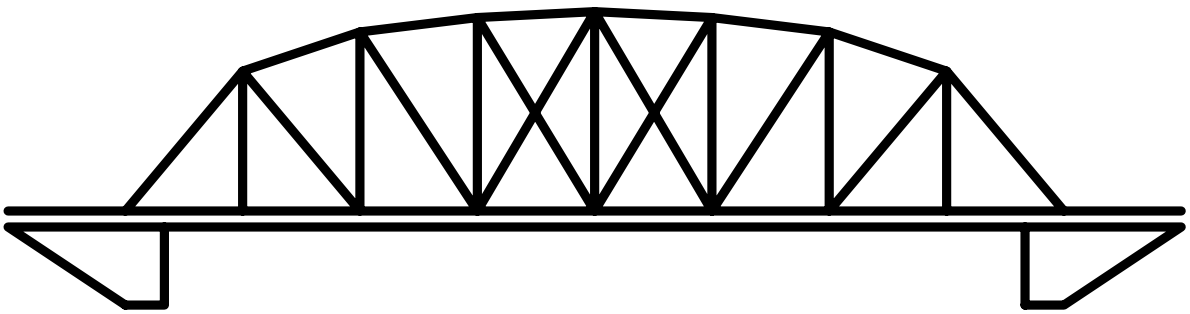
APPENDIX F

GUIDELINES FOR WELDING STRUCTURAL STEEL FOR BRIDGES



APPENDIX F
GUIDELINES FOR WELDING STRUCTURAL STEEL FOR BRIDGES

I. ***Applicable Specifications***

A. **New York State Steel Construction Manual** (NYSSCM)
1. Primary specification governing fabrication and erection of most structural steels.
   a. Welding
   b. Base metal
   c. Shop Drawings
   d. Fabrication
   e. Inspection
   f. Erection
   g. Nondestructive Testing

B. **AWS D1.5 Bridge Welding Code**
1. Used only for those applications not governed by NYSSCM.
   a. Welding A852M steel

C. **AASHTO Guide Specification for Highway Bridge Fabrication with HPS485W Steel.**
1. For welding HPS485W steel.

II. ***Determine Weldability or Special Welding Concerns for the Base Metal***

A. **ASTM A7M** (227 MPa min yield)
1. Carbon Steel Plates, Shapes and Bars
2. Found on most existing (1950's) NYSTA bridges
3. Weldability concerns
   a. Check the carbon equivalent of the steel before welding.
      (1) C_{eq} = %C+%Mn/4+%Si/4, or
      = %C+%Mn/6+%Ni/15+%Mo/5+%Cr/5+%Cu/15+%V/5
      (2) If C_{eq} = > 0.45, use 204º C preheat
   b. Alternatively, always use 204º C preheat

B. **ASTM A373M** (220 MPa min yield)
1. Structural Steel for Welding
2. Discontinued, replaced with A36M steel

C. **ASTM A94M** (310 MPa min yield)
   1. High Strength Structural Silicon Steel Shapes, Plates and Bars.
   2. When welding is allowed, must use special techniques.
   3. **SEEK ADVICE BEFORE ALLOWING ANY WELDING.**

D. **ASTM A36M** (250 MPa min yield)
   1. Carbon Steel Plates, Shapes and Bars for Structural Use
   2. Use routine welding procedures

E. **ASTM A572M Grade 345** (345 MPa min yield)
   1. High Strength Low Alloy Columbium Vanadium Steel Plates, Shapes and Bars.
   2. Use routine welding procedures.

F. **ASTM A588M** (345 MPa min yield)
   1. High Strength Low Alloy Structural Steel Plates, Shapes and Bars.
   2. Can be used in unpainted applications in certain environments.
   3. Minimum heat input requirements
      a. 35 kilojoules up to 19 mm thick.
      b. 50 kilojoules for 19 mm and over.
   4. Must match corrosion resistance and color of weld metal for unpainted applications.

