placed in all holes and washers (if required) are positioned as required	O	O
Joint brought to the snug-tight condition prior to the pretensioning operation	O	O
Fastener component not turned by the wrench prevented from rotating	O	O
Fasteners are pretensioned in accordance with the RCSC *Specification*, progressing systematically from the most rigid point toward the free edges	O	O

TABLE N5.6-3
Inspection Tasks After Bolting

Inspection Tasks After Bolting	QC	QA
Document acceptance or rejection of bolted connections	P	P

Pretensioning Methods

Turn-of-the-Nut

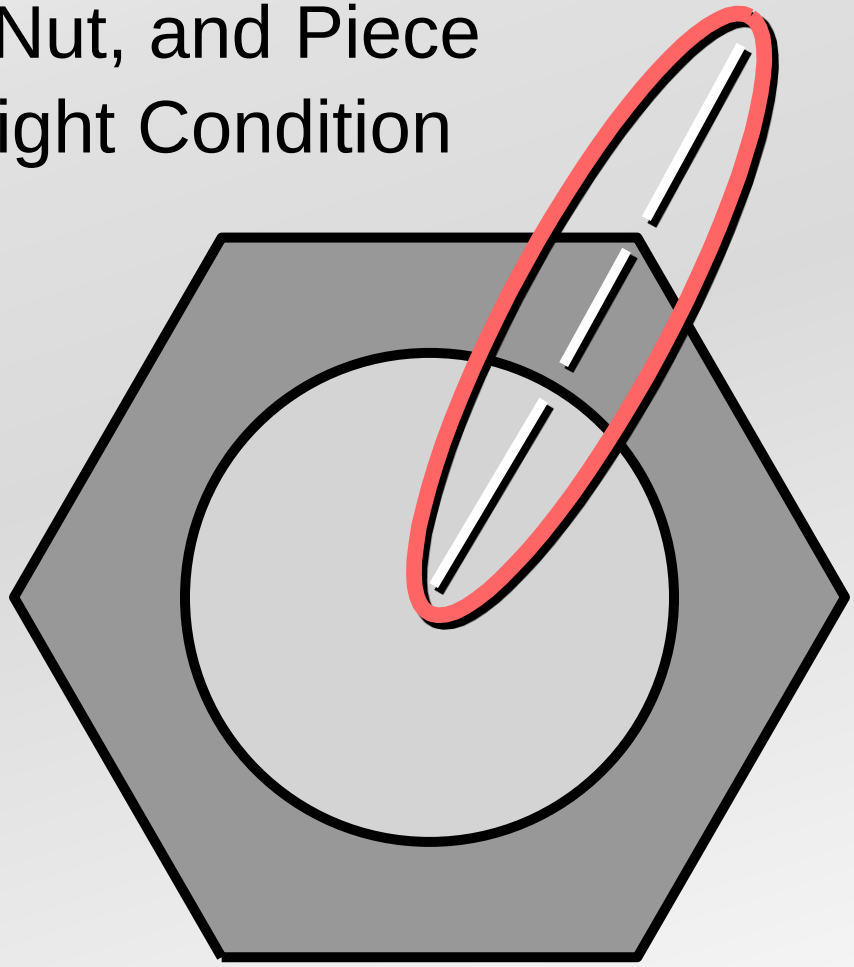
Calibrated Wrench

Twist-off-Type Bolts

Direct-Tension-Indicator

Turn-of-the-Nut Pretensioning

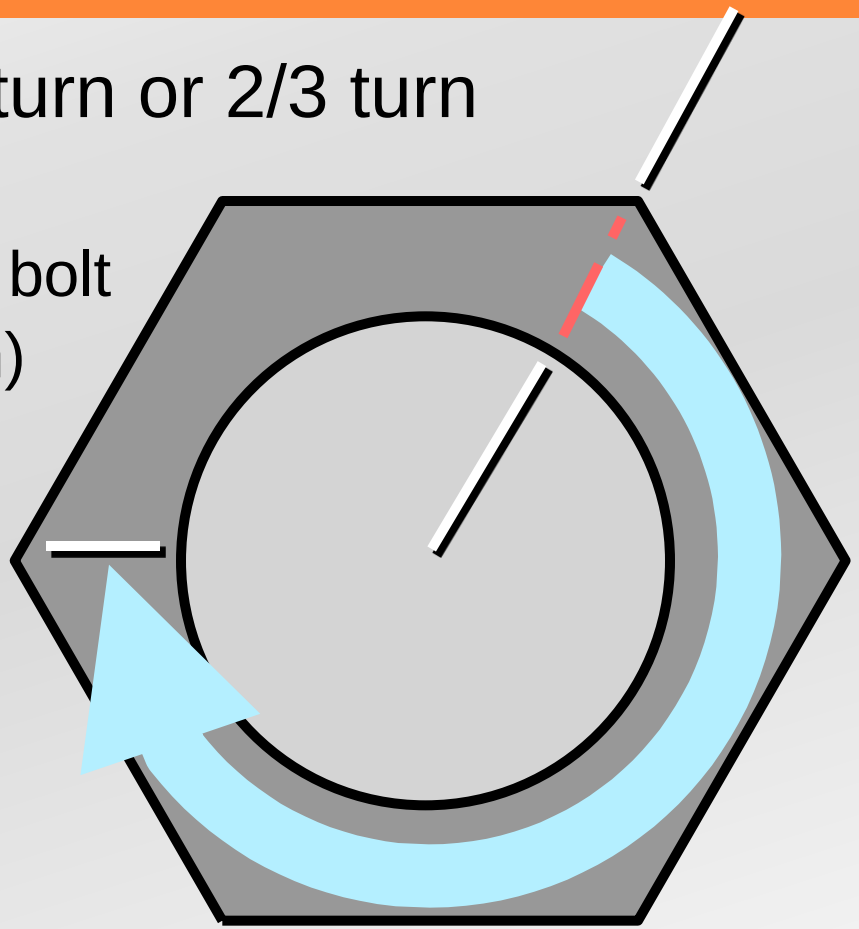
Mark Bolt, Nut, and Piece
At Snug-Tight Condition



