# 6000. STEEL

6100 & 6200
- 6130 - Design Data, Principles and Tools
- 6140 - Codes and Standards
- 6200 - Material

6300
- 6310 - Members and Components
- 6320 - Connections, Joints and Details
- 6330 - Frames and Assembles

6400
- 6410 - AISC Specifications for Structural Joints
- 6420 - AISC 303 Code of Standard Practice
- 6430 - AWS D1.1 Structural Welding Code

6500
- 6510 - Nondestructive Testing Methods
- 6520 - AWS D1.1 Structural Welding Code Tests

6600
- 6610 - Steel Construction
- 6620/6630 - NUREG-0800 / RG 1.94



# 6400. Fabrication and Construction -

## 6410. AISC Specifications for Structural Joints Using ASTM A325 or A490 Bolts

- Fastener Components, Bolted Parts, Joint Type and Limit States in Bolted Joints
- Use of Washers and Pre-installation Verification
- Installation and Inspection of bolts



# Connecting Structural Steel

- The primary connection methods for structural steel are bolting and welding
- A structure's strength depends on proper use of these connection methods
- Connections made in a fabrication shop are called shop connections
- Connections made in the field by the steel erector are called field connections
- Bolting and welding may be used for shop connections and field connections



# Connecting Structural Steel

- A fabrication shop will have a desired fastening method suited to its equipment and fabrication methods
- Field connections are typically bolted
- Welding may be used for field connections where bolting is either impractical or undesirable
- Welding is better suited to the controlled environment of a fabrication shop




# Specification for Structural Joints Using ASTM A325 or A490 Bolts

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



# 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)



# 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."

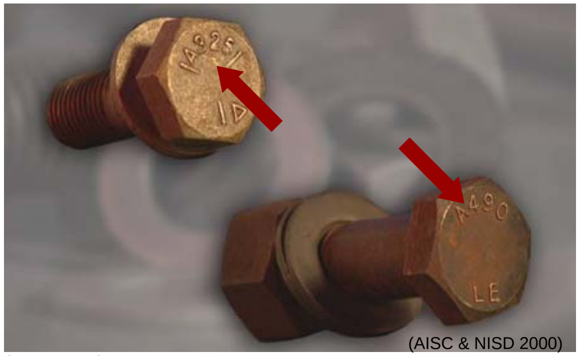
# Structural Bolting

- There are many bolt types, installation methods, and joint types used in structural steel construction
- When left exposed, bolts may be used to make an architectural expression

(Green, Sputo, and Veltri)



# ASTM Bolt Types

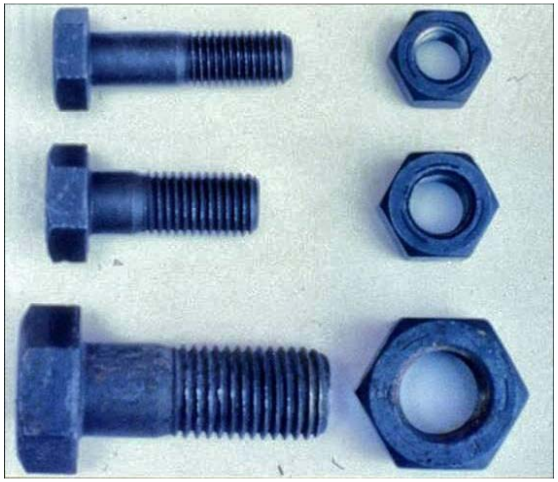



(AISC & NISD 2000)

- 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



# Common Bolt Sizes



- A325 and A490 bolts are available in diameters ranging from 1/2" to 1-1/2"
- The most common sizes are 3/4", 7/8", and 1"
- High-strength bolts are commonly available in incremental lengths up to 8"

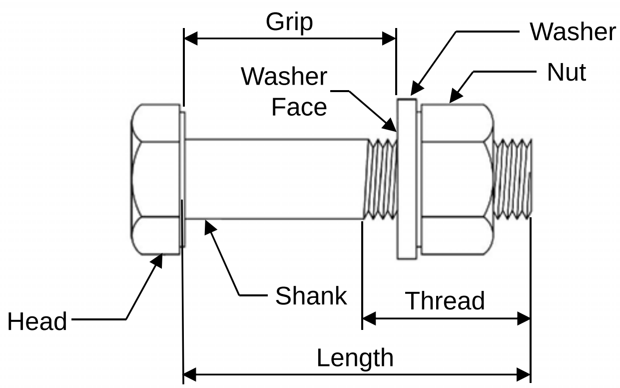
(AISC)



# 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)

# 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)

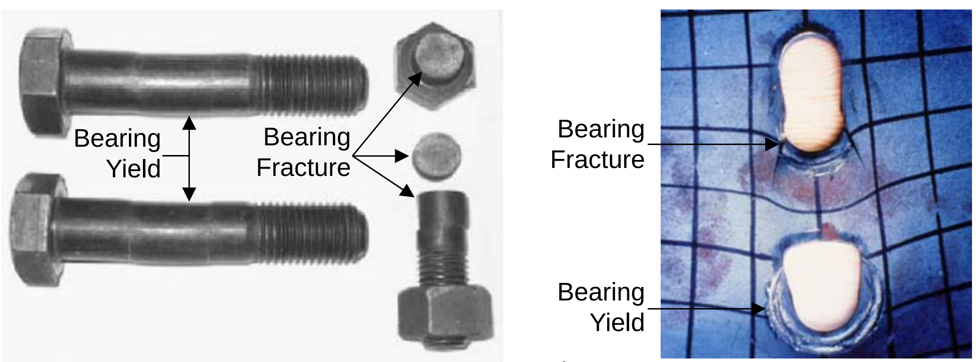


# Bolted Joint Types

- 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



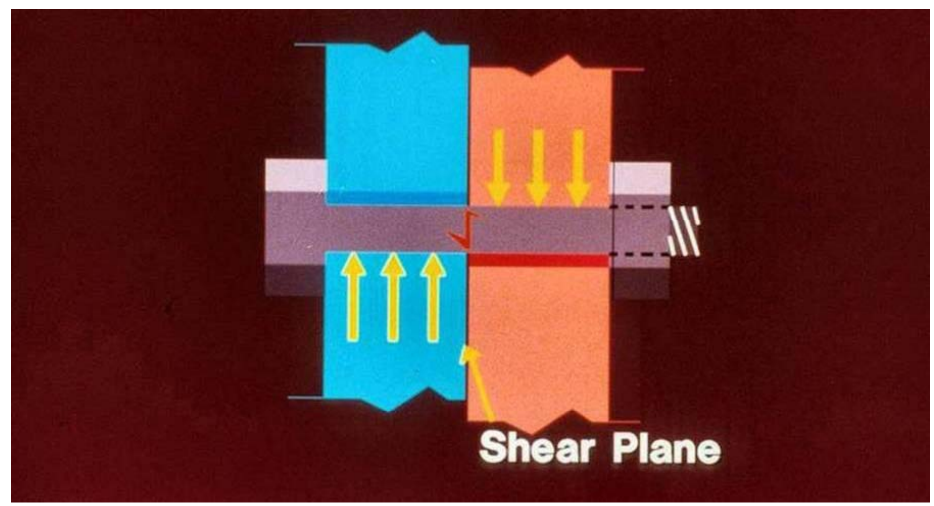
# Bolted Joint Failure Modes




- 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)



# Bearing Joints

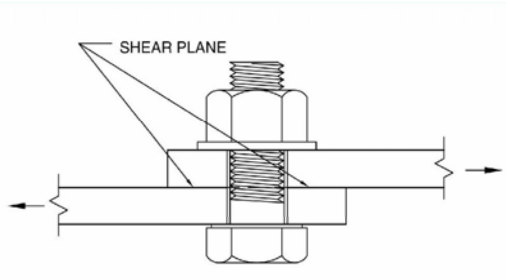



- In a bearing joint the connected elements are assumed to slip into bearing against the body of the bolt
- If the joint is designed as a bearing joint the load is transferred through bearing whether the bolt is installed snug-tight or pretensioned (AISC)

