NEW YORK STATE
STEEL CONSTRUCTION
MANUAL

DEPARTMENT OF TRANSPORTATION
James L. Larocca, Commissioner

OFFICE OF ENGINEERING
STRUCTURES DESIGN AND CONSTRUCTION DIVISION

Prepared by the METALS ENGINEERING UNIT
of the Construction Services Section
Warren G. Alexander, Supervisor

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SECTION 1
INTRODUCTION

The New York State Steel Construction Manual (SCM) is a mandatory part of the Contract Documents for Department of Transportation projects which include Items requiring the Contractor to furnish or rehabilitate fabricated structural metals.

The SCM supplements the Structural Steel Section, Materials Details for Castings, Forgings and Metals, and other provisions of the Standard Specifications as provided therein.

The SCM has been prepared in an effort to produce a single source document to describe minimum requirements for preparation of drawings, ordering and receipt of materials, fabrication by welding, bolting and riveting, transportation, erection and necessary testing and inspection of structural metals. It was not possible to print all information in one text so occasional reference to other Codes and Specifications is necessary.

Provisions of the American Welding Society, Structural Welding Code, which have been adopted by the State, and other provisions which have been modified to reflect specific New York State and/or Federal Highway Administration requirements are contained herein. We wish to thank the American Welding Society for permitting the State to reproduce portions of the Structural Welding Code, AWS D1.1-80. Their assistance is greatly appreciated.

When the reader compares this edition of the Steel Construction Manual to the 1973 edition, he will find that most sections have been heavily revised to take into account developments in design and technology since our last publication.

There are, however, few new provisions that are not already part of State Contract Documents by notes on the Plans, special provisions, etc. This edition is part of a continuing effort to keep the manual up to date and to reduce the need for special notes and special provisions.

You will note that all references to a Fracture Control Plan are new to this specification but not new to our Contract Documents. We have expanded our sections on Drawings and Inspection to clarify requirements and hopefully to avoid accidents and delays.

We have decided, in the Bolting and Riveting Section, to only require a hardened washer under the turned element if the bolt is installed in a standard size hole. This change is new in this Manual.

The Contract Documents provide that the Contractor/Fabricator/Erector is responsible for the quality of his own work. When the terms Fabricator and/or Erector are used, contractually, it shall mean the Contractor. Quality Control (QC) and Quality Assurance (QA) during fabrication and erection are the responsibility of the Contractor. Verification of the effectiveness of the Contractor’s fabrication/erection QC and QA programs is a prerogative of the State. Verification inspection, when performed by the State, shall not relieve the Contractor of his responsibility to furnish the quality of materials and workmanship required by the Contract Documents. See Section 3, Inspection, for a more detailed description of the duties of Inspectors and responsibility for Quality Control and Quality Assurance.

The provisions of this Manual apply to structural steel and other fabricated metal products produced and manufactured in the United States of America. When provisions of the Contract Documents permit the use of “Foreign” steel and other metal products, the procedures for Drawings, Mill Inspection and Shop Inspection shall be approved by the Deputy Chief Engineer (Structures), DCES, in conformance with the requirements of the Standard Specifications Section entitled “Control of Material”.
201. CONTRACT DRAWINGS

201.1 Definition. The drawings which are a part of the Contract Documents, hereinafter designated as the "Contract Drawings," "Contract Plans," or "Plans," are all Contract Drawings under the provisions of the Contract Documents and are not intended to be "Shop Drawings," "Erection Drawings," or other "Working Drawings" required by these specifications. The word Plans will generally be used throughout this manual to describe Contract Drawings.

201.2 Details and Specifications. Any details not sufficiently shown on the Plans will be furnished to the Contractor by the Deputy Chief Engineer (Structures), DCES, upon request. Any question about notes on the Plans or requests for clarification of specification requirements should be directed to the DCES.

201.3 Dimensions. In case of a difference on the Plans between scale dimensions and figures, the figures shall be followed.

201.4 Errors. The Contractor shall verify and be responsible for the correctness of all dimensions other than the principal controlling dimensions shown on the Plans, and shall call the attention of the DCES to any errors or discrepancies that he may discover therein. The Contractor shall have no claim for damages that may result from following an error except for an error in the principal controlling dimensions and material properties shown on the Plans or listed in the Specifications.

201.5 Principal Controlling Dimensions and Material Properties. The following shall be considered principal controlling dimensions and material properties:

a) Length of span, i.e., the horizontal distance between bearings, pin centerlines, or other points of support.

b) Length of member, out-to-out.

c) Thickness, width and length of all plates.

d) Dimensions, weight per foot and length of shapes.

e) Diameter, specification and grade of high strength bolts and rivets.

f) All dimensions of machined pins, hangers and bearing devices.

g) Camber and horizontal curvature of members.

h) Elevation of pedestals, bridge seats and other supports for structural steel.

i) Specification and grade of metal.

j) Size of welds.

The Contractor shall be responsible for modifying dimensions of members and pieces to compensate for weld shrinkage, distortion, elastic deformation, camber, sweep, slope, waste for proper machining and oxygen cutting, and other phenomena that may make initial in process fabricating dimensions and material ordering dimensions different from the final product design dimensions shown on the Plans.

202. SHOP DRAWINGS

202.1 Preparation. When required by the general specifications, the Contractor shall prepare as soon as possible after the contract is signed, complete and accurate shop drawings for all structural metals, machinery and other details, and the connections thereof to the substructure, foundation or other supporting parts.
202.2 **Size and Type.** Shop drawings shall be neatly drawn and clearly legible to produce microfilm negatives which conform to U.S. Department of Defense specifications. Shop drawings shall be cut to a standard size of 22 x 36 inches and arranged to conform to the Plans. Failure to submit shop drawings of the required size will be cause for their return without examination. The margin line shall be drawn 1/2 inch from the top, bottom and right hand edges and 2 inches from the left hand edge to permit binding. The working space on these drawings will therefore be 21 inches by 33 1/2 inches. A space 3 inches by 11 inches, the 11 inches being parallel to the length of the sheet, shall be reserved in the lower right hand corner for title and approval signature. The sheets shall be arranged so that as far as possible the notes will appear above each other near the right edge of the sheet. The drawings shall be arranged systematically within erection divisions or groupings and numbered consecutively in the lower right hand corner.

202.3 **Information Required on Shop Drawings.** The contract number, project identification number and contract name, together with the County in which the work is to be performed shall be clearly indicated in the title block on each sheet, together with the fabricator's name and shop order number for the work detailed on the sheet.

The shop drawings shall contain a bill of material on the sheet that details the member. If the member has such proportions that more than one sheet is required to fully detail it, the complete bill of material may be placed on the last sheet of the group of sheets detailing the member. The bill of material shall describe in detail all material used in the fabrication of the member. In addition, primary stress carrying pieces shall be described by their mill order number (Line No. & Item No.) so that direct reference to the mill test report describing the steel may be made without difficulty. In lieu of this requirement, the Contractor may submit, after the material has been delivered to the shop, shop drawings which have been revised to include the heat numbers of each piece used in the work that is subject to primary stress. When the structure requires the fabrication of Fracture Critical Members (FCM's), the original shop drawings or revised shop drawings shall accurately identify each fracture critical plate or shape and reference it to the certified copy of the results of chemical analysis and mechanical tests performed by the manufacturer in accordance with the requirements of the Contract Documents. Reference shall be made by heat number plus plate or shape identification. No FCM will be accepted without compliance with this requirement.