Turn-of-the-Nut Pretensioning

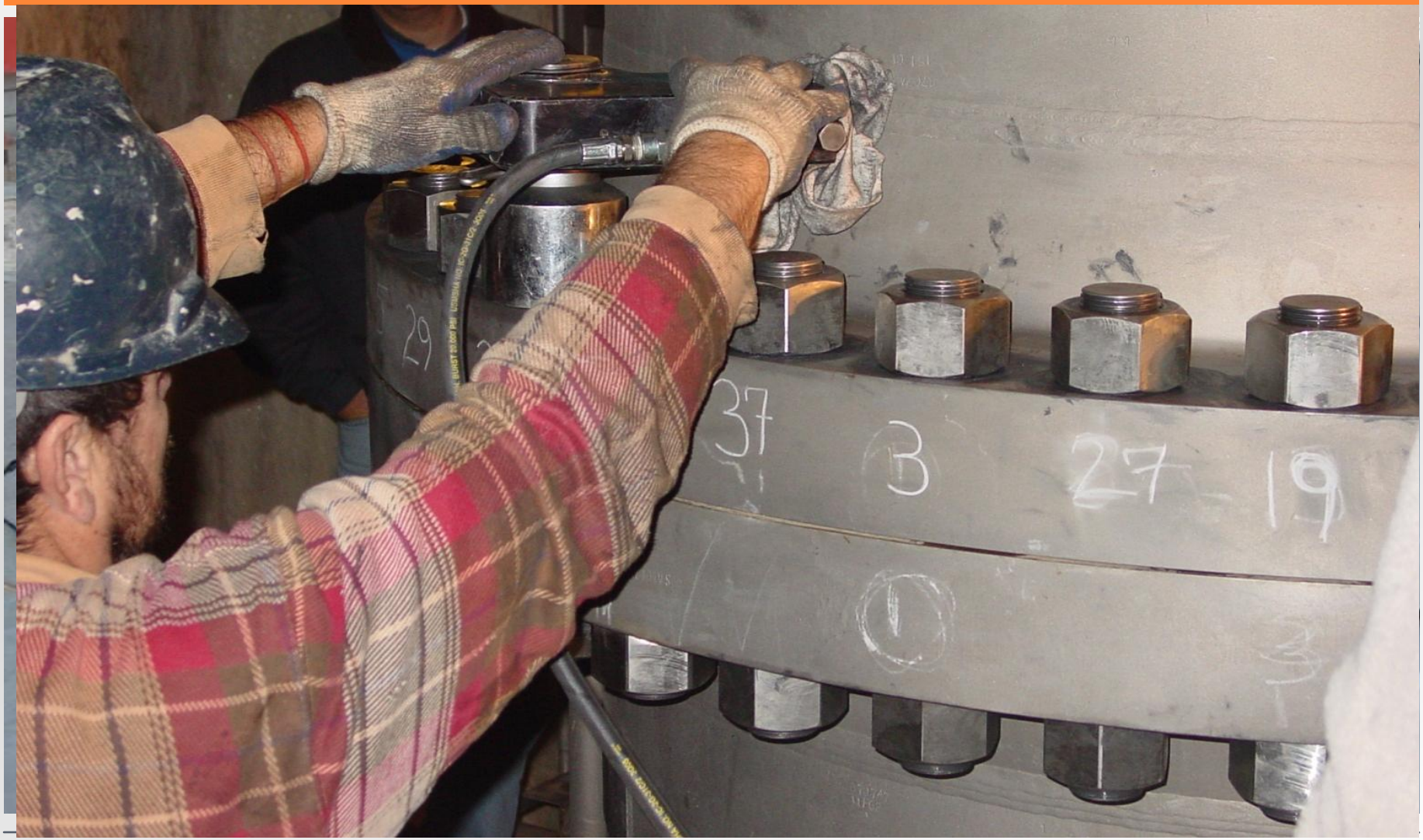
1/3 turn or 1/2 turn or 2/3 turn

(based on ratio of bolt diameter to length)