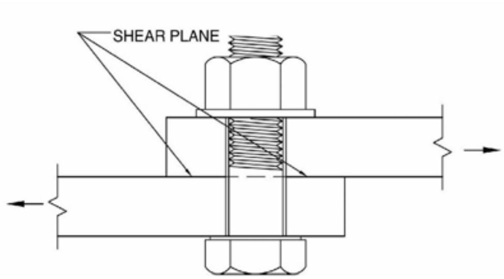
# Threads in the Shear Plane

- 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)



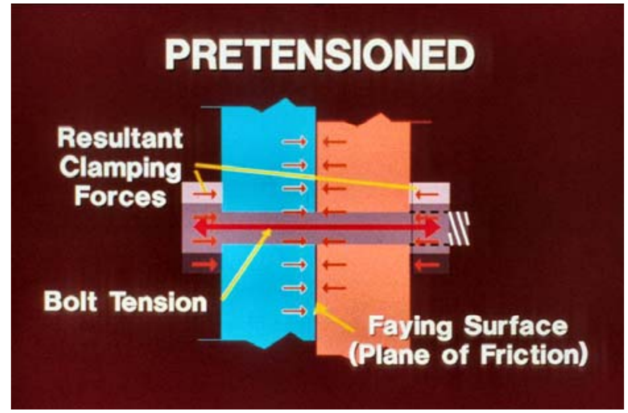

Threads Included In The Shear Plane




Threads Excluded From The Shear Plane



# Slip-Critical Joints




- In a slip-critical joint the bolts must be <u>fully pretensioned</u> 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)



# 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

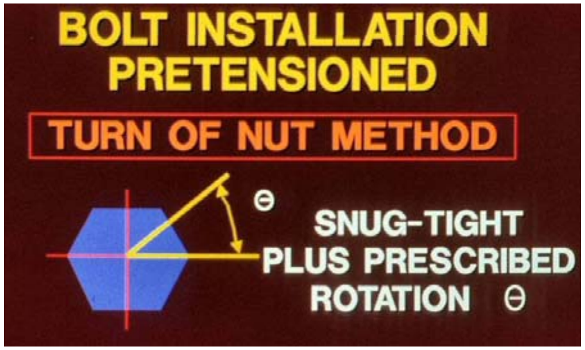


# Snug-tight Installation

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)

# 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)



# 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.

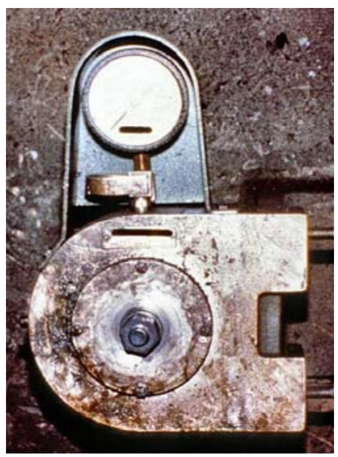
TABLE J3.1
Minimum Bolt Pretension, kips*

| Bolt Size, in. | A325 Bolts | A490 Bolts |
|---|---|---|
| ½ | 12 | 15 |
| ⅝ | 19 | 24 |
| ¾ | 28 | 35 |
| ⅞ | 39 | 49 |
| 1 | 51 | 64 |
| 1⅛ | 56 | 80 |
| 1¼ | 71 | 102 |
| 1⅜ | 85 | 121 |
| 1½ | 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.



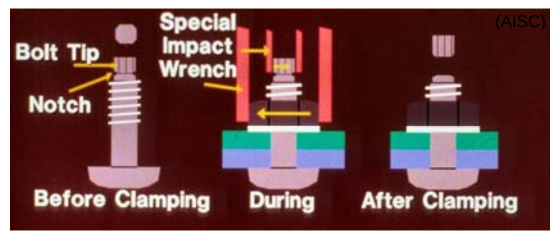
# Calibrated Wrench Installation



- 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)

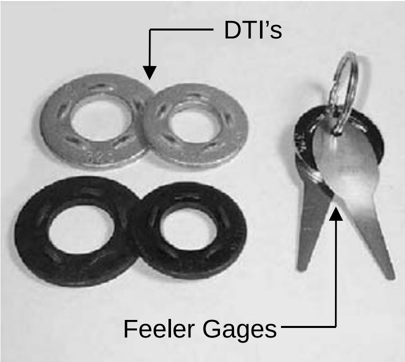


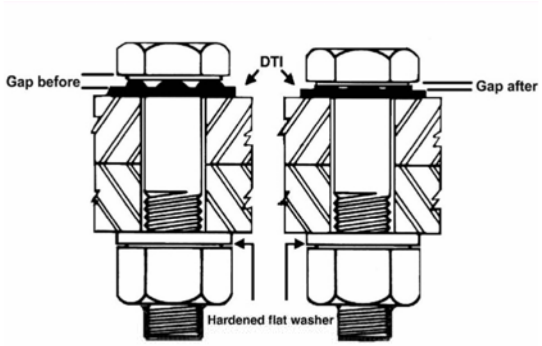
# ASTM F1852 Installation




- 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)

# ASTM F959 Direct Tension Indicators



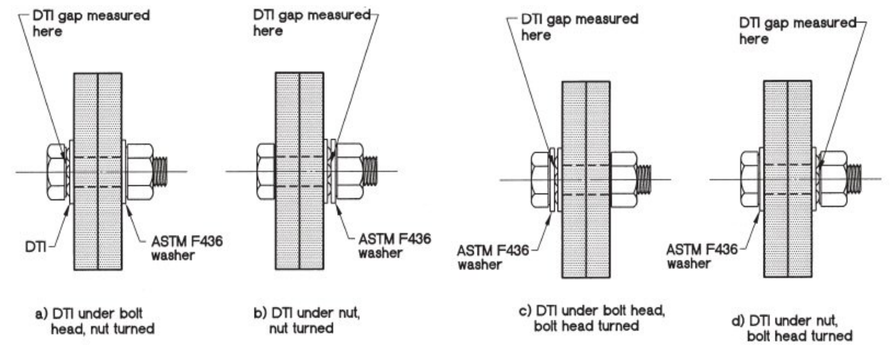




- Another way to try to ensure proper pretensioning of a bolt is through the use of direct tension indicators (DTIs)
- These washers have protrusions that must bear against the unturned element
- As the bolt is tightened the clamping force flattens the protrusions and reduces the gap
- The gap is measured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

(AISC & NISD 2000)



# Installation of DTIs




(Adapted from Figure C-8.1 RCSC 2000)

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

a) The bolt head is stationary while the nut is turned – DTI under bolt head

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

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

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



# Nominal Bolt Hole Dimensions

| Nominal Bolt Diameter, $d_b$ in. | Nominal Bolt Hole Dimensions[a,b], in. | | | |
|---|---|---|---|---|
| | Standard (diameter) | Oversized (diameter) | Short-slotted (width × length) | Long-slotted (width × length) |
| 1/2 | 9/16 | 5/8 | 9/16 × 11/16 | 9/16 × 1 1/4 |
| 5/8 | 11/16 | 13/16 | 11/16 × 7/8 | 11/16 × 1 9/16 |
| 3/4 | 13/16 | 15/16 | 13/16 × 1 | 13/16 × 1 7/8 |
| 7/8 | 15/16 | 1 1/16 | 15/16 × 1 1/8 | 15/16 × 2 3/16 |
| 1 | 1 1/16 | 1 1/4 | 1 1/16 × 1 5/16 | 1 1/16 × 2 1/2 |
| ≥ 1 1/8 | $d_b$ + 1/16 | $d_b$ + 5/16 | ($d_b$ + 1/16) × ($d_b$ + 3/8) | ($d_b$ + 1/16) × (2.5$d_b$) |

[a] The upper tolerance on the tabulated nominal dimensions shall not exceed 1/32-in. Exception: In the width of slotted holes, gouges not more than 1/16-in. deep are permitted.

