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## Specification for Structural Joints Using ASTM A325 or A490 Bolts

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June 23, 2000

*Supersedes the June 3, 1994 LRFD Specification for  
Structural Joints Using ASTM A325 or A490 Bolts  
and the June 3, 1994 ASD Specification for  
Structural Joints Using ASTM A325  
or A490 Bolts.*

Prepared by RCSC Committee 15—Specifications and approved by  
the Research Council on Structural Connections.

- The Research Council on Structural Connections (RCSC) prepares specifications and documents related to structural connections
- RCSC's Specification for Structural Joints Using ASTM A325 or A490 Bolts (2000) is a widely used specification which discusses joints, fasteners, limit states, installation, and inspections

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## Structural Bolting



- During hoisting, connectors will install a minimum of two bolts per connection
- The rest of the bolts are installed and tightened after the structure is plumbed
- A systematic pattern must be followed when tightening bolts so that a joint is drawn together and all fasteners are properly installed

(SSTC 2001)

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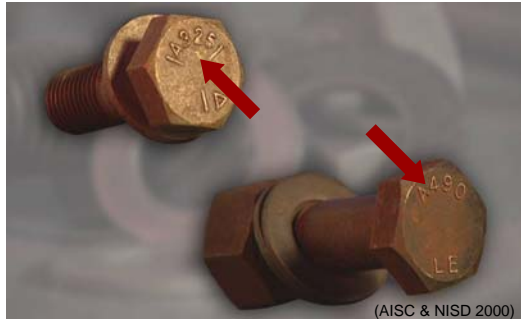
## Structural Bolting



Per the Occupational Safety & Health Administration Standard 1926.754(b)(2), "At no time shall there be more than four floors or 48 feet (14.6 m), whichever is less, of unfinished bolting or welding above the foundation or uppermost permanently secured floor, except where the structural integrity is maintained as a result of the design."

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## ASTM Bolt Types



- A307 – Low carbon steel
  - Not commonly used
  - Only used for secondary members
- A325 – High-strength medium carbon steel (above left)
  - Most common bolts used in building construction
- A490 – High-strength heat treated steel (above right)
  - Cost more than A325's, but are stronger so fewer bolts may be necessary
- Note that the ASTM designation is indicated on the head of the bolts above

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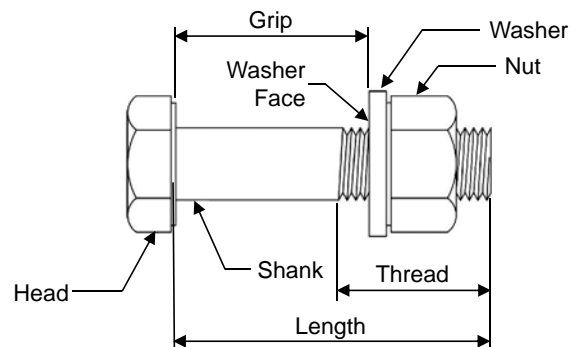
## Washers



- Hardened steel washers are used in many structural connections to spread pressure from the bolt tightening process over a larger area
- Washers may also be used to cover an oversized or slotted hole (RCSC 2000)
- Flat washers are most commonly used
- Tapered washers (above left) are used when the surface being bolted has a sloped surface, such as the flange of a channel or an S shape
- A325 bolts require a washer under the element (head or nut) being turned to tighten the bolt (shown under the nut, above right)
- A490 bolts require a washer under both the head and nut (AISC & NISD 2000)

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## Parts of the Bolt Assembly



- Grip is the distance from behind the bolt head to the back of the nut or washer
  - It is the sum of the thicknesses of all the parts being joined exclusive of washers
- Thread length is the threaded portion of the bolt
- Bolt length is the distance from behind the bolt head to the end of the bolt (AISC & NISD 2000)

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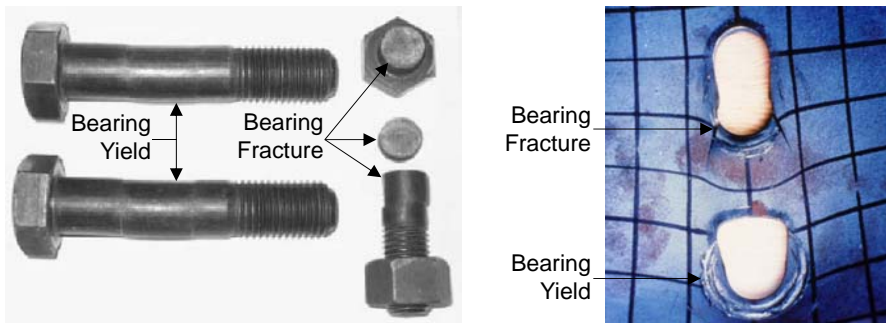
## Bolted Joint Types



- There two basic bolted joint types:
  - Bearing
    - The load is transferred between members by bearing on the bolts
  - Slip-critical
    - The load is transferred between members by friction in the joint

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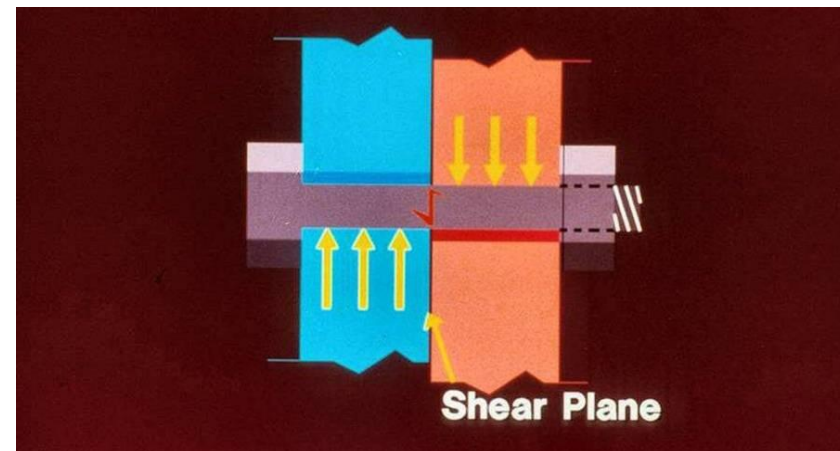
## Bolted Joint Failure Modes