G. **ASTM A709M**
   1. Carbon and High Strength Low Alloy Structural Steel Plates, Shapes & Bars, and Quenched and Tempered Steel Plates for use in Bridges.
   2. Available in Grades 250, 345, 345W, HPS485W, 690 and 690W (Similar to ASTM designations A36M, A572M, A588M, A852M and A514M respectively).
   3. Certain grades require special welding techniques.
   4. **SEEK ADVICE BEFORE SPECIFYING WELDING DETAILS ON GRADES HPS485W, 690 AND 690W.**

H. **ASTM A852M** (Quenched and Tempered High Strength Low Alloy Structural Steel Plates – 485 MPa minimum yield).
   1. Requires special welding techniques.
   2. Requires special control of both minimum and maximum preheat and interpass temperatures.
   3. **SEEK ADVICE BEFORE SPECIFYING WELDING DETAILS.**

I. **Other Steels**

1. ASTM A53M Type S Grade B (240 MPa min yield)
   a. Seamless Steel Pipe
   b. Types E, Type F Grade A & B and Type S Grade A not allowed by specification.
   c. Use routine welding procedures.
2. a. ASTM A242M (290-345 MPa min yield)
   b. High Strength Low Alloy Structural Steel Plates, Shapes and Bars.
   c. Can be used in unpainted applications in certain environments (2X more corrosion than carbon steel).
   d. Higher preheat requirements
   e. Weld the same as ASTM A588M steel.
3. ASTM A252M Grade 2 (240 MPa min yield)
   a. Steel Pipe Piles
   b. Use routine welding procedures.
4. ASTM A441M (290-345 MPa min yield)
   a. High Strength Low Alloy Manganese Vanadium Steel Plates, Shapes and Bars.
   b. Discontinued in 1989.
   c. Replaced with ASTM A572M steel.
   d. Use routine welding procedures.
5. ASTM A500M Grade B (290-317 MPa min yield)
   a. Cold Formed Welded & Seamless Carbon Steel Structural Tubing.
   b. Grades A, C & D not permitted by specification.
   c. Use routine welding procedures.
6. ASTM A501M Grade B (250 MPa min yield)
   a. Hot Formed Welded & Seamless Carbon Steel Structural Tubing.
   b. Use routine welding procedures.

III. ***Types of Welding Processes***

A. **Manual Shielded Metal Arc Welding**

1. Consumable "Stick" electrode placed in an electrode holder and completely manipulated by a welder

B. **Semiautomatic Flux Cored Arc Welding or Submerged Arc Welding**

1. Hand held equipment that controls the wire feed only
2. The advance of welding (travel speed) is manually controlled by the welder

C. **Automatic Flux Cored Arc Welding or Submerged Arc Welding**
   1. Welding equipment that controls the wire feed and travel speed without constant adjustment by the welding operator
   2. May be stationary or "tractor mounted"

IV. ***Welding Processes***

A. **Manual Shielded Metal Arc Welding** (SMAW or Stick)
   1. Must be low hydrogen electrodes (ex, E-7018, E-8018 C3)
      a. Designation definitions.
         (1) **E** = AWS electrode
         (2) **70** = tensile strength (ksi)
         (3) **X** = position (1=F,H,V,O; 2=F,H; 3=F)
         (4) **X** = coating type
         (5) **C3** = contains 1% nickel, has impact properties
   2. Approved low hydrogen electrodes.
      a. AWS E-7016
         (1) Operates on AC or DC current.
         (2) May be used in any position.
      b. AWS E-7018
         (1) Operates on AC or DC current.
         (2) Most commonly used in the field.
         (3) May be used in any position.
         (4) 25% Iron Powder in coating increases deposition rate.
      c. AWS E-7028
         (1) Operates on AC or DC current.
         (2) May be used in flat and horizontal welds only.
         (3) Prohibited from use in the root pass of groove welds.
      d. AWS E-8018-C3
         (1) Operates on AC or DC current.
         (2) Used for multi-pass welds on unpainted A588M steel to obtain corrosion resistant properties.
         (3) May be used in any position.
      e. AWS E-9018MR
         (1) Used for welding HPS485W Steel
   3. Must be delivered in hermetically sealed containers.
   4. Electrode Sizes
      a. Maximum electrode diameter
         (1) 6.4 mm for all welds made in the flat position, except root passes.
         (2) 6.4 mm for all horizontal welds.

(3) 4.8 mm for root passes of groove welds made in the flat position with backing and with an opening of 6 mm or more.
(4) 4.0 mm for welds made in the vertical and overhead positions.
(5) 4.8 mm for root passes of groove welds and all other welds not included above.

b. (1) Minimum Electrode Diameter
(2) None specified in codes.
(3) 4.0 mm preferred to maintain minimum heat input.