When payment is to be made on a pound-price basis, the computed pay weight of each shipping unit shall be clearly marked on the shop drawing on which the unit is detailed.

When payment is to be made on a lump sum basis, the shipping weight of each unit shall be shown on the shop drawing.

202.4 **Approval of Shop Drawings.** Shop drawings of primary components of the steel superstructures including layout details, detail drawings and sub-assembly drawings shall be fully reviewed. The review shall include the following:

- a) Principal controlling dimensions, as described in Article 201.5.
- b) Materials specifications, including approved weld filler metal requirements.
- c) Details of bolted connections and welded joints, including nondestructive testing.
- d) General structural framing.
- e) Assembly diagrams.
- f) Attachments (not part of the structure) to tension areas of structural members.
- g) End cuts of stringers and girders.
h) Notes pertaining to requirements for workmanship including blast cleaning, oxygen cutting, assembly, welding, machining and bolting.

i) Railing and bridge joints when details differ from those on the plans.

j) Bill of materials, including computed weights when pay measurement unit is pounds.

Certain elements of primary and secondary components of steel superstructures shall be reviewed to a lesser extent than that described above. The following items shall be examined briefly or on a random sample basis:

a) Diaphragms, cross frames, lateral bracing, wind bracing, inspection walks, and other relatively small secondary pieces.

b) Girder stiffener spacing shall be reviewed for general but not exact spacing.

c) Attachments for utilities shall be reviewed for their effect on main structural members.

d) Dimensions that will not affect structural integrity, or if wrong, will not cause harmful secondary stress.

In general the Contractor shall be responsible for fit. If errors occur causing difficulty during erection, it shall be the Contractor's responsibility to make the necessary corrections as approved by the DCES.

202.5 Shop Drawing Submittal Procedure. Shop drawings are required for all structural metals unless waived by the DCES or otherwise specified in the Contract Documents. Rolled beam bridges not requiring fabrication and miscellaneous metals will not require shop drawings. When the shop drawings prepared by the Contractor as specified are complete, duplicate reproductions shall be submitted to the DCES, who will review and indicate thereon any corrections deemed necessary by the State. The duplicate reproductions may be either two paper prints, or one paper print and one sepia or other approved reproducible. If two paper prints are submitted, one set of paper prints, with corrections indicated thereon will be returned to the Contractor. If one paper print and one sepia are submitted, the set of sepia reproductions will be returned to the Contractor with the following stamp:

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Submit Tracing for Approval Stamp
Correct Sepia and Resubmit
Make Indicated Changes to Tracing and Submit for Approval Stamp

Approval is limited to materials and type of details. No steel shall be shipped from the shop until the Inspector is furnished a print made from the approved tracing.

As soon as the Contractor receives a reproducible marked "Approved," "Approved for Fabrication Without Weights," or "Approved-As-Noted," he is authorized to reproduce the drawing (stamped sepia) and furnish necessary copies to the shop and to the Inspector. If he agrees to the notations on
the "Approved-As-Noted" drawings, he may begin the fabrication incorporating the required changes. If he feels that the notations on the drawing constitute "Extra Work" or "Disputed Work," the Contractor shall immediately notify the Department under the provisions of the Standard Specifications for Disputed Work.

On Contracts involving one or more railroads, the Contractor shall furnish each Railroad Company with duplicate paper reproductions of the shop drawings at the same time triplicate reproductions are submitted to the DCES for review. The Railroad shall forward one copy of the print with their comments to the DCES, who will incorporate them with other comments and return them to the fabricator.

When the revisions marked on the shop drawings have been agreed upon and completed, the original reproducibles shall be submitted to the DCES in a mailing tube for his approval stamp and signature. The Contractor shall carry out the construction in strict accordance with the approved shop drawings and shall make no further changes thereon except with the written approval of the DCES.

Approval by the DCES shall not relieve the Contractor from his responsibility for errors that may exist in the shop drawings. When the Contractor proposes to use materials or details that are different than those described in the Contract Documents, he shall seek approval of the variance from the State before submitting the shop drawings. Any difference between materials and details specified and those shown on the shop drawings shall, unless previously approved, be considered an error on the shop drawings and shall be corrected at the Contractor's expense.

Any revisions made to shop drawings after the first submission shall be clearly marked on the drawing by a revision symbol and dated unless the revision was the result of comments marked on the shop drawing by the State during shop drawing review.

202.6 Detention of Shop Drawings. The DCES shall be allowed two working days for the examination of each drawing in a set of shop drawings or ten working days minimum per set. A set of shop drawings shall be considered to be all drawings received from a given Contractor for a particular contract in any calendar day. If the shop drawings are detained for examination for a period longer than stated above, such detention will be taken into account when considering application by the Contractor for an extension of time for the completion of the contract.

All shop drawings are time and date stamped as they are received and recorded in a log at the office of the DCES. This log shall be the basis for determining when drawings must be returned without adjustment of the completion date as described in this Article.

The State will endeavor to return corrected and/or approved drawings with a minimum of delay. In order to expedite approval of critical drawings, the Contractor should indicate in his submittal, his order of preference for the review and return of drawings and should submit all drawings in the order of their importance to his construction program.

202.7 Distribution of Approved Shop Drawings. The Contractor (or Fabricator) shall distribute, as soon as possible after approval, paper prints of the approved shop drawings, as follows:

1-Set to the Deputy Chief Engineer (Structures)
2-Sets to the General Contractor
2-Sets to the Regional Director of Transportation
2-Sets to the designated Shop Inspection Agency for each shop where fabrication will be performed

For every Railroad Company or Public Agency involved in the contract, the Contractor shall furnish three (3) additional sets of paper prints and one (1) set of approved reproducible shop drawings made by an acceptable process.
202.8 Disposal of Original Reproducibles.  
After completion of the contract and before final payment thereof, the Contractor shall deliver to the Deputy Chief Engineer (Structures) all approved original reproducibles on duplicate sets of microfilm cards which meet federal standard MIL-M-38761, which shall thereafter remain the property of the State.

Also at the completion of the contract, the Regional Director's Office will receive one additional set of microfilm cards meeting the same standard.

202.9 Consultant Engineering Review. If a Consultant is assigned the review of shop drawings, special instructions will be issued by the DCES for submittal, approval distribution, and disposal of the shop drawings.

202.10 Cost of Shop Drawing Prints and Reproducibles. The cost of all shop drawing prints and reproducibles required by the Specifications shall be included in the price bid for the payment item requiring the drawings. Any prints and reproducibles requested beyond the number specified shall be furnished by the Contractor at cost.