[b] 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



# Equipment Requirements

- Common tools used by Ironworkers include spud wrenches, pins, and corrections bars of various sizes (above left)
- Impact wrenches will be needed for certain installations (above center)
- Electricity or compressed air is required depending on the impact wrench being used
  - A generator as well as an air compressor may be needed (above right)

# Storage of Components

Per the RCSC Specification:

- Fastener components must be protected from dirt and moisture in closed containers on the jobsite
- Only fasteners anticipated to be installed during the work shift are to be taken from protected storage
- Protected storage is defined as the continuous protection of fastener components in closed containers in a protected shelter
- Any unused fasteners must be promptly returned to protected storage



# Storage of Components

- The lubrication on fasteners is vital to their proper installation
- A water-soluble oil is used on most black bolts
- This oil is easily washed off when exposed to moisture
- Fasteners that accumulate rust or dirt must be cleaned and relubricated before they may be installed
- F1852 bolts (shown above) shall not be relubricated, except by the manufacturer

(RCSC 2000, SSTC 2001)

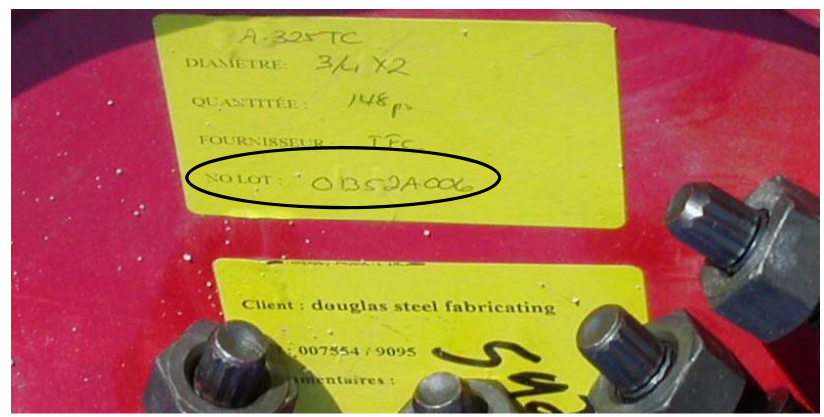


# Storage of Galvanized Fasteners

- Galvanized bolts and nuts (above) are provided by the supplier in a set and special storage requirements
- Each bolt/nut set is pretested by the supplier and shipped together and must be kept together as an assembly
- Poor thread fit may result if the bolt and nut are mismatched
- The lubrication on galvanized fasteners is generally more durable than that on black bolts, but protected storage is still recommended
- A490 bolts are not allowed to be galvanized (SSTC 2001)



# Production Lots




- Production lot traceability is required by many standards
- Even if not required, it is good practice to record the lot numbers and keep all fasteners separated by lot
- It is necessary to keep lots separate for proper pre-installation verification testing which is required for pretensioned and slip-critical joints
- Mixing bolts and nuts from different production lots is not permitted

(SSTC 2001)

# Inspections

- In addition to the erector's quality control program, tests and inspection 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
- Snug-tightened joints require visual inspection for firm contact and proper use of washers
- Pretensioned joints require pre-installation verification and routine observation of proper application
- Slip-critical joints require inspection of the faying surfaces in addition to the above inspections



# 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)

# 6400. Fabrication and Construction -

## 6410. AISC Specifications for Structural Joints Using ASTM A325 or A490 Bolts

Objective and Scope Met

- Fastener Components, Bolted Parts, Joint Type and Limit States in Bolted Joints
- Use of Washers and Pre-installation Verification
- Installation and Inspection of bolts



# 6000. STEEL

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6600
- 6610 - Steel Construction
- 6620/6630 - NUREG-0800 / RG 1.94



# 6400. Fabrication and Construction -

## 6420. AISC 303 Code of Standard Practice for Steel Buildings and Bridges

- Design Drawings and Specifications; Shop and Erection Drawings
- Shop Fabrication and Delivery; Erection
- Quality Assurance
- Digital Building Product Models



# Submittals

A. Shop Drawings: Show fabrication of structural steel components.

B. Qualification Data: For qualified fabricator, installer, and welder.

C. Welding certificates.

D. Mill test reports for structural steel, including chemical and physical properties.

E. Source quality-control reports.

# Quality Assurance

A. Fabricator Qualifications: A qualified fabricator that participates in the AISC Quality Certification Program and is designated an AISC-Certified Plant, Category STD.

B. Installer Qualifications: A qualified installer who participates in the AISC Quality Certification Program and is designated an AISC-Certified Erector, Category CSE.

C. Welding Qualifications: Qualify procedures and personnel according to AWS D1.1/D1.1M, "Structural Welding Code - Steel."

D. Comply with applicable provisions of the following specifications and documents:

1. AISC 303.
2. AISC 360.
3. RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts."



# Fabrication

A. Structural Steel: Fabricate and assemble in shop to greatest extent possible. Fabricate according to AISC's "Code of Standard Practice for Steel Buildings and Bridges" and AISC 360.

B. Shear Connectors: Prepare steel surfaces as recommended by manufacturer of shear connectors. Use automatic end welding of headed-stud shear connectors according to AWS D1.1/D1.1M and manufacturer's written instructions.



# Shop Connections

A. High-Strength Bolts: Shop install high-strength bolts according to RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts" for type of bolt and type of joint specified.

- Joint Type: Snug tightened.

B. Weld Connections: Comply with AWS D1.1/D1.1M for tolerances, appearances, welding procedure specifications, weld quality, and methods used in correcting welding work.



# Shop Priming

- A. Shop prime steel surfaces except the following:
    1. Surfaces embedded in concrete or mortar.
    2. Surfaces to be field welded.
    3. Surfaces to be high-strength bolted with slip critical connections.
    4. Surfaces to receive sprayed fire-resistive materials (applied fireproofing).
    5. Galvanized surfaces.
- B. Surface Preparation: Clean surfaces to be painted. Remove loose rust and mill scale and spatter, slag, or flux deposits. Prepare surfaces according to the following specifications and standards:
    1. SSPC-SP 3, "Power Tool Cleaning."

# Shop Priming (cont.)

C. Priming: Immediately after surface preparation, apply primer according to manufacturer's written instructions and at rate recommended by SSPC to provide a minimum dry film thickness of 1.5 mils (0.038 mm). Use priming methods that result in full coverage of joints, corners, edges, and exposed surfaces.



# Source Quality Control

A. Testing Agency: Owner will engage an independent testing and inspecting agency to perform shop tests and inspections and prepare test reports.
   1. Provide testing agency with access to places where structural-steel work is being fabricated or produced to perform tests and inspections.

B. Correct deficiencies in Work that test reports and inspections indicate does not comply with the Contract Documents.



# Source Quality Control (cont.)

C. Bolted Connections: Shop-bolted connections will be tested and inspected according to RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts."

D. Welded Connections: In addition to visual inspection, shop-welded connections will be tested and inspected according to AWS D1.1/D1.1M and the following inspection procedures, at testing agency's option:
   1. Liquid Penetrant Inspection: ASTM E 165.
   2. Magnetic Particle Inspection: ASTM E 709; performed on root pass and on finished weld. Cracks or zones of incomplete fusion or penetration will not be accepted.
   3. Ultrasonic Inspection: ASTM E 164.
   4. Radiographic Inspection: ASTM E 94.



# Erection

A. Set structural steel accurately in locations and to elevations indicated and according to AISC 303 and AISC 360.

B. Base Bearing and Leveling Plates: Clean concrete- and masonry-bearing surfaces of bond reducing materials, and roughen surfaces prior to setting plates. Clean bottom surface of plates.
   1. Set plates for structural members on wedges, shims, or setting nuts as required.
   2. Weld plate washers to top of base plate.
   3. Snug-tighten anchor rods after supported members have been positioned and plumbed. Do not remove wedges or shims but, if protruding, cut off flush with edge of plate before packing with grout.