5. Electrodes must be properly dried before use.
   a. 2 to 4 hours at 230º to 260º C in an approved electrode drying oven.
   b. After drying, must be placed in a storage oven at 120º C until used.
   c. Once removed, electrodes not used within 4 hours maximum must be discarded, or they must be redried for 1 hour at a temperature between 370º and 425º C.
   d. Maximum size of weld passes
   e. (1) Single pass fillet welds and root passes of multiple pass fillet welds.
      (2) 10 mm in the flat position.
      (3) 8 mm in the horizontal and overhead positions.
      (4) 12 mm in the vertical position.
   f. Maximum thickness of root passes in groove welds.
      (1) 6 mm in any position.
   g. Maximum thickness of layers subsequent to root passes of groove welds and multiple pass fillet welds.
      (1) 3 mm in the flat position.
      (2) 5 mm in the horizontal, vertical or overhead positions.
6. May be used in the **shop** or **field** for;
   a. Short or inaccessible welds where it is not practical to use automatic or semiautomatic welding equipment.
   b. Welding connection plates to rolled beams.
   c. Temporary and tack welds
   d. Repair welding
   e. Bearing Assemblies
7. The progression of all vertical welding must be UP

B. **Flux Cored Arc Welding** (FCAW)
1. Must be AWS E7XT-1 or E7XT-5 classification
   a. Designation definitions.
      (1) **E** = AWS electrode
      (2) **7** = 70,000 psi tensile strength
      (3) **X** = position (1=F,H,V,O; 2=F,H)
      (4) **T** = Tubular electrode
      (5) **1** = coating type
2. Shielding is provided by a flux contained within the electrode.
3. Specification requires an additional external gas shield, most commonly CO^2.
4. Must not be used in a draft or wind exceeding 2.2 m/s.
5. Not recommended for use in field applications.
6. Semiautomatic most commonly used in the shop for:
   a. Tack welding
   b. Welding secondary members
   c. Welding connection plates to rolled beam girders.
   d. Other short, difficult to access or out of position welds.
7. May be used as an automatic process, except the following must be considered:
   a. high intensity of arc rays.
   b. excess amount of smoke.
8. Welders and welding operators must have access to a power chipper or needle descaler and an air carbon arc gouger at all times.
9. Electrode Sizes
   a. Maximum electrode diameter:
      (1) 4.0 mm for all welds made in the flat or horizontal position.
      (2) 2.4 mm for all vertical welds.
      (3) 2.0 mm for welds made in the overhead position.
10. Maximum size of weld passes.
   a. Single pass fillet welds:
      (1) 12 mm in the flat and vertical positions.
      (2) 10 mm in the horizontal position.
      (3) 8 mm in the overhead position.
   b. Maximum thickness of all layers:
      (1) 6 mm in any position.

C. **Submerged Arc Welding** (SAW)

1. May be one of many AWS classifications. (See NYSSCM Table 706.1)
   a. Designation definition. (ex. F7A2-EM12K)
      (1) **F** = Flux
      (2) **7** = 70-95 ksi tensile strength
      (3) **A** = As Welded
      (4) **2** = CVN toughness requirement (20ft#@-20º F)
      (5) **E** = AWS electrode
      (6) **M** = Medium Manganese
      (7) **12** = 0.12% nominal carbon
      (8) **K** = Killed steel
2. The arc and molten metal is shielded by a blanket of fusible granular material called flux.
   a. No visible arc.
   b. The weld is made without flash, spatter or sparks.
   c. Very little smoke or visible fumes are produced.
3. May be used in the shop or field for groove welds in the flat position and fillet welds in the flat and horizontal positions only.
4. Most commonly used for principal welds.
   a. Plate Girders
      (1) welding flange and web splices.
      (2) welding flange to web fillet welds.
      (3) welding stiffeners and connection plates to the web.
   b. Rolled Beam Girders
      (1) welding cover plate to flange fillet welds.
      (2) welding connection plates to the web.
5. Maximum electrode diameter:
   a. 6.4 mm for flat and horizontal positions
6. Maximum size of weld passes:
   a. The depth or the width in cross section cannot exceed the width of the face.