203. STANDARD DETAILS FOR SHOP DRAWINGS

203.1 AASHTO Requirements. All Shop Drawings for bridges carrying highways shall be detailed in accordance with the provisions for design and workmanship of the current edition of the American Association of State Highway and Transportation Officials, “Standard Specifications for Highway Bridges” as modified by the Contract Documents which include this Manual.

203.2 AREA Requirements. All Shop Drawings for bridges carrying railroad tracks shall be detailed in accordance with the provisions for design and workmanship of the current edition of the American Railway Engineering Association Specifications for “Steel Railway Bridges,” as modified by the Contract Documents which include this Manual.

203.3 Detailing for Welded Fabrication. Full and complete information regarding location, type, size, and extent of all welds shall be clearly shown on the drawings. The drawings shall clearly distinguish between shop and field welds. Those joints or groups of joints in which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted. Contract design drawings shall specify the effective weld length and, for partial penetration groove welds, the required effective throat, as defined in Section 7, Welding. Shop drawings shall specify the groove depths applicable for the effective throat required for the welding process and position of welding to be used. The Plans shall show complete joint penetration or partial joint penetration groove weld requirements. The welding symbol without dimensions designates a complete joint penetration weld, as follows:

\[ \text{complete joint penetration weld (CP)} \]

The welding symbol with dimensions above or below the arrow designates a partial joint penetration weld, as follows:

\[ \begin{align*}
& \text{(E)}_1 \quad \text{partial joint} \\
& \text{(E)}_2 \quad \text{penetration weld}
\end{align*} \]

where

\[ E_1 = \text{effective throat, other side} \]
\[ E_2 = \text{effective throat, arrow side} \]

All groove welds shall be complete joint penetration welds unless specifically detailed as partial joint penetration welds on the plans.
Special groove details shall be specified where required.

Shop drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of material required to make them. All welding symbols shall conform to AWS A2.4, latest edition, and the requirements of Section 7, Welding. Both width and thickness of steel backing shall be detailed when used.

Any special inspection requirements shall be noted on the drawings or in the general notes.

The definition of welding terms used in the Manual shall be interpreted in accordance with the definitions given in Appendix D of this Manual or in the current edition of American Welding Society, "Terms and Definitions," (AWS A 3.0).

203.4 Girder Details. The shop drawings for main members shall include a description of the tension areas. This shall be done by dimensioning the limits of tension stress under dead load and live load and showing the dead load point of contraflexure. If the reversal zone is not defined on the Plans, it shall be assumed to extend 10 feet each side of the dead load point of contraflexure.

The girder details shall include a camber and horizontal sweep diagram. Offsets from a straight line (end to end of member) shall be given at intervals of 20 feet, or one tenth of the span length, whichever is less.

203.5 Field Splices in Stringers and Girders. When the specific location for a bolted or welded field splice in stringers and girders is not shown on the Plans, the Contractor will be permitted to introduce splices at locations of his choice. Those locations are subject to the approval of the DCES.

Splices shall meet the following requirements:

a) The Contractor will have the option of providing either welded or bolted splices unless specific types of splices are required by the Contract Documents.

b) No horizontal bolted splices will be allowed in the webs of members unless detailed on the Plans or approved by the DCES.

c) When the Contractor informs the DCES of his proposed bolted splice locations, the State will furnish the Contractor with the bolted splice design for each acceptable location. The Contractor shall detail the splice on Shop Drawings and submit them to the DCES for approval. Shop assembly diagrams shall be submitted for approval, detailing the appropriate assembly procedure described in Article 1103. The minimum control points shall be the points of support (Q, bearing or pin), field splices, and the point of minimum or maximum camber in each span.

d) When stringers or girders of any cross section are to be spliced by welding in the field, a detailed welding procedure shall be submitted to the DCES for his approval. The procedure shall be detailed on shop drawings and submitted for approval prior to the fabrication of structural steel. The request for approval of the detailed field welding procedure, including the method of supporting members during welding, shall be submitted directly to the DCES. All field welded splices shall be subjected to nondestructive testing in accordance with Section 17, Radiographic Inspection or Section 18, Ultrasonic Testing as determined by the DCES. The provisions of Article 1102, Shop Assembly of Field Welded Connections shall apply. FCM's will, in general, not be subjected to any welding in the field. Where field welding is permitted, the DCES will require weld soundness to be verified by both RT and UT.

e) Fill plates will not be permitted. Web and flange shop butt welds may be moved to extend the thicker plate so that bolted connections are made in materials of the same thickness. The location of bolted splices and extension of thicker flanges shall be such that the distance from a groove welded splice to the centerline of a field splice shall be five feet minimum or the
distance from a groove welded splice to the nearest bolt hole shall be one foot minimum, whichever is greater. All manufacturing dimensional tolerances shall be controlled so that bolted splices may be properly assembled without distortion and without requiring fills.

f) The DCES reserves the right to order, at no extra cost, a welded splice at any location where a bolted splice design will require high strength bolts in excess of eight inches long.

g) Butt welded field splices in stringers and girders shall be made by complete joint penetration groove welds which shall be radiographed as required by the Contract Documents.

h) Bolted designs shall use ASTM A325 high strength bolts only. The design shall be based upon the allowable shear for a friction-type connection. Bolt lengths shall be such that threads are excluded from shear planes in the connection.

i) When special corrosion resistant characteristics are required for the members to be spliced, ASTM A325, Type 3, high strength bolts shall be used.

203.6 Location of Shop Welded Splices in Fabricated Members. Shop welded splices may be located at points in fabricated members that are consistent with lengths of plate available from the mills. Welded joints should be located at points of reduced tensile stress, if this will not create additional labor or material costs for the Contractor.

When flanges or webs of welded plate girders are detailed on the Contract Drawings as a series of plates of varying thickness joined by butt welds, the Contractor may, for the purpose of eliminating butt welds, extend the length of the thicker plate to the end of the next thinner plate or to the end of the member if approved by the DCES. The extra material required by this procedure must be furnished at no cost to the State. The maximum thickness transition at any joint shall not exceed a ratio of 1 to 2. Web thickness ratios may exceed this limit if shown on the Plans. If the Contractor increases the thickness of the bottom flange plate at a bearing location, he shall maintain the original girder elevation by making suitable compensating changes in the elevation or dimensions of the supports as approved by the DCES. In lieu of this, the Contractor may remove the increased thickness by machining the bottom flange plate at the bearing to maintain the original girder elevation. The transition between the machined surfaces and the adjacent plate surface shall have a slope not greater than 1 on 2 1/2.

203.7 Bearing Stiffeners. All bearing stiffeners on straight rolled beams and welded plate girders shall be fillet welded to the web and either welded to the bottom flange with a complete joint penetration groove weld or milled to bear against the bottom flange. On horizontally curved beams and girders, bearing stiffeners must be groove welded to the bottom flange. When the bearing stiffener is greater than one inch thick, the Contractor may request that partial penetration welds or fillet welds be approved to weld the bearing stiffener to the flange so that flange distortion will be reduced. Such requests shall be made as part of the shop drawing submittal and shall make provision for inspection to verify proper mill-to-bear conditions before the welds are made. All bearing stiffeners may be either fillet welded or placed paint tight against the top flange, except that where the top flange is in tension, the bearing stiffener must be placed paint tight against the top flange and not welded to the flange. The ends of all beams and girders and all bearing stiffeners shall be vertical after dead load deflection.