Then Rotate as Specified in RCSC Tables

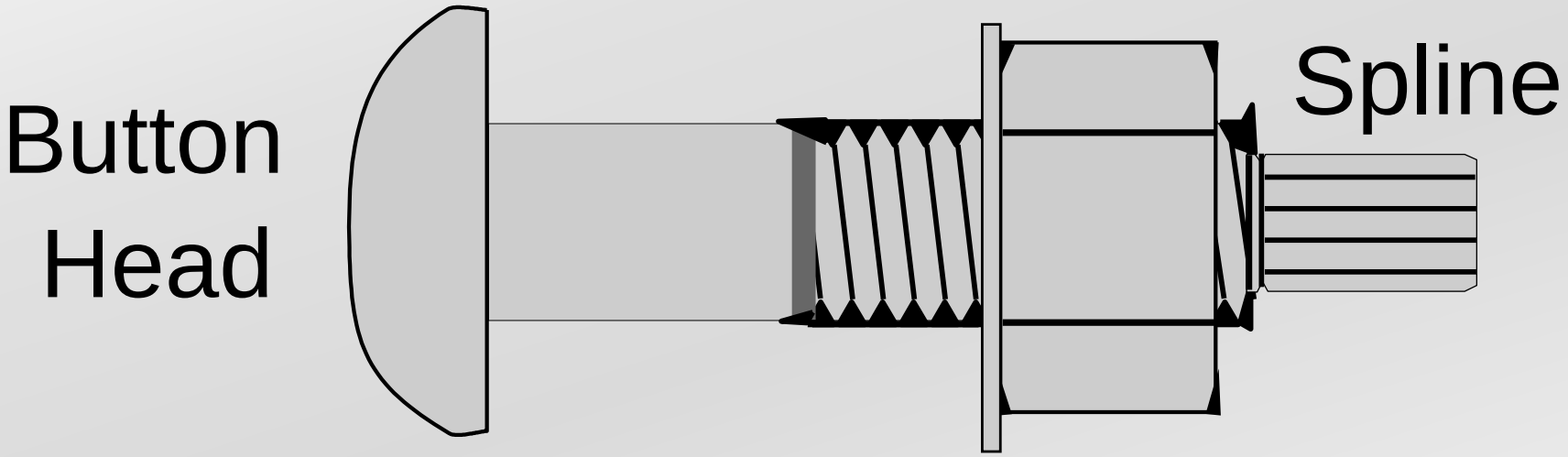
Calibrated Wrench



Calibrated Wrench Method

- Use properly calibrated wrench
- Snug all bolts prior to full tightening
- Use systematic tightening for all bolts, then "touch up" after tightening
- Re-calibrate wrench as required (fairly often)
  - Daily, or for any change in air supply, lubrication, or thread conditions, or…
  - When switching to a different lot of fasteners

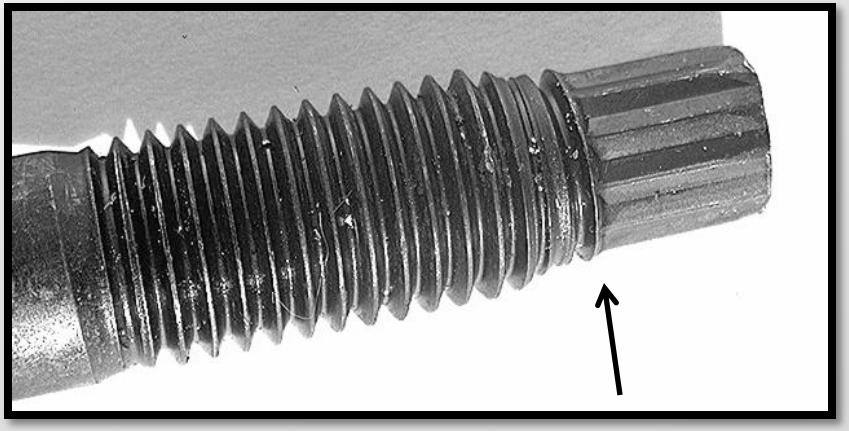
Tension-Control Bolts



- Tightened using a special wrench. Inner chuck engages splined end and outer envelopes the nut.

- Installation requires only one person and takes place form one side of the joint

Tension-Control Bolts



Annular Groove at Spline

The spline breaks off at the annular groove when the "torque developed by the friction between the nut and bolt threads and at the nut–washer interface overcomes the torsional shear resistance of the bolt material at the annular groove. … If the system has been properly manufactured and calibrated, the target bolt pretension is achieved at this point."

Source: AISC Design Guide 17

Outer Chuck Spins Hex Nut

Inner Chuck Holds Onto Spline

Tension-Control Bolts

- Must tighten systematically around joint
- Must snug all bolts tight before snapping ends
- Must be kept away from weather elements
- Since it is a torque controlled process, use established torques as periodic field check

Direct Tension Indicator (DTI)

- Washer-type element, under bolt head or nut

Does Q = N + 1

- Yes, if… Q = QA/QC for Steel (Q_{STEEL})
- And if N = AISC 360 Chapter N
- And if “1” means… 1 person spending 1 hour to read AISC Chapter N and write 1 page of exceptions / revisions and clarifications on inspection intervals

Thanks… Now We Can Build!