V. ***Welding Symbols***

A. **Welding symbol definition.**

1. See the attached AWS Chart.

VI. ***Welding Positions***

A. **See NYSSCM Figures 810 a, b, and c for definitions**
1. Flat
2. Horizontal
3. Vertical
4. Overhead

VII. ***Welding Certification and Qualification Documentation***

A. **Welder & Welding Operator Certification**
1. Welder - definition.
   a. A person who performs a manual or semiautomatic welding operation.
   b. Shop Welder
      (1) A person employed by the contractor or fabricator to perform welding in a fabrication plant.
      (2) Must be qualified by tests conducted at the plant and witnessed by an independent inspection agency.
      (3) Qualification valid for three years from date of acceptance, providing there is no more than a six month lapse of service within this period.
   c. Field Welder
      (1) A person employed by the contractor or fabricator to perform welding in the field.
      (2) Must be qualified by tests conducted by NYSDOT.
      (3) Must have a current NYSDOT certificate only.
2. Welding Operator - definition.
   a. A person who operates automatic welding equipment.
   b. Shop Welding Operator:
      (1) A person employed by the Contractor or fabricator to operate welding equipment in a fabrication plant.
      (2) Must be qualified by tests conducted at the plant and witnessed by an independent inspection agency.
      (3) Qualification valid for three years from date of acceptance, providing there is no more than a six month lapse of service within this period.
   c. Field Welding Operator:
      (1) A person employed by the contractor or fabricator to operate welding equipment in the field.
      (2) Must be qualified by tests conducted by NYSDOT.
      (3) Must have a current NYSDOT certificate only.

B. **Procedure Qualification Record** (PQR) (NYSSCM Figure 801a)
   1. PQR - definition.
      a. A test to determine the validity of a specific set of welding parameters for the welding process.
      b. Basis for approval of the Welding Procedure Specification (WPS).
      c. Valid for 3 years from the date of acceptance.
   2. When is a PQR required?
      a. Each Contractor/Fabricator must perform a separate test for each electrode or electrode/flux combination, except;
      b. Not required for manual SMAW, providing the welding parameters conform to manufacturer's recommendations.

C. **Welding Procedure Specification** (WPS) (NYSSCM Figure 704)
   1. WPS - definition.
      a. A recipe for making a weld.
      b. The document details specific parameters for welding a given joint using a given weld process.
      c. Must be approved for each joint and weld process.
      d. Based on an approved PQR.
      e. The approved WPS communicates the approved welding parameters to the welder, welding operator and inspector.
   2. When is a WPS required?
      a. Always
         (4) For each type of joint to be used in the work.
         (5) For each welding process.
         (6) For each electrode or electrode flux combination.

VIII ***Fillet Welds*** (See NYSSCM Art. 703.1)

A. **Have a equilateral triangular cross section** and are applied to the surface of material they join.

B. **The size is determined by measuring the leg size.**

C. **Maximum Size** (leg)
   1. Equal to the thickness of the base metal for material less than 6 mm thick.
   2. Equal to 2 mm less than the thickness of the base metal for material 6 mm or more in thickness.

D. **Minimum Size**
   1. 6 mm for Bridges.
   2. Varies based on the thickness of the thicker part joined.

E. **Minimum Length**
   1. 4 times the weld size or 38 mm, whichever is greater.

IX ***Complete Penetration Groove Welds***

A. **See NYSSCM Article 703.3 for specific types and parameters.**

B. **Have a throat thickness equal to the material they join.**
   1. Requires backgouging if made from both sides.
   2. Requires backing if made from one side.
      a. Backing must be steel.
      b. Backing must be continuous.
      c. Backing on welds transverse to the direction of computed stress must be removed and the joint ground flush.

X ***Partial Penetration Joints***

A. **Not allowed for use on main stress carrying members.**

XI ***Temporary and Tack Welds***

A. **In tension areas of main members.**
   1. Tack welds not incorporated in a final weld are not permitted on girder flanges subject to tensile stress.
   2. Temporary welded attachments to tension areas are prohibited.
   3. The contract plans should define the location of tension areas.

B. **Preheat**
   1. Always required unless the tack weld and adjacent heat affected zone is remelted and incorporated into a final submerged arc weld.
   2. Always required when welding in the field.

C. **Always discourage temporary or tack welds in the field.**
   1. Temporary or tack welds not incorporated into a final weld must be removed flush with the original surface.
   2. Weld removal areas must be inspected by Magnetic Particle Inspection.