203.8 Intermediate Stiffeners and Connection Plates. Intermediate stiffeners and connection plates for simply supported plate girders shall consist of plates fillet welded to the web and to the flange which is in compression at that point under dead load. They shall be placed either vertical, or perpendicular to the flange or to a tangent to the flange at that location and shall be located as shown on the Plans. On fascia girders of continuous spans where stiffeners are installed on only one side of the web, the stiffeners shall be attached as described above. On interior girders of continuous spans, the stiffeners shall be attached as described above except in the stress reversal zones where they shall be placed paint tight against both flanges and not welded to either flange. Intermediate stiffeners or connection plates in pairs (one on each side of web) may be placed paint tight against both flanges and not welded to the flange.
The snipes for the flange to web weld shall be detailed as described in Article 607.

Intermediate stiffeners or connection plates shall be placed at least 6 inches from a groove welded splice in the web or flange.

When necessary to provide clearance at a lateral gusset plate, intermediate stiffeners and/or connection plates shall be fitted as follows:

a) When the flange width is less than 17 inches, the intermediate stiffener and/or connection plate shall be placed paint tight against the lateral gusset plate and shall be sniped to provide maximum bearing, but not less than 2 inches, in the horizontal direction. The vertical dimension of the snipe shall be 5 times the web thickness as described in Article 607.

b) When the flange width is 17 inches or greater, the intermediate stiffener and/or connection plate shall be sniped as described in Article 607 and shall be clipped on a 45° angle only as necessary to provide clearance for the lateral gusset plate. A minimum of 2 inches bearing must be maintained.

c) When neither of the above requirements apply, the intermediate stiffeners and/or connection plate shall be fitted as approved by the DCES.

203.9 Longitudinal Stiffeners. Longitudinal stiffeners shall be continuous for their full length as shown on the plans unless interrupted by a field splice in the girder. They shall be assembled full length using complete penetration groove welds before attachment to the web with full length continuous fillet welds. Connection plates intersecting longitudinal stiffeners shall be notched and fillet welded or groove welded to the longitudinal stiffener at each intersection. Longitudinal stiffeners shall be groove welded to end bearing stiffeners and any other stiffener or connection plate where the longitudinal stiffener is terminated. If a longitudinal stiffener is interrupted by a field splice, it shall be terminated on each side of the splice with 8 inches of groove weld to the web and a 1 foot radius transition to the web surface (see Figure 203.9). The transition may be of any shape that will provide, after welding, cutting and finish grinding, a smooth transition from the web surface at a minimum radius of one foot. Special care shall be taken to avoid notches and weld defects at the point where the stiffener is finished tangent with the web. The detail shown in Figure 203.9 shall be used to terminate longitudinal stiffeners where there are no intermediate stiffeners or connection plates.

FIGURE 203.9 — LONGITUDINAL STIFFENER AT BOLTED SPLICE
203.13 Lateral Bracing and Diaphragm Connections. In general lateral bracing and diaphragms shall be bolted to the girder as shown on the Plans. Oversize holes will be allowed for these connections, provided:

a) They occur in only one component of the bolted connection.

b) The holes in the girder flange or stiffener/connection plate are made standard size.

c) The locations of the oversize holes are indicated on the Shop Drawings.

d) The exposed oversize holes are covered with a hardened washer.

e) There is no field reaming of oversize holes without the approval of the DCES.

Bolt holes in the flange of a girder shall be a minimum of 6 inches, preferably 12 inches, from a groove welded flange splice. The dimensions of bolt holes shall conform to Articles 613 & 614.

203.11 Bearing Sole Plates. When the steel is to be erected to a grade of five or less, it will not be necessary to machine the top of the sole plate to compensate for a bevel unless otherwise noted on the Plans. No machining of the top of the sole plate will be required if the surface is plane and true as described in Article 612, Machining of Contact Surfaces.

203.12 Curved Girders. When the Contract Plans specify welded plate girders with horizontal curvature, the girders shall be fabricated using heat-curving procedures in accordance with Section 15 or by oxygen cutting the flanges to the required radius prior to assembly to the web. The camber data for welded plate girders shall be provided by the DCES.

The horizontal curvature and camber, if specified, for rolled beams, shall be fabricated using only heat-curving procedures in accordance with Section 15.

203.13 Bolt Spacing and Edge Distance. The minimum distance between centers of fasteners shall not be less than the following:

For 1-1/8 inch fasteners ................................................................. 4 inches
For 1 inch fasteners ..................................................................... 3-1/2 inches
For 7/8 inch fasteners ................................................................. 3 inches
For 3/4 inch fasteners ................................................................. 2-1/2 inches
For 5/8 inch fasteners ................................................................. 2-1/4 inches

The minimum distance from the center of any fastener to the edge of a plate shall be:

For 1-1/8 inch fasteners ................................................................. 2 inches
For 1 inch fasteners ..................................................................... 1-3/4 inches
For 7/8 inch fasteners ................................................................. 1-1/2 inches
For 3/4 inch fasteners ................................................................. 1-1/4 inches
For 5/8 inch fasteners ................................................................. 1-1/8 inches

In the flanges or legs of rolled sections the minimum edge distance shall be:

For 1-1/8 inch fasteners ................................................................. 1-3/8 inches
For 1 inch fasteners ..................................................................... 1-1/4 inches
For 7/8 inch fasteners ................................................................. 1-1/8 inches
For 3/4 inch fasteners ................................................................. 1 inch
For 5/8 inch fasteners ................................................................. 7/8 inch
For sealing, the maximum spacing of fasteners along the free edge of a plate shall be 4 inches plus four times the thickness of the thinner plate, but not more than 7 inches.

The maximum distance from any edge shall be eight times the thickness of the thinnest outside plate, or section but shall not exceed 5 inches.

204. ERECTION PROCEDURES

204.1 General. The Contractor shall submit a detailed structural steel erection procedure to the DCES and to the Regional Director for each structure in the Contract. These procedures shall meet all the drawing requirements of Article 202, Shop Drawings and shall include the required information in Articles 204.2 [drawings] and 204.3 [calculations]. Copies of the drawings shall also be sent for comments to any railroad company or public agency affected by the proposed erection procedure. These drawings must be received at least 30 days prior to the proposed beginning of erection. The Regional Director’s office will review any portion of the erection procedure that affects the maintenance of traffic, modifies the existing pavement, or the flow of water and shall verify actual site conditions with what is shown on the erection plans. All comments or revisions required by DCES, Regional office, railroad company, or public agency shall be incorporated in the final submission, which shall then be reviewed by the DCES.

In addition to the requirements of the SCM the lifting procedures shall meet all of the requirements of NYSDOT Standard Specifications Section 107.05 P Lifting.

Distribution of copies of the reviewed erection procedure drawings shall be made as described in Article 202.7, except distribution to the Shop Inspection Agency is not required.