# Erection (cont.)

4. Promptly pack grout solidly between bearing surfaces and plates so no voids remain. Neatly finish exposed surfaces; protect grout and allow to cure. Comply with manufacturer's written installation instructions for shrinkage-resistant grouts.

C. Maintain erection tolerances of structural steel within AISC's "Code of Standard Practice for Steel Buildings and Bridges."



# Field Connections

A. High-Strength Bolts: Install high-strength bolts according to RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts" for type of bolt and type of joint specified.
   1. Joint Type: Snug tightened.

B. Weld Connections: Comply with AWS D1.1/D1.1M for tolerances, appearances, welding procedure specifications, weld quality, and methods used in correcting welding work.
   1. Comply with AISC 303 and AISC 360 for bearing, alignment, adequacy of temporary connections, and removal of paint on surfaces adjacent to field welds.



# Field Quality Control

A. Testing Agency: Owner will engage a qualified independent testing and inspecting agency to inspect field welds and high-strength bolted connections.

B. Bolted Connections: Bolted connections will be tested and inspected according to RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts.“

C. Welded Connections: Field welds will be visually inspected according to AWS D1.1/D1.1M.



# Field Quality Control (cont.)

1. In addition to visual inspection, field welds will be tested and inspected according to AWS D1.1/D1.1M and the following inspection procedures, at testing agency's option:
   a. Liquid Penetrant Inspection: ASTM E 165.
   b. Magnetic Particle Inspection: ASTM E 709; performed on root pass and on finished weld. Cracks or zones of incomplete fusion or penetration will not be accepted.
   c. Ultrasonic Inspection: ASTM E 164.
   d. Radiographic Inspection: ASTM E 94.

D. Correct deficiencies in Work that test reports and inspections indicate does not comply with the Contract Documents.

# Digital Building Product Models

- CIS/2 (CIS/2 is the file exchange format that facilitates BIM, Building Information Modeling, for structural steel )

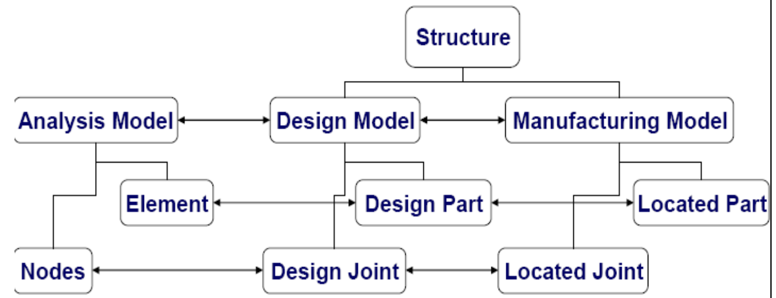
  CIM (Computer Integrated Manufacturing) Steel Integration Standards/Version 2
- LPM

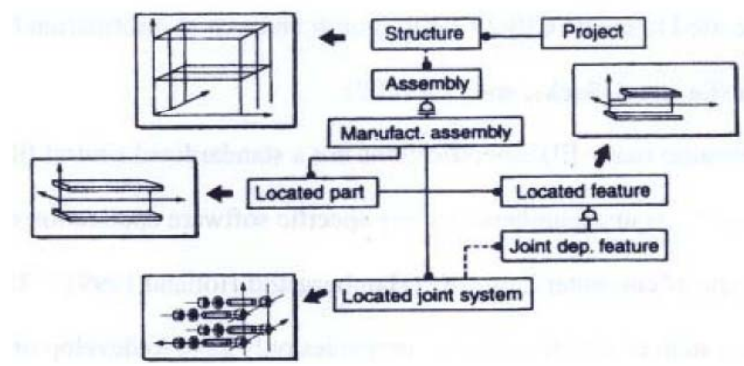
  Logical Product Model
  - Analysis Model
  - Design Model
  - Manufacturing Model
- DMC

  Data Management Conformance



# CIS/2 Models



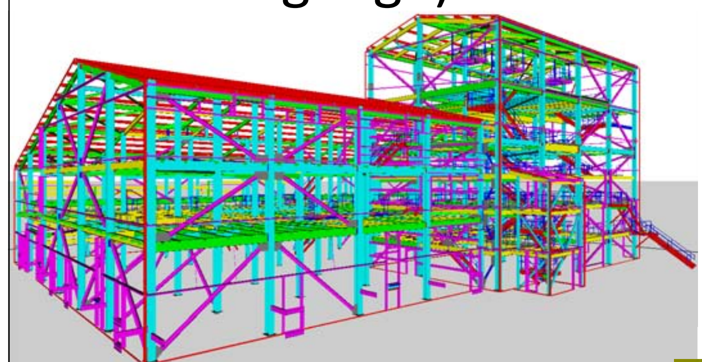



# Section A3.1 Design Drawings and Specification-Design Model

- Data Management Conformance Classes.
- Include entities that define each steel element.
- Include steel elements identified in the Contract Documents … required for strength and stability…
- Govern all other forms of information …

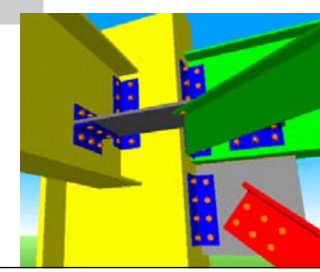


# VRML (Virtual Reality Modeling Language) based on CIS/2



Large VRML model with 11,079 parts

Connection details with bolts and welds.



# 6420. AISC 303 Code of Standard Practice for Steel Buildings and Bridges

- Fabrication Detailing Video (by AISC)
  - FabricationDetailingPart1.mpg
  - FabricationDetailingPart2.mpg



# 6400. Fabrication and Construction -

## 6420. AISC 303 Code of Standard Practice for Steel Buildings and Bridges

Objective and Scope Met

- Design Drawings and Specifications; Shop and Erection Drawings
- Shop Fabrication and Delivery; Erection
- Quality Assurance
- Digital Building Product Models



# 6000. STEEL

6100 & 6200
- 6130 - Design Data, Principles and Tools
- 6140 - Codes and Standards
- 6200 - Material

6300
- 6310 - Members and Components
- 6320 - Connections, Joints and Details
- 6330 - Frames and Assembles

6400
- 6410 - AISC Specifications for Structural Joints
- 6420 - AISC 303 Code of Standard Practice
- 6430 - AWS D1.1 Structural Welding Code

6500
- 6510 - Nondestructive Testing Methods
- 6520 - AWS D1.1 Structural Welding Code Tests

6600
- 6610 - Steel Construction
- 6620/6630 - NUREG-0800 / RG 1.94



# 6400. Fabrication and Construction -

## 6430. AWS D1.1 Structural Welding Code

- Design of Welded Connections
- Technique (Shielded Metal Arc Welding; C-Submerged Arc Welding; Gas Metal Arc and Flux Cored Arc Welding; Electroslag and Electrogas Welding; Plug and Slot Welds; Stud Welding)
- Qualification and Inspection
- Tubular Structures
- Strengthening and Repairing Existing Structures
- Weld Quality

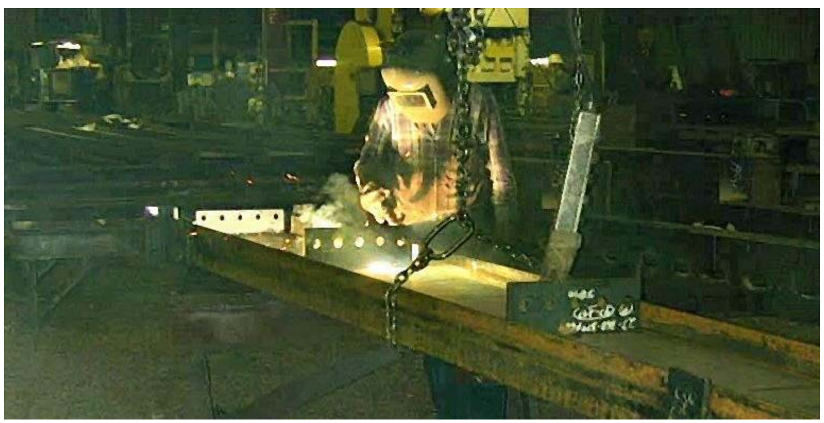
# ANSI/AWS D1.1 Structural Welding Code: Steel