3. Weld removal sites must be hardness tested.
   a. Areas harder than Rockwell C27 are unacceptable.

XII ***Stud (SHEAR CONNECTOR) Welds***

A. **Studs must be welded with automatically timed stud welding equipment.**

1. SMAW may be used with specific approval, providing;
   a. Welding is done with 4.0 mm diameter E-7018 electrodes.
   b. The fillet weld size must be 8 mm minimum.
   c. The stud base is prepared so that the outside circumference fits tightly against the base metal.
   d. All rust and mill scale is removed from the base metal by blasting or grinding.
   e. The base metal is properly preheated.
   f. All fillet welds are of acceptable quality as defined in Section 7 of the NYSSCM.

B. **At the time of welding, the studs and the base metal must be free of scale, rust, dirt, paint, grease or other foreign material.**

C. **Welding must not be done when the base metal temperature is below -18ºC.**
   1. Increased testing must be done when the base metal temperature is less than 0º C.

XIII ***Field Welding versus Shop Welding.***

A. **Preheat requirements:**
   1. Preheat based on grade of steel and thickness of base metal for shop welding (See Table 708).
   2. Minimum preheat for field welding is 120º C for all but ASTM A7M steel.
   3. Minimum preheat of 200º C must be used for ASTM A7M steel unless carbon equivalent tests are performed.

B. **Welder Certification:**
   1. Field welders must have current NYSDOT Certificate for the thickness and position to be used in the work.
   2. Shop welders do not carry certificates. Qualification is based on a letter from an independent inspection agency, approved by the owner.

C. **Welding Processes:**
   1. Field welding is routinely limited to manual SMAW.
   2. FCAW is not recommended for use in the field.
   3. SAW is used in the field for certain applications.

XIV *Welding Fracture Critical Members*

A. **Specification:**
   1. Section 9 of the NYS Steel Construction Manual.

B. **Base Metal:**
   1. Plates and shapes must be produced to fully killed fine grain practice.
   2. All plates must be rolled on a sheared mill.
   3. All plates must have oxygen cut edges.
   4. All plates and shapes must have improved toughness;
      a. P frequency tests must be performed at both ends of the plate or shape.
      b. Increased toughness requirements.

C. **Welding Processes:**
   1. SMAW and SAW may be used.
   2. FCAW may only be used with written approval.
      a. **SEEK ADVICE BEFORE APPROVING FCAW.**

D. **Welding:**
   1. Preheat and interpass temperatures are increased.
   2. Tests for diffusible hydrogen of deposited weld metal must be performed by the electrode/flux manufacturer using consumables to be used in the work.
   3. SAW flux must be baked at 285º C and stored at 120º C until used in the work.

E. **Welding Procedure Qualification:**
   1. Must be performed less than 6 months prior to the start of fabrication.
   2. One test performed at "T" equal to 1" and another at "T" equal to the maximum thickness to be used in the work, plus a test for fillet welds is required.

F. **Welders, Welding Operators and Tackers** must be qualified by tests less than 6 months prior to the start of fabrication, unless routinely qualified annually.

G. **Repairs:**
   1. May be Category I, II or III, depending on the type of discontinuity.
      a. Category I repairs may be made without documentation or prior approval.
      b. Category II repairs require documentation, but may be repaired by pre-approved procedures.
      c. Category III repairs may be made only after approval on an individual basis.
   2. Documentation:
      a. Full size shop drawing describing the repair.
      b. Category III repairs must accurately describe the location of the discontinuity in the member.

H. **Inspection:**
   1. Radiographic;
      a. More sensitivity required.
      b. "FCM" must appear on each radiograph.
   2. Ultrasonic;
      a. When t => 13 mm, all joints required to be radiographed must also be ultrasonically tested.
      b. All discontinuities with an indication rating more serious than +15 must be reported.
   3. Magnetic Particle;
      a. Must be performed with a yoke.

XV ***Weld Quality***

A. **Acceptable Weld Profiles:**
   1. See NYSSCM Figure 723

B. **Unacceptable Weld Profiles:**
   1. See NYSSCM Figure 723

C. **Discontinuities vs. Defects:**
   1. A discontinuity must be evaluated to a standard or code.
   2. Certain discontinuities are always defects.
   3. Discontinuities that are acceptable by a standard or code remain discontinuities.
   4. Discontinuities that are unacceptable by a standard or code are defects.
   5. A weld is considered acceptable by visual inspection if it conforms to the provisions of NYSSCM Article 724.1.