- Bolts in bearing joints are designed to meet two limit states:
  1. Yielding, which is an inelastic deformation (above left)
  2. Fracture, which is a failure of the joint (above left)
- The material the bolt bears against is also subject to yielding or fracture if it is undersized for the load (above right)
- Tension connections act similarly to bearing connections
  - Many times, connections in direct tension are reconfigured so that the bolts act in shear (AISC)

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## Bearing Joints

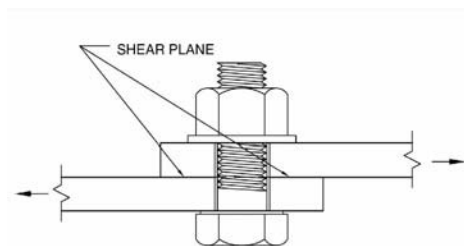


- In a bearing joint the connected elements are assumed to slip into bearing against the body of the bolt
- If the joint is designed as a bearing joint the load is transferred through bearing whether the bolt is installed snug-tight or pretensioned (AISC)

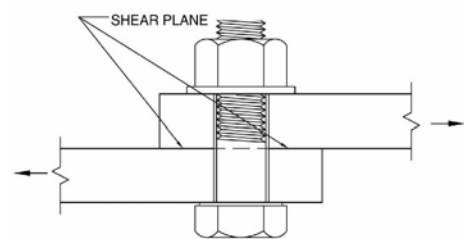
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## Threads in the Shear Plane

- The shear plane is the plane between two or more pieces under load where the pieces tend to move parallel from each other, but in opposite directions
- The threads of a bolt may either be included in the shear plane or excluded from the shear plane
- The capacity of a bolt is greater with the threads excluded from the shear plane
- The most commonly used bolt is an ASTM A325 3/4" bolt with the threads included in the shear plane (AISC & NISD 2000)



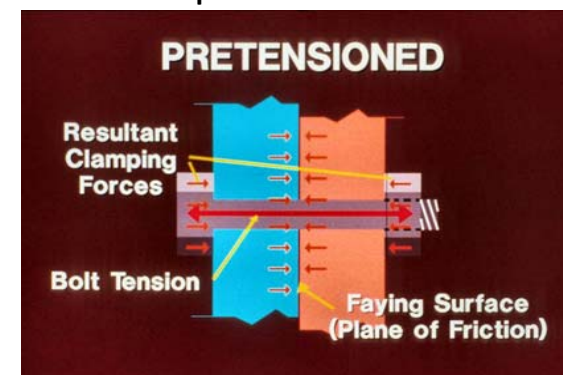
Threads Included In The Shear Plane



Threads Excluded From The Shear Plane

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## Slip-Critical Joints



- In a slip-critical joint the bolts must be fully pretensioned to cause a clamping force between the connected elements
- This force develops frictional resistance between the connected elements
- The frictional resistance allows the joint to withstand loading without slipping into bearing against the body of the bolt, although the bolts must still be designed for bearing
- The faying surfaces in slip-critical joints require special preparation (AISC)

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## When to Use Slip-Critical Joints



Per the RCSC Specification (2000), Slip-critical joints are only required in the following applications involving shear or combined shear and tension:

1. Joints that are subject to fatigue load with reversal of the loading direction (not applicable to wind bracing)
2. Joints that utilize oversized holes
3. Joints that utilize slotted holes, except those with applied load approximately perpendicular to the direction of the long dimension of the slot
4. Joints in which slip at the faying surfaces would be detrimental to the performance of the structure

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## Snug-tight Installation

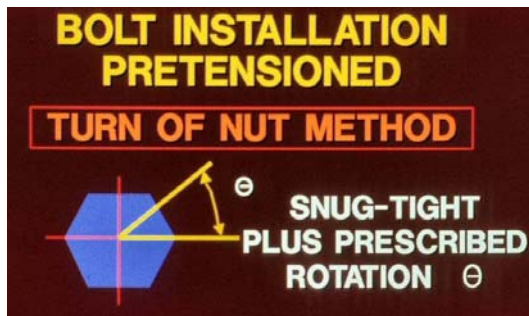


Snug-tight is the tightness attained with a few hits of an impact wrench or the full effort of an ironworker using an ordinary spud wrench to bring the connected plies into firm contact

(RCSC 2000)

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## Turn-of-Nut Installation



- Installation beyond snug-tight is called pretensioning
- Turn-of-nut pretensioning involves several steps:
  1. The bolt is snug-tightened
  2. Matchmarks are placed on each nut, bolt, and steel surface in a straight line
  3. The part not turned by the wrench is prevented from turning
  4. The bolt is tightened with a prescribed rotation past the snug-tight condition
- The specified rotation varies by diameter and length (between 1/3 and 1 turn)

(RCSC 2000, AISC)

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## Introduction of Fasteners

- When high-strength bolts are to be tensioned, minimum limits are set on the bolt tension. See AISC Table J3.1
- Tension equal to **70% of the minimum tensile strength** of the bolt
- Purpose of tensioning is to achieve the clamping force between connected parts.

Bolt Size, in.	A325 Bolts	A490 Bolts
1/2	12	15
3/4	19	24
7/8	28	35
1	39	49
1 1/4	51	64
1 1/2	56	80
1 3/4	71	102
1 3/8	85	121
1 7/8	103	148

\*Equal to 0.70 of minimum tensile strength of bolts, rounded off to nearest kip, as specified in ASTM specifications for A325 and A490 bolts with UNC threads.