- Guidelines for design of welded joints as well as prequalified joint geometries
  - Statically loaded structures
  - Dynamically loaded structures
  - Tubular sections
- Details the processes used with particular joints
- How to qualify welding procedures and personnel
- Outlines quality and inspection in welded construction
- Filler metal recommendations





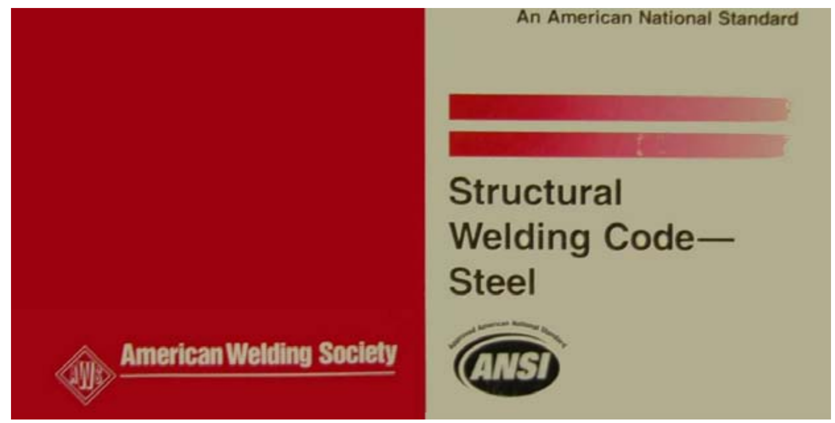

# Structural Welding



- 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



# 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)

# 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



# Strength of Structural Welds

**Available Strength of Welded Joints**

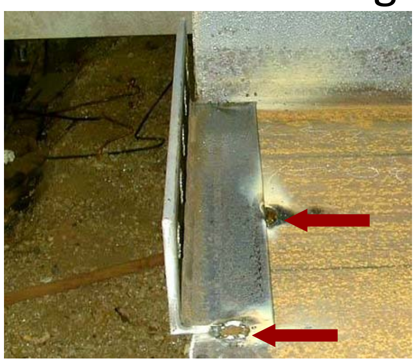
| Load Type and Direction Relative to Weld Axis | Pertinent Metal | Φ and Ω | Nominal Strength ($F_{bm}$ or $F_w$) | Effective Area ($A_{BM}$ or $A_w$) | Required *Filler metal* Strength Level [(a)(b)] |
|---|---|---|---|---|---|
| COMPLETE-JOINT-PENETRATION GROOVE WELDS | | | | | |
| Tension<br>Normal 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<br>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<br>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. [(c)] |

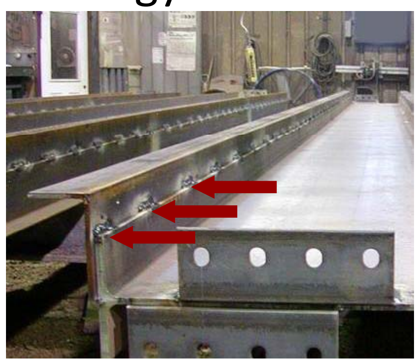
(Part of Table J2.5 AISC 2005)

- 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



# Welding Terminology

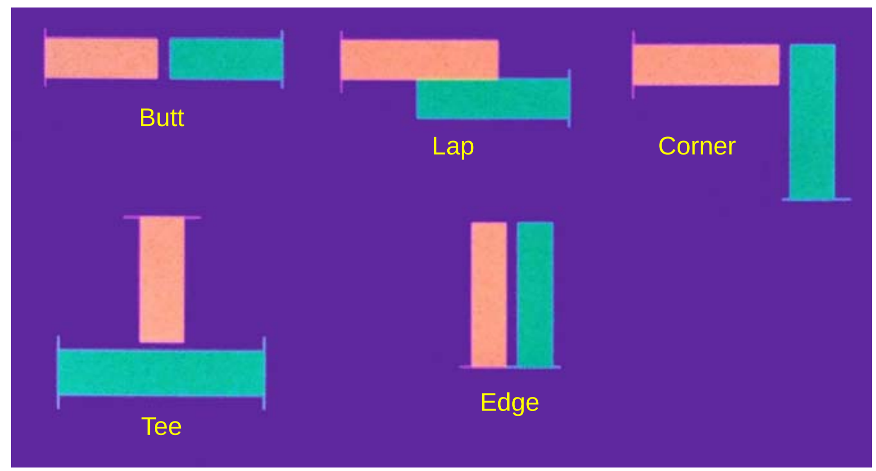




- Tack Weld (above left)
  - A temporary weld used to hold parts in place while more extensive, final welds are made
- Continuous Weld
  - A weld which extends continuously from one end of a joint to the other
- Stitch Weld (above right)
  - A series of welds of a specified length that are spaced a specified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

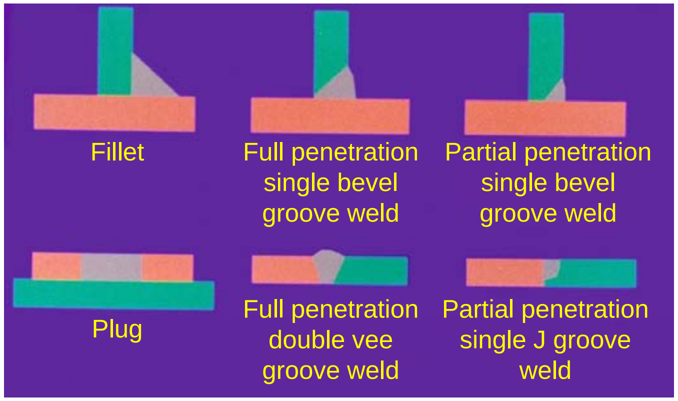


# Welding Terminology




- 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)

# Welding Terminology

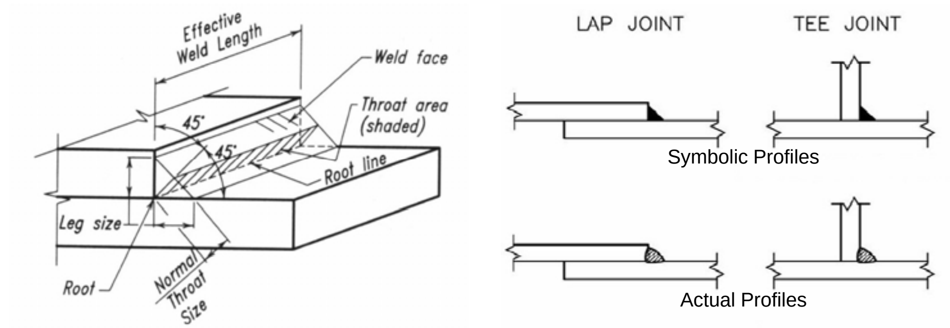



- Weld types define the configuration of the weld and its underlying design approach
- Fillet welds and groove welds are most common
- Groove welds fall into two categories
  - Full penetration – the entire member cross-section is welded
  - Partial penetration – just part of the member cross-section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

(AISC)