204.2 Required Information [Drawings]. Erection drawings shall be prepared by a Professional Engineer registered to practice in New York State. The following minimum information shall be placed on the erection drawings for each individual structure. Erection procedures for similar structures or twin bridges may be shown on the same sheet.

a) Title block with contract number, project identification number (PIN)
b) Project and contract name and county in which the work is to be performed, together with the contractor’s name and address, fabricator’s and sub-fabricator’s name and address as appropriate, bridge identification number (BIN), and the fabricator’s unique shop order number or purchase number for the work detailed on the sheet.
c) Plan of the work area showing support structures, roads, railroad tracks, canals or streams, utilities or any other information relative to erection, including lifting and release of the member.
d) Erection sequence for main members and secondary members (crossframes, diaphragms, lateral bracing, portals, etc.), noting use of holding cranes or temporary supports, falsework, and bents. The erection sequence shall describe the procedure required to stabilize each member during the pick and upon release of the crane.
e) Delivery location of each girder.
f) Location of each crane for each pick.
g) Capacity chart for each crane and boom length used in the work. Cranes lifting over active railroad facilities shall have a minimum lifting capacity of 150 percent of the lift weight.
h) Pick point location(s) on each member.
i) Lifting weight of each member (including clamps, spreader beams, etc.).
j) Lift and setting radius for each pick (or maximum lift radius).
k) Description of lifting devices or other connecting equipment.
1) Girder tie-down details or other method of stabilizing erected girders. All diaphragms or temporary bracing between adjacent girders shall be connected consistent with the requirements of Section 14 before release of the crane. All requests for revisions to this requirement must be supported by the necessary engineering calculations and submitted with the erection procedure.

m) Bolting requirements, including the minimum number of bolts and erection pins required to stabilize members during the erection sequence.

n) Blocking details for stabilizing members supported on expansion bearings and on bearings that do not limit movement in the transverse direction.

o) The method and location of temporary support for field spliced or curved girders, including shorting, falsework, holding cranes, stiffening trusses, guys, etc. The State will examine, but not approve details of temporary supports. The design, erection, and stability of these supports shall be the sole responsibility of the Contractor. Calculations for falsework and temporary details signed by a NYS Licensed Professional Engineer shall be submitted for DCES review.

p) Offsets necessary to adjust expansion bearings during erection to provide for temperature variance and dead load rotation when appropriate.

The following notes shall be placed on the Erection Drawings.

1) No crane will be operated in a manner that will exceed its rated capacity at any radius as specified by the crane manufacturer.

2) The table or chart prepared by the crane manufacturer to describe the maximum lift at all conditions of loading shall be posted in each crane cab in clear view of the operator.

3) The Contractor shall be responsible for verifying the weight of each lift and for insuring the stability of each member during all phases of erection, including lifting and release of the member.

4) Members shall be subject to only light drifting to align holes. Any drifting that results in distortion of the member or damage to the holes will be cause for rejection of the member.

5) Field reaming of holes shall not be performed unless required by the Contract Documents or approved by the DCES.

6) The final alignment and profile of the erected steel shall conform to the requirements of the Contract Documents. Measurements shall be made by the Contractor as described in Articles 1212, 1213, and 1214 of the New York State Steel Construction Manual.

7) When the structure utilizes a Geosynthetic Reinforced Earth substructure, cranes or crane outriggers shall not be placed within limits specified on the plans during erection.

204.3 Required Information [Calculations]. The following calculations shall be prepared by a New York State Registered Professional Engineer and provided for each structure submitted:

a) Calculations to verify the structural integrity and stability of the girders during transportation and erection until completion of the bridge assembly.

b) Design calculations indicating the load capacity and stability of temporary supports for the structure and the crane.

c) Calculations to indicate the capacity of Contractor fabricated rigging including but not limited to lift beams, spreader beams and beam clamps. Submit manufacturer’s certification or catalog cuts for pre-engineered devices.

d) An analysis of the substructure when crane footprint causes a surcharge loading on the structure.

e) Surcharge loading to underground facilities should be avoided. An analysis of underground utilities and buried structures when the crane footprint causes a surcharge on such facilities.
describe the deficiencies and the proposed repair shall be prepared by the Contractor (Fabricator) and submitted to the Deputy Chief Engineer (Structures) for approval, in accordance with Article 726.

205.2 Required Information. When written repair procedures are required for the repair of defects, repair procedure drawings shall be prepared to show the defect in plan view, elevation and section as necessary to adequately locate and describe the defect and the proposed repair. A space shall be provided on the sheet for the inspector's signature to show that he has inspected the defect and has found that the drawings accurately describe the defect as it appears prior to repair. The proposed repair procedure shall be described in detail including at least the following information, listed in a proposed sequence of operation:

a) The area of the steel adjacent to the defect shall be cleaned by grinding to expose the surface boundaries of the defect.

b) Plan views and sections of the excavations of defects shall be shown. All air carbon are gouging shall be followed by grinding to remove carbon pick-up and to remove surface irregularities.

c) Magnetic particle testing shall be performed in accordance with Section 18 to insure that the limits of the defects have been completely removed prior to welding the excavation.

d) All preheat and interpass temperatures shall be shown. When required, peening, post heat, and stress relief heat treatment procedures shall also be described.

e) Run-off tabs and back-up bars shall be shown in detail. They shall be removed after welding and all surfaces shall be finished flush by machining or grinding.

f) The welding procedure specification shall be shown.

g) Nondestructive testing procedures shall be performed at the completion of the repair. The methods and procedures shall be described on the repair drawing.

h) A space shall be provided for the Inspector's signature indicating the work has been acceptably completed in accordance with the approved repair procedure.

205.3 Sample Repair Drawing. An example of a repair drawing prepared to show a typical repair of a base metal crack is included in Appendix B of this Manual.

206. TRANSPORTATION DRAWINGS

206.1 General. All members, both straight and curved, shall be shipped and stored with their webs vertical unless otherwise approved by the DCES. Transportation drawings must be prepared by the Contractor (Fabricator) and submitted to the DCES for approval whenever members must be shipped on their sides. Transportation drawings may also be required for members shipped with their webs vertical when there is doubt about the intensity of stress induced by the procedures used to handle, transport or store the members. Any curved member shipped with a cantilever overhang of more than 25 feet shall require transportation drawings.
206.2 **Required Information.** Transportation drawings shall include at least the following information:

a) The drawings may be sketch sheets or full size shop drawings as necessary to fully describe the procedures.

b) Calculation sheets shall be included to show the dead load plus impact stresses induced by the loading and transportation procedure. Impact stresses shall be at least 200% of the dead load stress. The total load including impact shall be not less than 300% of the dead load.

c) The location of all support points shall be shown. Supports shall be detailed to be under the flanges regardless of the member's orientation.

d) Tie-downs (types and locations) shall be shown. A sufficient number shall be used to provide redundancy so that if any one tie-down fails, the member will remain stable.

e) Temporary stiffening trusses or beams shall be shown if they are necessary to provide temporary support (stiffness) to the member during shipping.

f) Details of a four-way articulating bolster are to be furnished for each truck transporter to insure that truck movements will not produce unnecessary stress in the attached structural steel.