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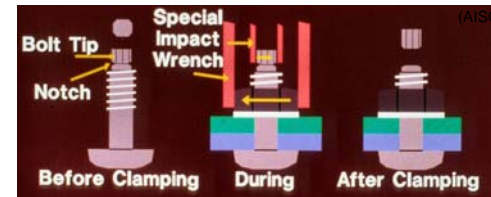
## Calibrated Wrench Installation



- Calibrated Wrench pretensioning uses an impact wrench (above left) to tighten the bolt to a specified tension
- A Skidmore-Wilhelm calibration device (above right) is used to calibrate the impact wrench to the torque level which will achieve the specified tension
- A sample of bolts representative of those to be used in the connections are tested to verify that the correct tension will be achieved (RCSC 2000, AISC)

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## ASTM F1852 Installation

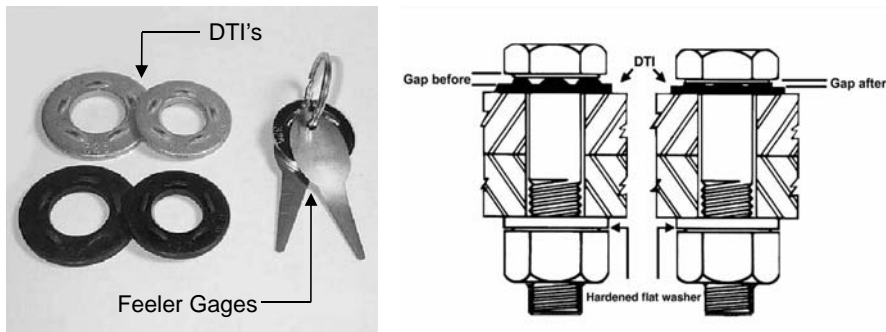


- F1852 bolts are twist-off-type tension-control bolts
- These bolts must be pretensioned with a twist-off-type tension-control bolt installation wrench that has two coaxial chucks
- The inner chuck engages the splined end of the bolt
- The outer chuck engages the nut
- The two chucks turn opposite to one another to tighten the bolt
- The splined end of the F1852 bolt shears off at a specified tension (AISC 2003)



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## ASTM F959 Direct Tension Indicators

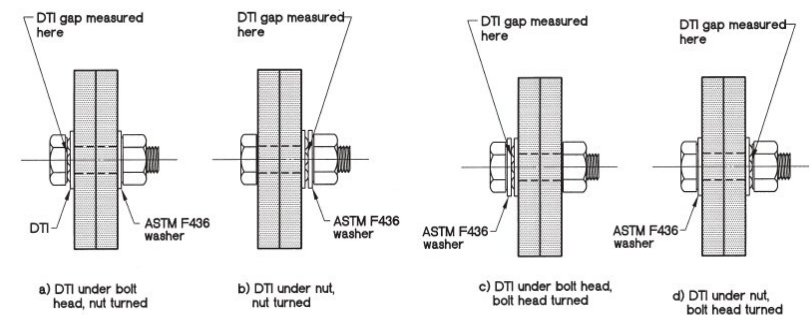


- Another way to try to ensure proper pretensioning of a bolt is through the use of direct tension indicators (DTIs)
- These washers have protrusions that must bear against the unturned element
- As the bolt is tightened the clamping force flattens the protrusions and reduces the gap
- The gap is measured with a feeler gage
- When the gap reaches the specified size the bolt is properly pretensioned

(AISC & NISD 2000)

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## Installation of DTIs



(Adapted from Figure C-8.1 RCSC 2000)

It is essential that direct tension indicators be properly oriented in the assembly

- The bolt head is stationary while the nut is turned – DTI under bolt head
- The bolt head is stationary while the nut is turned – DTI under nut (washer required)
- The nut is stationary while the bolt head is turned – DTI under bolt head (washer required)
- The nut is stationary while the bolt head is turned – DTI under nut (RCSC 2000)

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# Nominal Bolt Hole Dimensions

Nominal Bolt Diameter, $d_b$ , in.	Nominal Bolt Hole Dimensions <sup>a,b</sup> , in.			
	Standard (diameter)	Oversized (diameter)	Short-slotted (width × length)	Long-slotted (width × length)
$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{9}{16} \times \frac{1}{4}$	$\frac{9}{16} \times \frac{1}{4}$
$\frac{5}{8}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{11}{16} \times \frac{7}{8}$	$\frac{11}{16} \times \frac{9}{16}$
$\frac{3}{4}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{13}{16} \times 1$	$\frac{13}{16} \times \frac{7}{8}$
$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{1}{16}$	$\frac{15}{16} \times 1\frac{1}{8}$	$\frac{15}{16} \times 2\frac{3}{16}$
<b>1</b>	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{16} \times 1\frac{9}{16}$	$1\frac{1}{16} \times 2\frac{1}{2}$
$\geq 1\frac{1}{8}$	$d_b + \frac{1}{16}$	$d_b + \frac{5}{16}$	$(d_b + \frac{1}{16}) \times (d_b + \frac{3}{8})$	$(d_b + \frac{1}{16}) \times (2.5d_b)$

<sup>a</sup> The upper tolerance on the tabulated nominal dimensions shall not exceed  $\frac{1}{32}$ -in. Exception: In the width of slotted holes, gouges not more than  $\frac{1}{16}$ -in. deep are permitted.  
<sup>b</sup> The slightly conical hole that naturally results from punching operations with properly matched punches and dies is acceptable.