# Fillet Welds

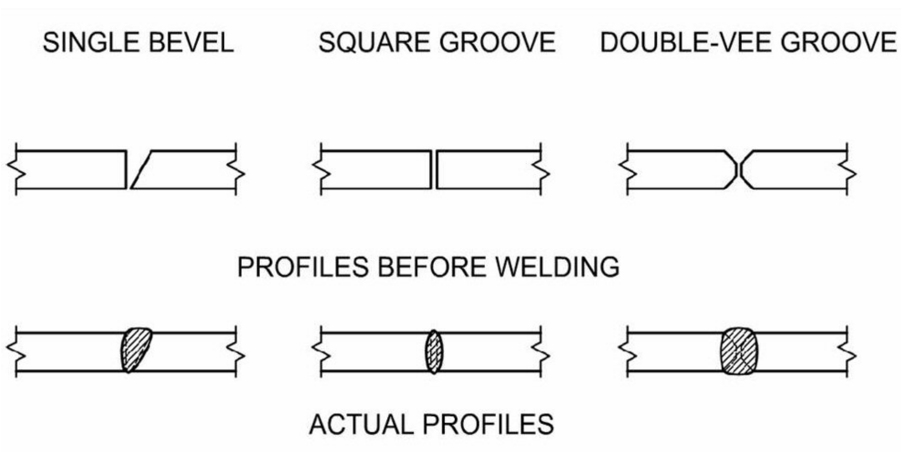



- The most commonly used weld is the fillet weld
- Fillet welds are theoretically triangular in cross-section
- Fillet welds join two surfaces at approximately right angles to each other in lap, tee, and corner joints

(AISC & NISD 2000)



# Groove Welds

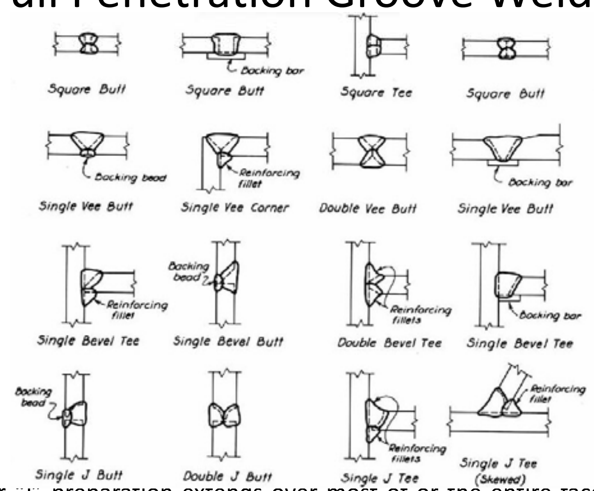



- Groove welds are specified when a fillet weld is not appropriate for the job
  - The configuration of the pieces may not permit fillet welding
  - A strength greater than that provided by a fillet weld is required
- Groove welds are made in the space or groove between the two pieces being welded

(AISC & NISD 2000)



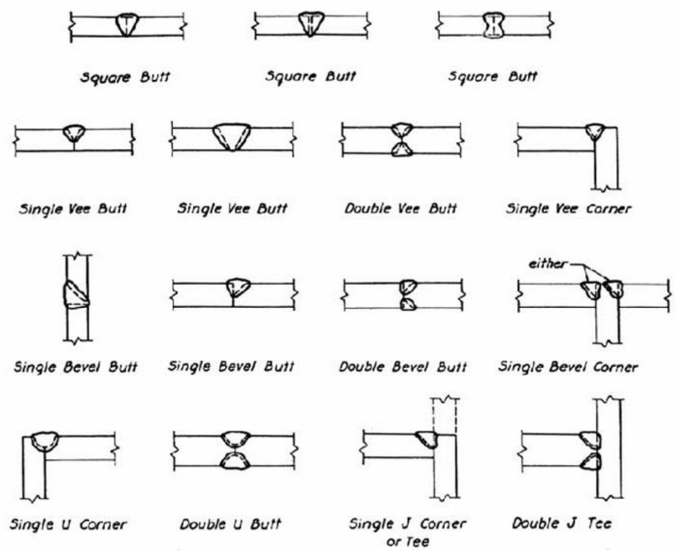
# Full Penetration Groove Welds




- The bevel or "J" preparation extends over most of 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

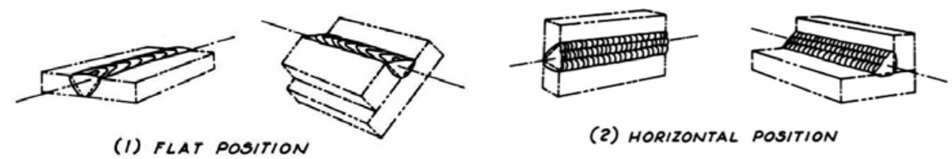



Partial joint penetration welds are used when it is not necessary for the strength of the joint to develop the full cross section of the members being joined

(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)



# Weld Symbols

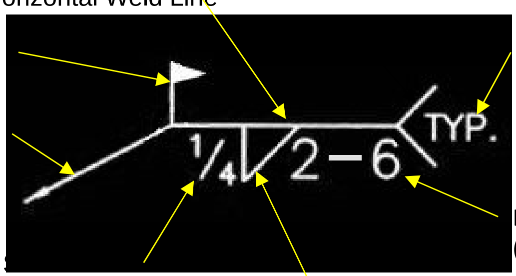
- Weld symbols are used to communicate the specific details and requirements of each weld to the welder
- Weld symbols are included on fabrication and erection drawings

**Basic Weld Symbols**

| Back | Fillet | Plug or Slot | Groove or Butt: Square | V | Bevel | U | J | Flare V | Flare Bevel |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

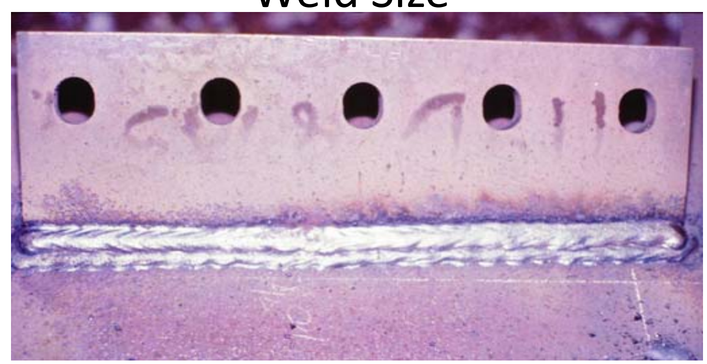
**Supplementary Weld Symbols**

| Backing | Spacer | Weld All Around | Field Weld | Contour: Flush | Convex | For other basic and supplementary weld symbols, see AWS A2.4 |
|---|---|---|---|---|---|---|
| | | | | | | |





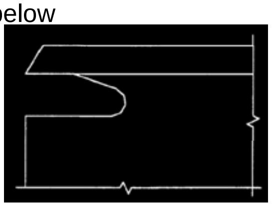

# Weld Size



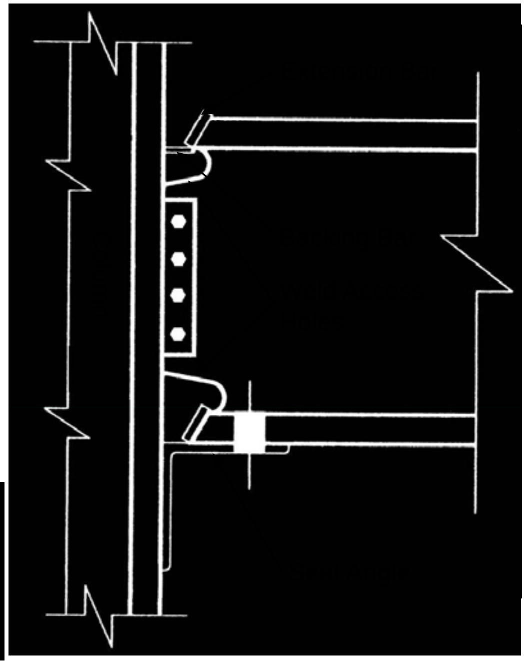
- The size of a weld must match the size specified on the drawings
- Some welds may meet the required size after a single pass of the welder
- Larger weld sizes may require multiple passes to meet the size requirement
- Common single pass welds include fillet welds up to and including 5/16 inch and thin 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