207. **HEAT CURVING DRAWINGS**

207.1 **General.** Drawings shall be prepared by the Contractor (Fabricator) and submitted to the DCES for approval whenever beams or girders are to be heat curved with the web in the horizontal position or when external preloads are to be applied (see Section 15, Heat Curving, Cambering, and Straightening). The drawings shall show the location of all supports, amount and location of external loads (if used), typical heat patterns and other information to describe the work. Calculation sheets shall be included to show the stresses induced in the member by the loading method.
301. GENERAL

Fabrication/Erection Inspection and Testing (Quality Control) and Verification Inspection and Testing (Quality Assurance) are separate functions. For the purposes of this Manual, the terms Quality Control (QC) and Quality Assurance (QA) shall be used. Quality Control (Fabrication/Erection Inspection and Testing) shall be performed as necessary prior to assembly, during assembly, during welding and after welding to insure that materials and workmanship meet the requirements of the Contract Documents. Quality Assurance (Verification Inspection and Testing) shall be performed in a timely manner to avoid delays in the work. Quality Control (Fabrication/Erection Inspection and Testing) is the responsibility of the Contractor unless otherwise provided in the Contract Documents. Quality Assurance (Verification Inspection and Testing) is the prerogative of the State, who may perform this function or waive independent verification (QA) or stipulate that both QC and QA shall be performed by the Contractor.

The Quality Assurance (Verification) Inspector is the duly designated person who acts for and on behalf of the State on all inspection and quality matters within the scope of the Contract Documents. The Quality Control (Fabrication/Erection) Inspector is the duly designated person who acts for and on behalf of the Contractor on all inspection and quality matters within the scope of the Contract Documents. When the term inspector(s) is used without further qualification, it applies equally to QC and QA within the limits of responsibility designated in this Section.

302. QUALIFICATION OF INSPECTORS

Inspectors shall be qualified and certified by one of the following procedures:

a) The Inspector(s) shall be an AWS Certified Welding Inspector (CWI) qualified and certified in accordance with the provisions of AWS QC1, Standard for Qualification and Certification of Welding Inspectors,

or,

b) The Inspector(s) shall be qualified by the Canadian Welding Bureau (CWB) to the requirements of Canadian Standard Association (CSA) Standard W178.2, Certification of Welding Inspectors,

or,

c) An Engineer or Technician trained by the Metals Engineering Unit of the Structures Subdivision, New York State Department of Transportation and approved by the Deputy Chief Engineer, Structures.

Except as provided below, only individuals so qualified shall be authorized to perform Quality Control (Fabrication/Erection) or Quality Assurance (Verification) Inspection and tests under the provisions of the Contract Documents.

The Inspector may be supported by Assistant Inspectors who may perform specific inspection functions under the supervision of the Inspector. Assistant Inspectors shall be qualified by training and experience to perform the specific functions to which they are assigned. The work of Assistant Inspectors shall be regularly monitored by the Inspector.

Personnel performing nondestructive tests under the provisions of Sections 16 through 19 need not be qualified and certified under the above provisions.
303. RESPONSIBILITIES OF INSPECTORS

303.1 General. The Inspector shall ascertain that all fabrication, handling, transportation, and erection is performed in accordance with the provisions of the Contract Documents.

QC and QA Inspectors shall be furnished complete shop drawings and those portions of the Contract Documents that describe material and quality requirements for the products to be fabricated and/or erected.

The inspector shall be notified in advance of the start of operations that are subject to QC and QA Inspection and Tests.

The Contractor shall furnish the Inspector two copies of the mill order and shall give ample notice to the Inspector prior to beginning the work at the mill and shop, so that Quality Assurance Inspection may be provided by the State, if elected by the DCES. No materials shall be cast, rolled, forged or fabricated before the Inspector has been notified where the orders have been placed.

303.2 Inspection of Materials. The Inspector shall make certain that only materials conforming to the requirements of the Contract Documents are used.

All structural metal shall be furnished to the requirements of the ASTM Designation shown on the plans or listed elsewhere in the Contract Documents. All structural steel shapes and plates used in areas subject to tensile stress as designated on the plans or specified in Section 715 of the Standard Specifications shall be furnished to minimum Charpy V-notch toughness requirements as described in Section 715.

Certified copies of the results of chemical analysis and mechanical tests required by the specifications shall be furnished for all structural metals. These test data shall be given to the Shop Inspector for submittal to the DCES with his final inspection report. When structural metals are furnished under items which do not require Shop Inspection, these data shall be submitted to the Engineer-in-Charge, who will perform visual inspection and examine certified test reports to determine if the materials furnished conform to the requirements of the Contract Documents.

303.3 Inspection of Welding Procedure, Qualification and Equipment. The Inspector shall make certain that all welding procedures are qualified and covered by an approved Welding Procedure Specification or are qualified by tests in accordance with Section 8A, Welding Procedure Qualification. Welding Procedure Specifications and Welding Procedure Qualification Tests shall be subject to the approval of the DCES prior to beginning the work. The Inspector shall inspect the welding equipment to be used in the work to make certain that it conforms to the requirements of this Manual.

303.4 Inspection of Welder, Welding Operator and Tacker Qualifications. The Inspector shall only permit welding to be performed by welders, welding operators, and tackers who are qualified in accordance with the provisions of Section 8B, Welder, Welding Operator, and Tacker Qualification. When the quality of a welder's, welding operator's, or tacker's work appears to be below requirements of this Manual, the Inspector shall require that the welder, welding operator or tacker demonstrate his ability to produce sound welds by means of a simple test such as the fillet weld break test described in Section 8B or shall require complete requalification in accordance with Section 8B. The Inspector shall require requalification of any welder, welding operator, or tacker who cannot demonstrate to the satisfaction of the DCES, that he has used the process for which he has been qualified without a break in work experience greater than six months since last qualified as required by Section 8B.

303.5 Inspection of Work and Records. The Inspector shall make certain that the size, length, location and quality of all welds conform to the requirements of this Manual and the approved Shop Draw-
ings and that no unspecified welds have been added without approval of the DCES. The Inspector shall make certain that only welding procedures which meet the provisions of Section 8A, Welding Procedure Qualification, are employed.

The Inspector shall make certain that electrodes for the SMAW and FCAW processes are used only in the positions and with the type of welding current and polarity for which they are qualified. The Inspector shall, at suitable intervals, observe the technique and performance of each welder, welding operator, and tacker to make certain that the requirements of Section 7B, Workmanship and Technique are met.

The Inspector shall examine the work to make certain that it meets the requirements of this Manual as applicable. Size and contour of welds shall be measured with suitable gauges. Visual inspection for cracks in welds and base metal and other defects and/or discontinuities shall be aided by strong light, magnifiers and other devices that may be found helpful. The Inspector shall identify with a distinguishing mark all parts or joints that he has inspected and accepted or rejected.

The Inspector shall keep a record of qualification for welders, welding operators, and tackers, all procedure specifications, procedure qualification test results, material certifications, heat-shrink procedures, approved repair procedures and all other reports of visual inspection and nondestructive tests required by the Contract Documents.