(Table 3.1 RCSC 2000)

- Bolts are installed in one of four types of holes (see table above)
- Standard holes can be used anywhere
- Oversized holes may only be used in slip-critical connections
- Short-slotted holes are used with the slot perpendicular to the direction of stress
- Long-slotted holes are primarily used when connecting to existing structures

# Inspections for the Construction Manager



There are several bolted connection inspections a construction manager can perform:

- Look at the bolt stick-out (above)
  - Stick-out is the amount the bolt extends beyond the outside surface of the nut
  - Positive or zero stick-out is acceptable
  - Negative stick-out, where the end of the bolt is inside the nut, is not acceptable

# Inspections for the Construction Manager



- Inspect the turn-of-nut matchmarks to ensure the bolts have been pretensioned
- If F1852 bolts are used, make sure the ends have been snapped off all bolts (above)
  - In some cases, due to insufficient clearance for the installation wrench, F1852 bolts will be tightened by alternative methods so the ends will not be snapped off

# Bolting Cost Considerations



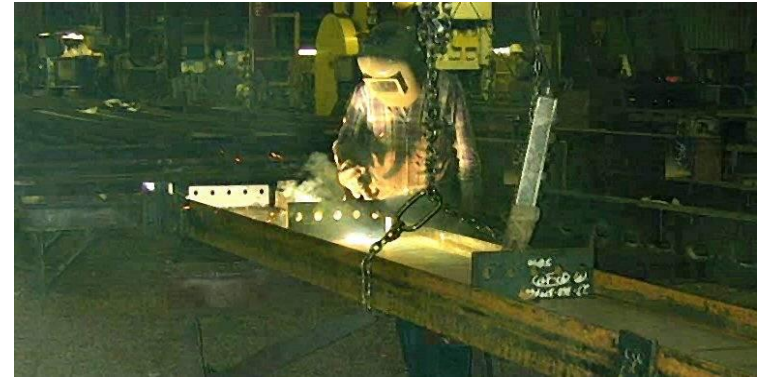
The types of joints used in a structure are somewhat dependent on the overall design of the structure, but these are some points to consider:

- The erector may prefer certain bolt and joint types over others due to equipment requirements, experience, and installation times
- Snug-tightened joints are normally the most economical bolted joints (Ruby 2003)
- For pretensioned joints, F1852's and DTI's are popular and can be economical
- Slip-critical joints are the most costly joints, and should only be specified when necessary (Ruby 2003)



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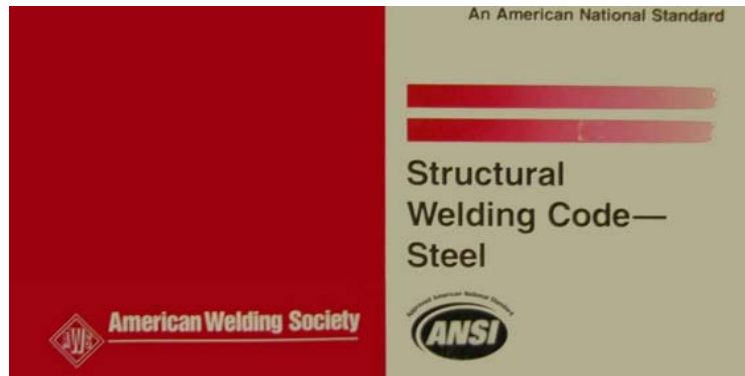
## Structural Welding



- Another common method for connecting structural steel is welding
- Welding can be performed in the shop or in the field
- Many fabrication shops prefer to weld rather than bolt
- Welding in the field is avoided if possible due to welding condition requirements
- There are several welding processes, types, and positions to be considered in building construction

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## Structural Welding



- The American Welding Society (AWS) is a nonprofit organization with a goal to advance the science, technology and application of welding and related joining disciplines
- AWS develops codes, recommended practices, and guides under strict American National Standards Institute (ANSI) procedures
- D1.1 Structural Welding Code – Steel, one of the most consulted codes in the world, is produced by AWS (AWS 2004a)

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## Structural Welding



- Welding is the process of fusing multiple pieces of metal together by heating the filler metal to a liquid state
- A properly welded joint is stronger than the base metal

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# Strength of Structural Welds

## Available Strength of Welded Joints

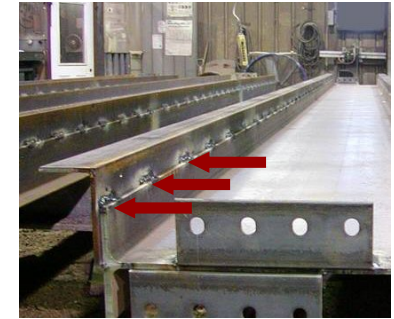
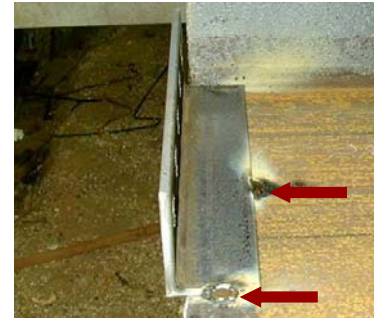
Load Type and Direction Relative to Weld Axis	Pertinent Metal	$\phi$ and $\Omega$	Nominal Strength ( $F_{EM}$ or $F_p$ )	Effective Area ( $A_{EM}$ or $A_w$ )	Required Filler metal Strength Level <sup>(b)(6)</sup>
COMPLETE-JOINT-PENETRATION GROOVE WELDS					
Tension Normal to weld axis	Strength of the joint is controlled by the base metal			Matching filler metal shall be used. For T and corner joints with backing left in place, notch tough filler metal is required. See Section J2.6	
Compression Normal to weld axis	Strength of the joint is controlled by the base metal			Filler metal with a strength level equal to or one strength level less than matching filler metal is permitted.	
Tension or Compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.			Filler metal with a strength level equal to or less than matching filler metal is permitted	
Shear	Strength of the joint is controlled by the base metal			Matching filler metal shall be used. <sup>(c)</sup>	