6. A weld is considered acceptable by other nondestructive inspection if, after testing and evaluation, it conforms to the requirements for visual inspection, plus it meets the minimum acceptance standards of the appropriate section of the NYSSCM, as described in Section 16, Radiographic Testing; Section 17, Ultrasonic Testing; Section 18, Magnetic Particle Inspection; or Section 19, Dye Penetrant Inspection.

XVI ***Basic Terminology***

A. **Air Carbon Arc Gouging:**
   1. A process for metal removal where an electric arc melts the base metal and a high velocity stream of compressed air blows it away.
   2. May be done manually or mechanically.
   3. May be used for backgouging or cutting.
   4. Must always be followed by grinding to remove carbon pickup and slag.

B. **Backgouging:**
   1. The removal of weld and base metal from the second side of a joint to assure complete penetration after welding from the second side.
   2. May be done by air carbon arc gouging or grinding.
   3. The root of the gouge must have a 6 mm minimum radius
   4. The sides of the gouge must slope back at a 20º minimum angle

C. **Interpass Temperature:**
   1. For multiple pass welds, the temperature (minimum or maximum) of the deposited weld immediately before the next pass is started.
   2. The minimum interpass temperature is the same as the minimum preheat.
   3. The maximum interpass temperature is as stated in the WPS, if applicable.
   4. Interpass temperature for welding ASTM A852M steel must be limited to 220º C maximum.

D. **Preheat:**
   1. The application of heat to bring the temperature of the steel to a specified minimum immediately prior to the start of welding or cutting operations.
   2. All field welding must be done with a minimum preheat and interpass temperature of 120º C, except that;
      a. A7M steel should be preheated to 200º C.
      b. A242M and A588M steel may require higher preheat and interpass temperatures, depending on thickness.
   3. Preheat must be controlled by the use of temperature indicating crayons.

4. Preheat must be measured at least 75 mm laterally and in advance of the weld, and on the far side of the base metal.
5. In general, preheat and interpass temperature should not exceed 260º C.

E. **Polarity of DC Current:**
1. A definition of the direction of current flow.
2. Reverse (+) Polarity;
   a. Electrode connected to the positive terminal of a DC power source.
   b. Work lead is connected to the negative terminal.
3. Negative (Straight) Polarity.
   a. Electrode connected to the negative terminal of a DC power source.
   b. Work lead is connected to the positive terminal.

F. **Toughness:**
1. A measure of the impact strength in ft lbs. of steel or weld metal.

XVII *Nondestructive Testing*

A. **Radiographic Testing** (RT):
1. X- or gamma rays are passed through a weld and base metal to expose a photographic film on the far side of the material.
2. Sensitive to slag, porosity, fusion and penetration type defects.
3. Crack detection may be difficult.
4. Primarily used in the shop.
5. Required method of test for all butt joints in primary tension members.
6. Radiographic film becomes a permanent record of quality.
7. Safety concerns;
   a. Regulated by OSHA.
   b. Regulated by Nuclear Regulatory Commission.
   c. Technicians must be certified ASNT Level II.

B. **Ultrasonic Testing** (UT):
1. High frequency sound waves are passed through weld and base metal.
2. Indications appearing on the instrument screen must be interpreted and evaluated by the UT technician.
3. Most sensitive to cracks, fusion and penetration defects oriented normal to the sound beam.
4. Least sensitive to porosity type discontinuities.
5. May be used in the shop or field.
6. Test results dependent on the ability of the operator.

7. Technicians must be NYS certified;
   a. A list of Certified Technicians is maintained in the Structural Design Bureau.
8. Cannot be used to test fillet welds.

C. **Magnetic Particle Inspection** (MP):
1. A magnetic field is established in the base metal.
2. Iron powder filings are sprayed over the magnetic field.
3. Filings gather to form a discontinuity indication at a break in the magnetic field.
4. Sensitive to surface and near surface discontinuities.
5. Yoke technique preferred.
6. Specification permits prod technique.
7. Can be used in the shop or field.
8. Technicians must be ASNT certified.
9. Material being tested must be ferromagnetic.

D. **Dye Penetrant Inspection** (DP):
1. A colored dye is sprayed on the weld and base metal surface.
2. The excess dye is removed and a spray developer applied.
3. Sensitive to surface discontinuities.
4. Can be used in the shop or field.
5. Useful for materials that are non-magnetic.

E. **Visual Inspection:**
1. The most frequently used test method for shop and field.