# 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)

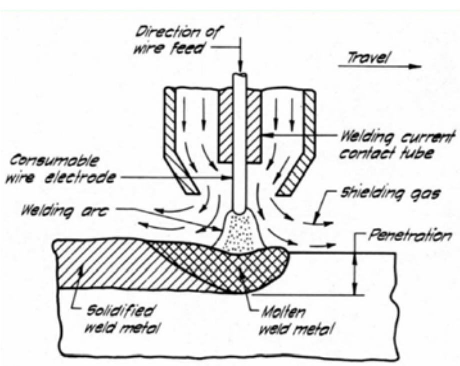


# SMAW Welding

- 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)



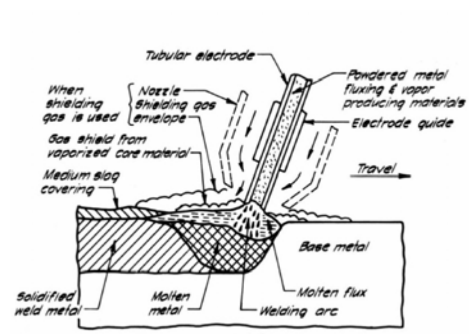
# GMAW Welding




- 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)



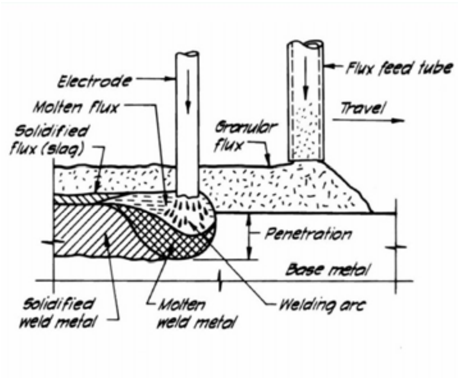
# FCAW Welding




- 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)

# 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)



# Welding Equipment

- Equipment used for welding will vary depending on the welding process and whether the welding is being done in the shop or in the field
- A Flux Cored Arc Welding machine for shop welding is pictured above left
- A Shielded Metal Arc Welding machine for field welding is pictured above right

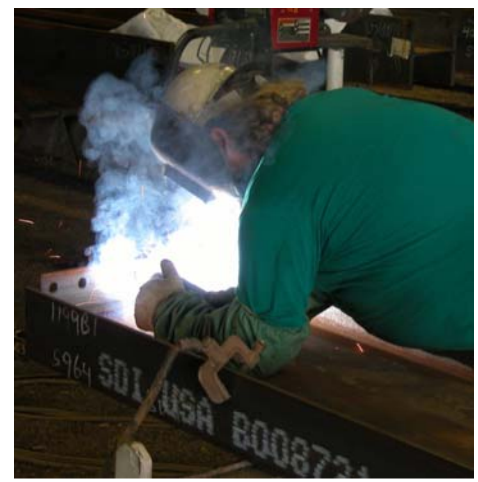


# Weather Impacts on Welding

- Welding in the field is avoided if possible due to welding condition requirements
- Field welding is not to be performed while it is raining, snowing, or below 0° F
- In certain ambient temperatures preheating of the material to be welded is required
- AWS Code D1.1 (2004b) specifies minimum preheat and interpass temperatures, which are designed to prevent cracking



# Welding Safety



- It is important for both the welder and those working in the area around a welding process to be safety conscious
- The welding arc should never be looked at with the naked eye
- AWS publishes many safety and health fact sheets which are available for download at their web site: www.aws.org

# Welding Safety

- Helmet
- Face shield or goggles
- Gloves
- Boots
- Heavy fabric or leather shirt
- Cuffless pants
- Leather leggings



# Welding in Existing Structures

Welding to existing structures during retrofit projects requires careful consideration of numerous factors:

- Determine weldability – Identify the steel grade to establish a welding procedure
- Select and design the weld – Fillet welds are preferred and avoid over welding
- Surface preparation – Remove contaminants such as paint, oil, and grease
- Loads during retrofit – An engineer should determine the extent to which a member will be permitted to carry loads while heating, welding, or cutting
- Fire hazards – Follow all governing fire codes, regulations, and safety rules to avoid fires
- For complete details see the AISC Rehabilitation and Retrofit Guide (2002b)



# 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
  - Porosity
  - Cracks
  - Insufficient penetration
  - Wrong size
  - Poor workmanship

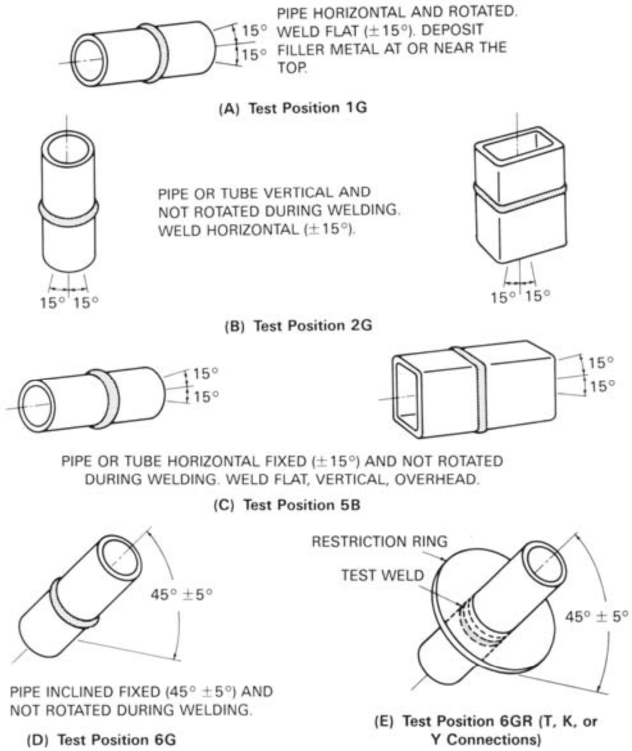


# Visual Inspection

- 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)

# Welding of Tubular Structures






# 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



## *Porosity*

- Caused by gases released during melting of the weld area but trapped during solidification, chemical reactions, Contaminants
- They are in form of spheres or elongated pockets
- Porosity can be reduced by
- Proper selection of electrodes
- Improved welding techniques
- Proper cleaning and prevention of contaminants
- Reduced welding speeds

## *Slag Inclusions*

- Compounds such as oxides ,fluxes, and electrode-coating materials that are trapped in the weld Zone
- Prevention can be done by following practices :
- Cleaning the weld bed surface before the next layer is deposited
- Providing enough shielding gas
- Redesigning the joint

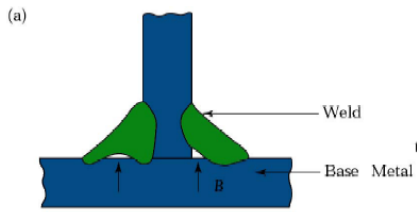


## *Incomplete Fusion and Penetration*

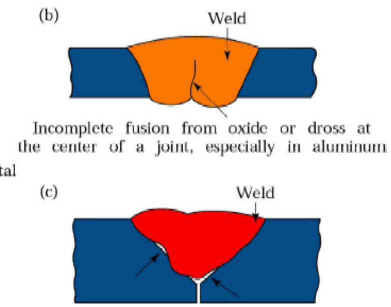
- Produces lack of weld beads
- Practices for better weld :
- Raising the temperature of the base metal
- Cleaning the weld area, prior to the welding
- Changing the joint design and type of electrode
- Providing enough shielding gas

# 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




Incomplete fusion in fillet welds. B is often termed 'bridging'




Incomplete fusion in a groove weld



# Weld Profile:

- Under filling results when the joint is not filed with the proper amount of weld metal.
- Undercutting results from the melting away of the base metal and consequent generation of a groove in the shape of a sharp recess or notch.
- Overlap is a surface discontinuity usually caused by poor welding practice and by the selection of improper material.