(Part of Table J2.5 AISC 2005)

- Welds may be loaded in shear, tension, compression, or a combination of these
- Capacities for welds are given in the AISC Specification Section J2 (2005)
- The strength of a weld is dependent on multiple factors, including: base metal, filler metal, type of weld, throat and weld size

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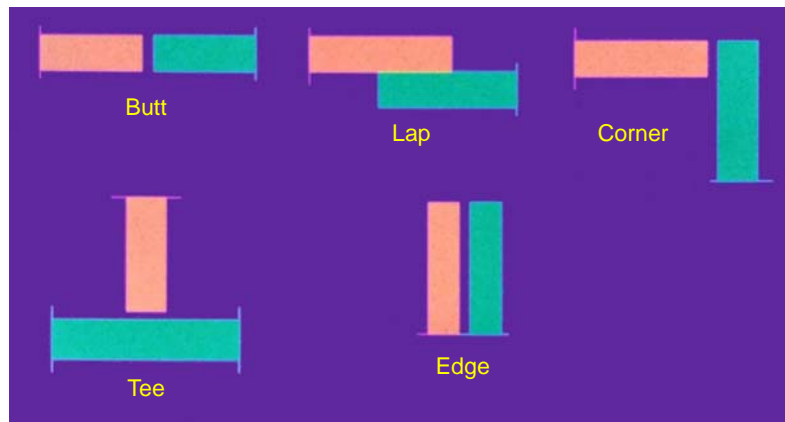
# Welding Terminology



- Tack Weld (above left)
  - A temporary weld used to hold parts in place while more extensive, final welds are made
- Continuous Weld
  - A weld which extends continuously from one end of a joint to the other
- Stitch Weld (above right)
  - A series of welds of a specified length that are spaced a specified distance from each other

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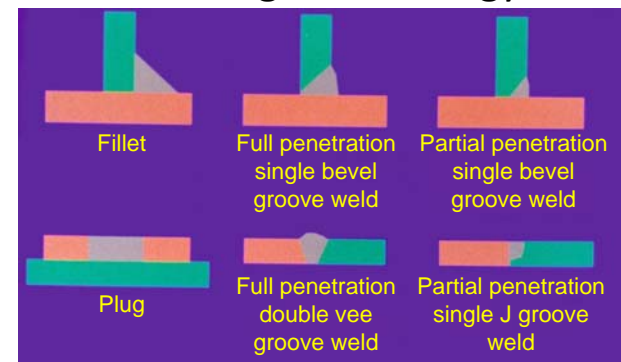
# Welding Terminology



- Shown above are types of structural joints which are established by positions of the connected material relative to one another
- Lap, tee, and butt joints are most common (AISC)

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# Welding Terminology



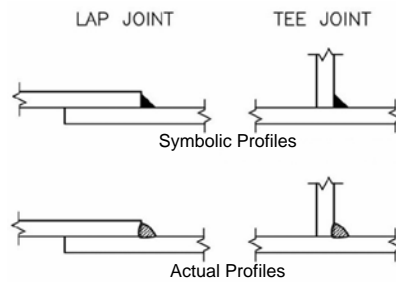
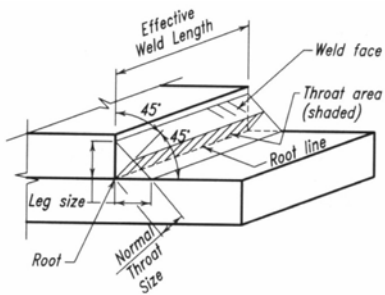
- Weld types define the configuration of the weld and its underlying design approach
- Fillet welds and groove welds are most common
- Groove welds fall into two categories
  - Full penetration – the entire member cross-section is welded
  - Partial penetration – just part of the member cross-section is welded

(AISC)

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## Fillet Welds



- The most commonly used weld is the fillet weld
- Fillet welds are theoretically triangular in cross-section
- Fillet welds join two surfaces at approximately right angles to each other in lap, tee, and corner joints

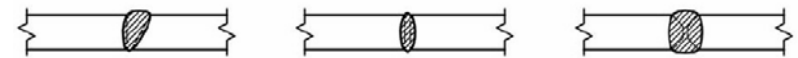
(AISC & NISD 2000)

## Groove Welds

SINGLE BEVEL      SQUARE GROOVE      DOUBLE-VEE GROOVE



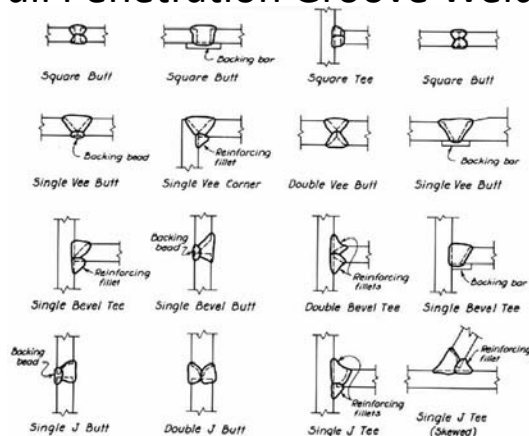
PROFILES BEFORE WELDING



ACTUAL PROFILES

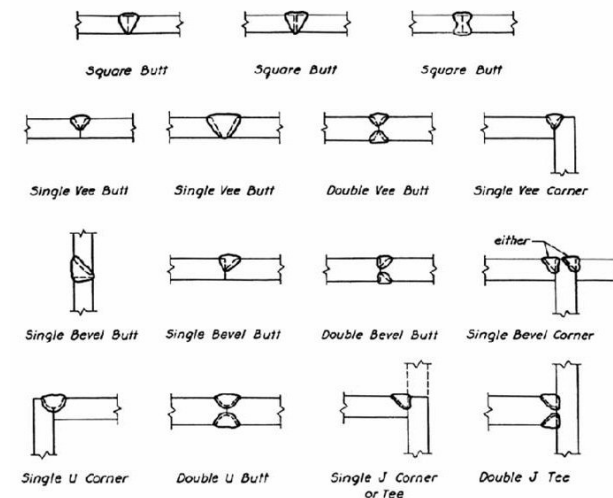
- Groove welds are specified when a fillet weld is not appropriate for the job
  - The configuration of the pieces may not permit fillet welding
  - A strength greater than that provided by a fillet weld is required
- Groove welds are made in the space or groove between the two pieces being welded (AISC & NISD 2000)