303.6 Photographs and Drawings. When defects are discovered and material is rejected, the DCES may require photographs and dimensioned drawings to accompany the repair procedure submitted by the Contractor to aid in the evaluation of the repair procedure. The same provision shall apply to any structural steel rejected for workmanship deficiencies, failure to meet dimensional tolerances, or damage due to rough handling or accident. In addition, the State may require photographs of specific work or assembly conditions during shop fabrication that are a proper part of the permanent job record. When the DCES requests photographs of any portion of the shop fabrication, the Contractor may furnish the photographs at no additional cost to the State or allow the State to take the photographs. The Contractor shall have the right to direct the taking of photographs so that only the work is recorded and so that no procedure or equipment that is the private development (industrial secret) of the fabricator is revealed.

303.7 Inspector's Mark ofAcceptance for Shipment. When the structural steel is ready for shipment from the shop and is properly loaded on the rail cars, trucks, or barges, the Inspector representing the State shall affix the acceptance stamp of his company. This acceptance mark shall be made by paint or ink stamp placed near the erection mark on the piece. Each shipping piece, bundle, keg, box or bound pallet shall be acceptance marked by the Inspector by direct marking on the piece as described above or by acceptance marking on durable tags when the material is boxed or bundled.

Application of the Inspector's acceptance stamp implies that at the time of shipment from the shop, it was the opinion of the Inspector that the structural steel was fabricated from accepted materials by approved processes, painted and loaded for shipment in accordance with the requirements of the Contract Documents. Application of the Inspector's stamp of approval for shipment does not imply that the structural material will not be rejected by the State if subsequently found to be defective.

303.8 Report of Shipment of Structural Material (Form B and GC 4b). The acceptance document for all material subject to shop inspection is the Report of Shipment of Structural Material (Form B and GC 4b). When the material is shipped from the shop to the project or to non-shop storage, the Inspector shall complete and sign Form B and GC 4b to cover all materials subject to his inspection. This document shall indicate to the Engineer that the structural material, if not damaged by shipment, storage, erection, or subsequently found to be defective in workmanship or materials, may be paid for under the rules for payment or partial payment established by the Department.
303.9 Shipment of Rejected Material or Material Not Offered for Shop Inspection. When the Contract Documents indicate that materials and fabrication will be subject to shop inspection, no materials will be accepted at the project that do not bear the Inspector's mark of acceptance. If it is determined that materials are not acceptance marked because they were not offered for shop inspection, or shipped after rejection at the shop, the materials shall be returned to the shop for inspection and correction as necessary. In lieu of this requirement, the State may, at its discretion, allow inspection to be performed at the project site. This work will be performed by the shop inspector or other representatives of his company and all costs for this inspection in the field shall be borne by the Contractor as a condition of the State's approval of inspection of rejected material in the field.

304. FACILITIES FOR INSPECTION

The Contractor shall provide all facilities for inspection of material and workmanship both at the producing mill and the fabricating shop. The Inspector shall be allowed free access to all parts of the premises that are used in the work. Work done while the Inspector has been refused access shall be automatically rejected.

305. INSPECTOR'S AUTHORITY

The State Inspector shall have the authority to reject materials and workmanship which do not conform to the requirements of the Contract Documents. State (QA) inspection of materials and workmanship when assigned by the DCES may be conducted before, during and after fabrication. Materials and workmanship which are inspected "in process" (while being fabricated) and which are found to contain defects or to have been subjected to damaging fabrication procedures shall be rejected while still in process. See Article 306, Obligations of the Contractor. The Inspector shall have the right to perform, at the expense of the State, nondestructive tests of materials and workmanship. State inspection at the mill and shop is a quality assurance function that may be exercised at the option of the DCES. It is intended as a means of facilitating the work and avoiding errors. It shall be expressly understood that it will not relieve the Contractor of his responsibility to perform both Quality Control and Quality Assurance inspection and tests to insure that his products meet the requirements of the Contract Documents and shall not relieve the Contractor of his responsibility concerning unacceptable materials and workmanship and the responsibility to acceptably repair or replace the same as described in Article 306.

Inspection by State representatives is not a substitute for Quality Control and Quality Assurance by the Contractor.

306. OBLIGATIONS OF THE CONTRACTOR

The Contractor shall be responsible for the acceptability of his products. His QC and QA Inspectors shall make all necessary visual inspections prior to assembly, during assembly, during welding and after welding to insure that materials and workmanship meet the requirements of the Contract Documents. The Contractor shall comply with all requests of the QA Inspector (his own employee or the State Inspector, as appropriate) to correct deficiencies in materials and workmanship as provided in the Contract Documents.

In the event that faulty welding, or its removal for rewelding, damages the base metal so that, in the judgment of the State, its retention is not in accordance with the intent of the Contract Documents, the Contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the DCES.

When nondestructive testing other than visual inspection is specified in the Contract Documents, it shall be the Contractor's responsibility to insure that all welds meet the quality requirements for the specified nondestructive test.
If nondestructive testing other than visual inspection is not specified in the original Contract Document but is subsequently requested by the State, the Contractor shall perform any required testing or shall permit testing to be performed by the State. Nondestructive tests shall conform to the requirements of Sections 16, 17, 18 or 19 as ordered by the DCES. The State shall be responsible for all associated costs including handling, surface preparation, nondestructive testing and the repair of discontinuities other than those that would be expected to be discovered by visual inspection or discovered by testing specified in the Contract Documents. The rates for work associated with nondestructive testing ordered after execution of the Contract Document shall be agreed upon between the State and the Contractor. However, if such testing should disclose an attempt to defraud or gross nonconformance to requirements of this Manual, repair work and/or replacement shall be done at the Contractor's expense.

307. NONDESTRUCTIVE TESTING

307.1 General. When nondestructive testing other than visual inspection is required, it shall be described in the Contract Documents. This information shall designate the categories of welds to be examined, the extent of examination of each category, and the method or methods of testing.

Welds that do not meet the requirements of this Manual shall be repaired by methods described in Section 7B, Workmanship and Technique, or as approved by the DCES. When radiographic testing is used, the procedures and techniques shall be in accordance with the provisions of Section 16 of this Manual. When ultrasonic testing is used, the procedures and techniques shall be in accordance with the provisions of Section 17 of this Manual. When magnetic particle testing is used, the procedures and techniques shall be in accordance with the provisions of Section 18 of this Manual. When dye penetrant testing is used for detecting discontinuities that are open to the surface, dye penetrant testing shall be performed by procedures and techniques that conform to the requirements of Section 19 of this Manual.

307.2 Personnel Qualification. Personnel performing radiographic, magnetic particle and dye penetrant tests shall be qualified in accordance with the current edition of the American Society for Nondestructive Testing, Recommended Practice Number SNT-TC-1A. Only individuals qualified for NDT Level I and working under the supervision of an individual qualified to NDT Level II, or individuals qualified for NDT Level II, may perform the above nondestructive tests.

Personnel performing ultrasonic tests shall be qualified by a written examination and performance test administered by the DCES.