# Discontinuities in Fusion Welds

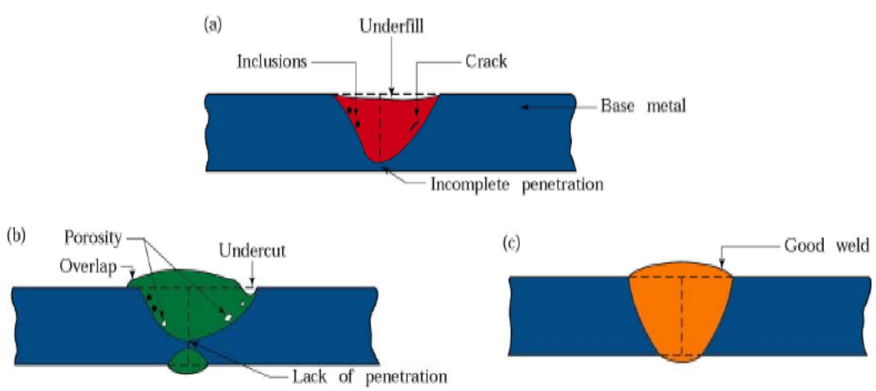



Fig : Schematic illustration of various discontinuities in fusion welds.



# Cracks

- Cracks occur in various directions and various locations

Factors causing cracks:

- Temperature gradients that cause thermal stresses in the weld zone
- Variations in the composition of the weld zone.
- Embrittlement of grain boundaries
- Inability if the weld metal to contract during cooling

# Cracks

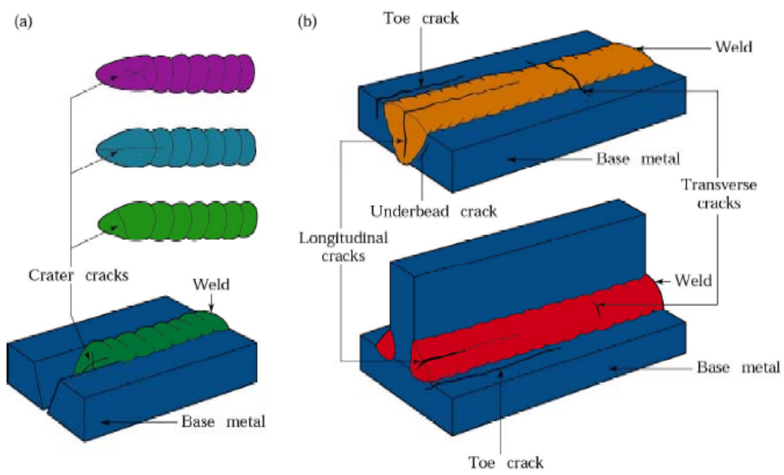



Fig : Types of cracks (in welded joints) caused by thermal stresses that develop during solidification and contraction of the weld bead and the surrounding structure. (a) Crater cracks (b) Various types of cracks in butt and T joints.



# Cracks

- Cracks are classified as Hot or Cold.
- *Hot cracks* – Occur at elevated temperatures
- *Cold cracks* – Occur after solidification
- Basic crack prevention measures :
- Change the joint design ,to minimize stresses from the shrinkage during cooling
- Change the parameters, procedures, the sequence of welding process
- Preheat the components to be welded
- Avoid rapid cooling of the welded components



# Cracks in Weld Beads

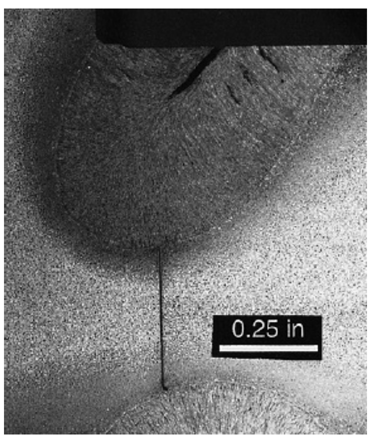



Fig : Crack in a weld bead, due to the fact that the two components were not allowed to contract after the weld was completed.



# Lamellar tears :

- Occurred due to the shrinkage of the restrained components in the structure during cooling.
- Can be avoided by providing for shrinkage of the members
- Changing the joint design
- Surface Damage : These discontinuities may adversely affect the properties of welded structure, particularly for notch sensitive metals.

## Residual Stresses:

- Caused because of localized heating and cooling during welding, expansion and contraction of the weld area causes residual stresses in the work piece.
- Distortion,Warping and buckling of welded parts
- Stress corrosion cracking
- Further distortion if a portion of the welded structure is subsequently removed
- Reduced fatigue life



## Distortion after Welding

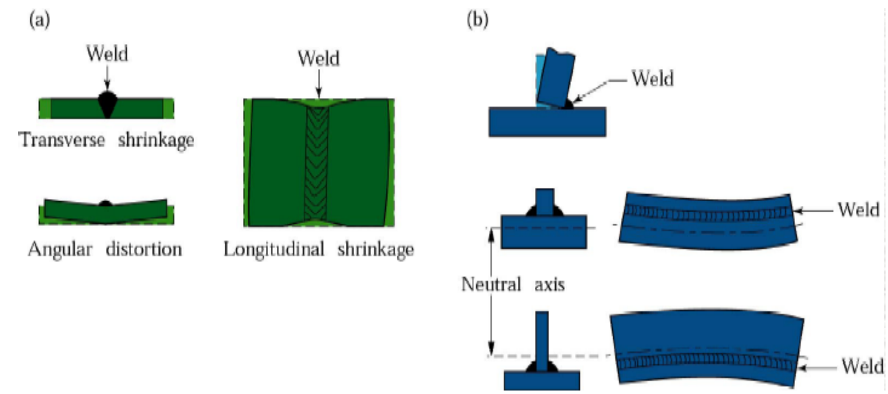



Fig : Distortion of parts after welding : (a) butt joints; (b) fillet welds. Distortion is caused by differential thermal expansion and contraction of different parts of the welded assembly.



## Residual Stresses developed during welding

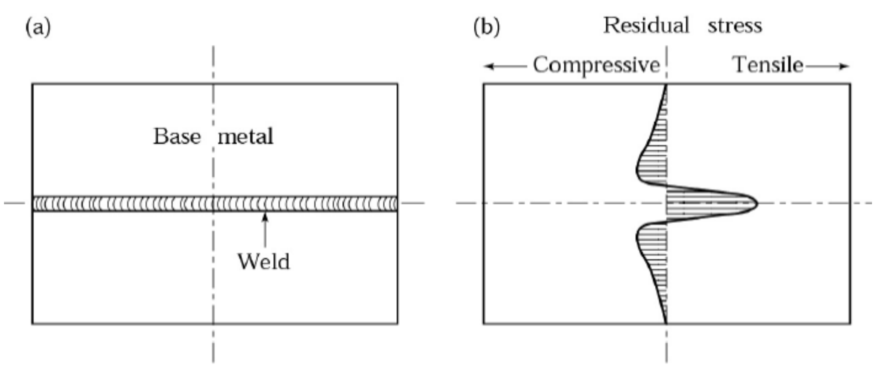



Fig : Residual stresses developed during welding of a butt joint.



## 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

## Welding Cost Considerations

- Fillet weld is less expensive than groove weld
  - No special preparation
  - No backing required
  - Less volume of weld
- Partial penetration groove weld is less expensive than full penetration groove weld
- Labor represents the majority of the cost associated with welding



## Bolting and Welding Scheduling Considerations

- Bolting is generally a faster operation than welding
- Bolting does not have the temperature and weather condition requirements that are associated with welding
- Unexpected weather changes may delay welding operations



# 6400. Fabrication and Construction -

## 6430. AWS D1.1 Structural Welding Code

### Objective and Scope Met

- Design of Welded Connections
- Technique (Shielded Metal Arc Welding; C-Submerged Arc Welding; Gas Metal Arc and Flux Cored Arc Welding; Electroslag and Electrogas Welding; Plug and Slot Welds; Stud Welding)
- Qualification and Inspection
- Tubular Structures
- Strengthening and Repairing Existing Structures