## Full Penetration Groove Welds



- The bevel or preparation extends over most or the entire face of the material being joined
- Complete fusion takes place
- In some types of full penetration groove welds the material will be beveled from one side of the plate with a separate plate on the opposite side – called backing or a backing bar (AISC & NISD 2000)

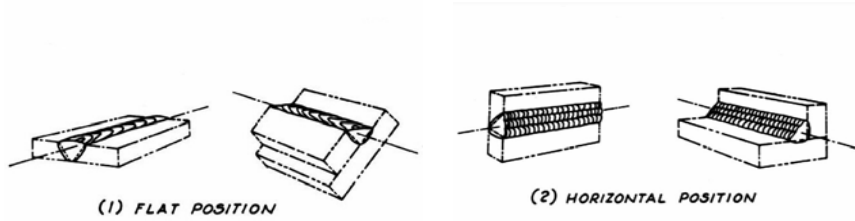
## Partial Penetration Groove Welds



Partial joint penetration welds are used when it is not necessary for the strength of the joint to develop the full cross section of the members being joined

(AISC & NISD 2000)

## Welding Positions



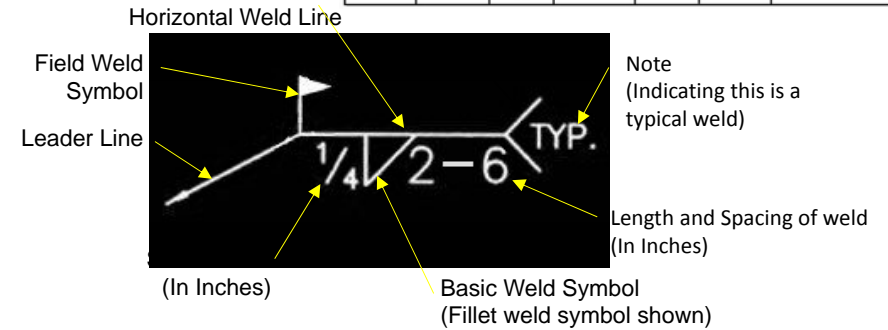
- There are four recognized welding positions:
  - Flat – The face of the weld is approximately horizontal and welding is performed from above the joint
  - Horizontal – The axis of the weld is horizontal
  - Vertical – The axis is approximately vertical or in the upright position
  - Overhead – Welding is performed from below the joint
- The flat position is preferred because it is easier and more efficient to weld in this position (AISC & NISD 2000)

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## Weld Symbols

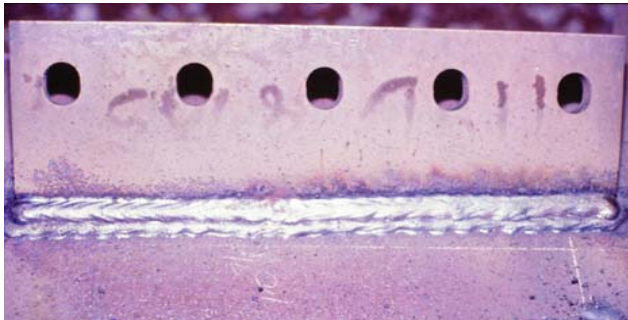
- Weld symbols are used to communicate the specific details and requirements of each weld to the welder
- Weld symbols are included on fabrication and erection drawings

Basic Weld Symbols										
Back	Fillet	Plug or Slot	Groove or Butt						Flare V	Flare Bevel
			Square	V	Bevel	U	J			
Supplementary Weld Symbols										
Backing	Spacer	Weld All Around	Field Weld	Contour		For other basic and supplementary weld symbols, see AWS A2.4				
				Flush	Convex					



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## Weld Size

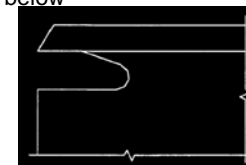


- The size of a weld must match the size specified on the drawings
- Some welds may meet the required size after a single pass of the welder
- Larger weld sizes may require multiple passes to meet the size requirement
- Common single pass welds include fillet welds up to and including 5/16 inch and thin plate butt welds with no preparation
- Common multiple pass welds include single bevel full penetration groove welds, single bevel partial penetration groove welds, and fillet welds over 5/16 inch
- The weld in the above picture is a multiple pass fillet weld

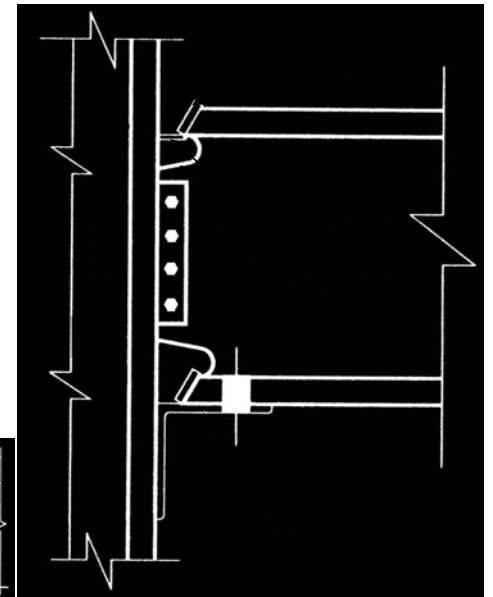
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## Weld Accessibility

- Access holes are required for some welds, such as the welded flange connection shown to the right
  - The top access hole allows for a continuous backing bar to be placed under the top flange
  - The bottom access hole allows for complete access to weld the entire width of the bottom flange
- A detail of a weld access hole for a welded flange connection is shown below



(Adapted from AISC 2002a)



(Adapted from AISC 2001)

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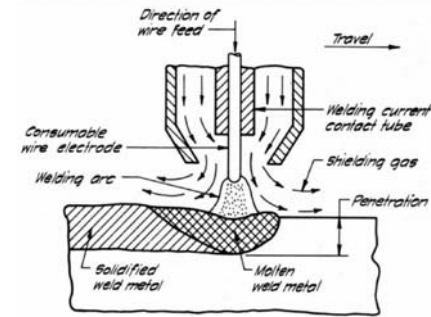
## SMAW Welding



- Shielded Metal Arc Welding (SMAW) is also known as manual, stick, or hand welding
- An electric arc is produced between the end of a coated metal electrode and the steel components to be welded
- The electrode is a filler metal covered with a coating
- The electrode's coating has two purposes:
  - It forms a gas shield to prevent impurities in the atmosphere from getting into the weld
  - It contains a flux that purifies the molten metal (AISC & NISD 2000)

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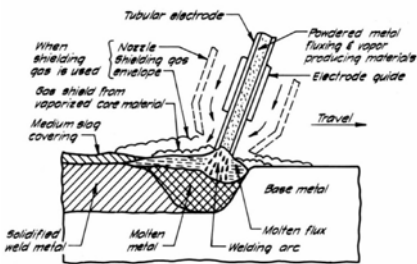
## GMAW Welding



- Gas Metal Arc Welding (GMAW) is also known as MIG welding
- It is fast and economical
- A continuous wire is fed into the welding gun
- The wire melts and combines with the base metal to form the weld
- The molten metal is protected from the atmosphere by a gas shield which is fed through a conduit to the tip of the welding gun
- This process may be automated (AISC & NISD 2000)

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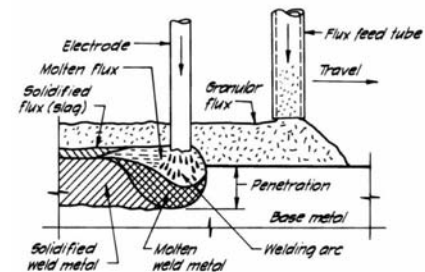
## FCAW Welding



- Flux Cored Arc Welding (FCAW) is similar to the GMAW process
  - The difference is that the filler wire has a center core which contains flux
  - With this process it is possible to weld with or without a shielding gas
    - This makes it useful for exposed conditions where a shielding gas may be affected by the wind
- (AISC & NISD 2000)

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## SAW Welding



- Submerged Arc Welding (SAW) is only performed by automatic or semiautomatic methods
- Uses a continuously fed filler metal electrode
- The weld pool is protected from the surrounding atmosphere by a blanket of granular flux fed at the welding gun
- Results in a deeper weld penetration than the other process
- Only flat or horizontal positions may be used (AISC & NISD 2000)

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## Weld Inspections



- In addition to the erector's quality control program, tests and inspections are specified by the Engineer of Record and/or the local building authority
- A local building inspector may request that tests in addition to those specified by the Engineer of Record be performed
- Some problems that can be found in welds include:
  - Lack of fusion
  - Cracks
  - Wrong size
  - Porosity
  - Insufficient penetration
  - Poor workmanship

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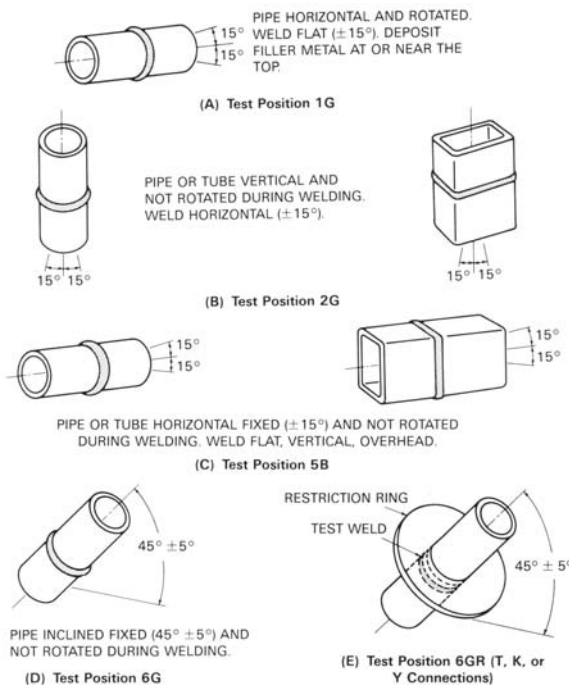
## Visual Inspection



- Visual inspection is the most frequently used inspection and is the only inspection required unless the specification calls for a more stringent inspection method
- Inspection is done by the welder before, during, and after welding
- When outside inspection is required it should also be done before, during, and after welding
- Minor problems can be identified and corrected before the weld is complete (AISC & NISD 2000)

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## Welding of Tubular Structures



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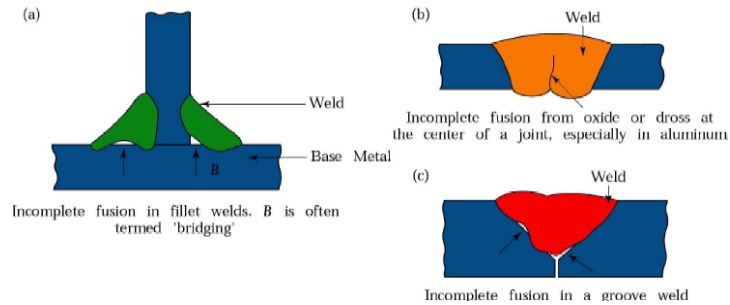
## Weld Quality

- Welding discontinuities can be caused by inadequate or careless application
- The major discontinuities that affect weld quality are
  - Porosity
  - Slag Inclusions
  - Incomplete fusion and penetration
  - Weld profile
  - Cracks
  - Lamellar tears
  - Surface damage
  - Residual stresses

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## Penetration:

- Incomplete penetration occurs when the depth of the welded joint is insufficient
- Penetration can be improved by the following practices :
  - Increasing the heat input
  - Reducing the travel speed during the welding
  - Changing the joint design
  - Ensuring the surfaces to be joined fit properly



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## Discontinuities in Fusion Welds

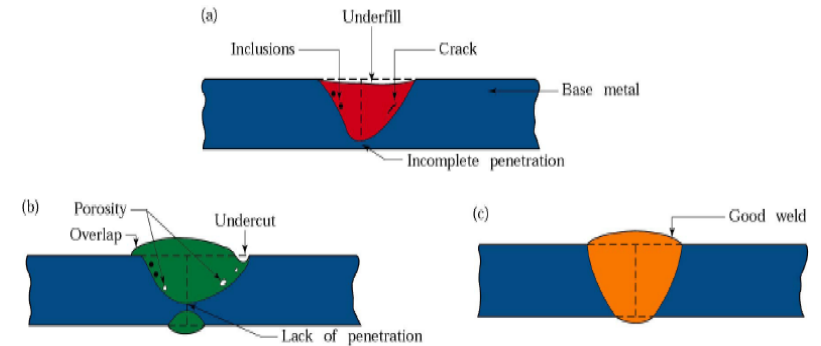


Fig : Schematic illustration of various discontinuities in fusion welds.

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## Cracks

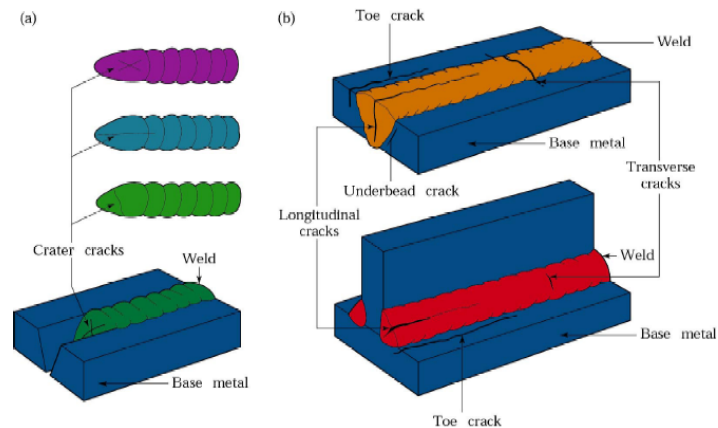


Fig : Types of cracks (in welded joints) caused by thermal stresses that develop during solidification and contraction of the weld bead and the surrounding structure. (a) Crater cracks (b) Various types of cracks in butt and T joints.

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## Distortion after Welding

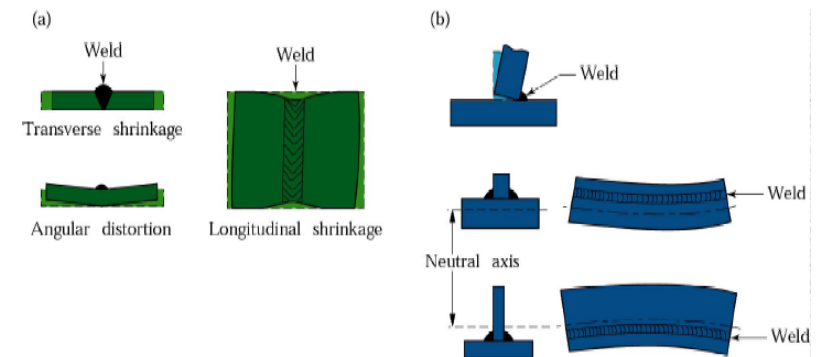


Fig : Distortion of parts after welding : (a) butt joints; (b) fillet welds. Distortion is caused by differential thermal expansion and contraction of different parts of the welded assembly.

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## Residual Stresses developed during welding

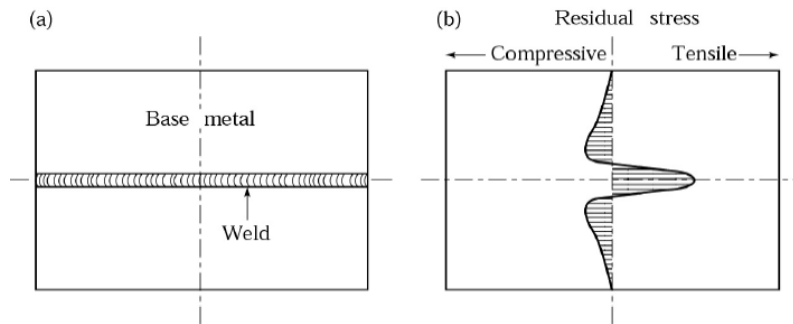


Fig : Residual stresses developed during welding of a butt joint.

## Stress relieving of welds :

- Preheating reduces reduces problems caused by preheating the base metal or the parts to be welded
- Heating can be done electrically, in furnace, for thin surfaces radiant lamp or hot air blast
- Some other methods of stress relieving : Peening, hammering or surface rolling