308. MILL AND SHOP INSPECTION

All fabricated metal products furnished shall be subject to shop inspection by the State unless otherwise provided in the Contract Documents or waived by the DCES. Steel not permitted to be furnished as stock steel under the conditions set forth herein shall be subject to mill inspection, unless the producing mill is exempt from routine State inspection based upon acceptance of the mill's internal Quality Control and Quality Assurance programs by the DCES. A copy of the producing mill and/or foundry QC/QA Procedure Manual shall be submitted to the DCES for approval prior to beginning the work, if the producer wishes to be considered for exemption from routine State inspection, sampling and tests. The products from approved mills will be accepted based upon certification acceptance of the plate, shapes, castings and/or forgings as appropriate.

Producing mills and/or foundries outside the United States and Canada will be subject to inspection and approval by the DCES prior to beginning the work, as required by the section of the Standard Specifications entitled "Control of Material".
SECTION 4
GENERAL FABRICATION REQUIREMENTS

401. MINIMUM SHOP FACILITIES FOR FABRICATION

The Contractor (Fabricator) shall provide sufficient lifting capacity, physical plant and equipment for the fabrication and painting of structural steel. A minimum of two overhead cranes shall be provided. The cranes in each working area shall have a combined rated capacity equal to the lifting weight of the heaviest assembly fabricated for shipment unless alternate lifting and turning facilities are approved by the DCES.

Lifting chains shall be provided with adequate softeners to prevent damage to the corners of material during lifting and turning. If hooks are used for lifting, they shall have sufficient width of jaw and throat to prevent damage to the flanges or to the web-to-flange welds.

Spreader beams, or multiple cranes, shall be provided for lifting plates and long slender members to prevent overstress and distortion from handling.

Shops shall have sufficient enclosed floor spaces to allow all oxygen cutting, air carbon arc gouging, assembly, welding and painting to be performed inside, except that shop assembly of field connections for trusses, girders and arches may be performed outside the shop buildings.

The DCES will approve limited fabrication, welding and painting outside the shop, provided the fabricator has made provisions to insure that the quality of work produced outside the shop buildings will not be adversely affected by weather or other conditions.

All cutting, fitting, welding and painting shall be done in areas that are kept dry. Further, areas for automatic and semiautomatic welding shall be kept at a temperature not lower than 40°F for at least one hour before work begins and at all times when work is being performed. In painting areas, the steel shall be at a temperature not lower than 40° F upon application of paint and shall remain at 40°F minimum until the paint is dry.

Unless modified by other provisions of the Contract Documents, fully automatic welding equipment shall be provided for making all flange-to-web welds and for attaching all stiffener and connection plates to webs of welded plate girders. Web to flange welds in box girders, arches, towers and truss web and chord members shall be made by fully automatic welding equipment unless otherwise approved by the DCES. Semiautomatic (hand-guided) or fully automatic welding equipment shall be used for all other principal welds.

The use of the Manual Shielded Metal Arc process shall be limited to welding connection plates to rolled beams, welding bearing assemblies, minor detail attachments, and other limited welding applications where the use of automatic or semiautomatic welding equipment is impractical because of limited access, or the isolated location and short length of welds involved.

All welders using the Flux Cored Arc Welding or Manual Shielded Metal Arc Welding processes shall have access to a power chipper or needle descaler and to an air carbon arc gouger at all times.

402. ORDERING OF MATERIALS

The Contractor shall bear all costs for damages which may result from the ordering of materials prior to the approval of the shop drawings as described in Article 202, unless the State makes changes in the principal controlling dimensions and material properties, as described in Article 201, after the opening of bids.
403. COMMENCEMENT OF SHOP WORK

No shop work shall be started until the shop drawings have been approved. Any shop work started prior to the approval of shop drawings shall be done at the Contractor’s risk.
SECTION 5
BASE METAL

501. GENERAL

This Manual covers structural steels used in bridge and building construction that have a specified minimum yield point of 50 ksi or less. All steel shall be furnished in accordance with the provisions of the applicable material specification shown in the Contract Documents. Unless otherwise specified, structural steel shall conform to material specification entitled "Structural Steel" in the Standard Specifications.

Stock steel will be accepted for miscellaneous parts not subject to calculated stress. No mill inspection will be required for stock steel. Stock steel will be accepted on the basis of the results of chemical analysis and mechanical tests performed by the manufacturer.

502. WELDED STRUCTURAL STEELS

502.1 Specifications. Steel to be welded shall conform to the requirements of the latest edition of one of the following material specifications:

a) Standard Specification for Structural Steel (ASTM A36)
b) Standard Specification for High-Strength Low-Alloy Structural Manganese Vanadium Steel (ASTM A441)
c) Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes (ASTM A500 - Grade B)
d) Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing (ASTM A501)
e) Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality (ASTM A572-Grade 50)
f) Standard Specification for High-Strength Low-Alloy Structural Steel with Minimum Yield Point to 4 inches thick (ASTM A588)
g) Standard Specification for High-Strength Low-Alloy Structural Steel (ASTM A242)
h) Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless (ASTM A53-Grade B)
i) Standard Specification for Welded and Seamless Steel Pipe Piles (ASTM A252-Grade 2)

502.2 Additional Requirements.

a) Steel conforming to ASTM A242, A500-Grade B and A501 shall not be used unless specified in the Contract Documents or approved by the DCES. A500-Grade B and A501 steels may not be suitable for dynamically loaded members in welded structures, where low-temperature notch toughness properties are important.

b) When an ASTM A242 type of low-alloy structural steel is considered for use, it shall be subject to a special investigation as to weldability by the DCES and the DCES shall specify all pertinent information covering material, design and workmanship not covered by these Specifications.

c) When a structural steel other than those listed above is approved and such steel is proposed for welded construction, the weldability of the steel and the procedure for welding it shall be established by qualification tests in accordance with the requirements of Section 8, Qualification, and such other requirements as prescribed by the DCES.
d) Combinations of any of the steel base metals listed in Article 502.1 may be welded together. In joints involving combinations of base metals, welding preheat shall be in accordance with Table 708 for the higher strength steel being welded.

503. STEEL FOR PINS, ROLLERS AND EXPANSION ROCKERS

Steel for pins, rollers and expansion rockers shall conform to Article 502.1 a), b), e), f), or ASTM A668, Class C, D, F, or G as specified in the Contract Documents.

504. BACKING, EXTENSION BARS, AND RUN OFF PLATES

504.1 Backing. Backing used for welding steels listed in Article 502.1 may conform to any of the specifications listed in that Article, except that back up bars which are to be left in place on weathering steels shall be of matching chemistry.

504.2 Extension Bars and Run Off Plates. Extension bars and run-off plates for steels listed in Article 502.1 may conform to any of the specifications listed in that Article, or may meet the chemical requirements of steels designated AISI 1015 thru 1020.

505. INTERNAL SOUNDNESS OF PLATES AND SHAPES

505.1 Laminar Defects at Edges and Ends.

a) Detection of Defects. All plates and shapes shall be subject to a careful visual inspection of edges and ends for the presence of laminar discontinuities and inclusions. The Inspector shall also determine by visual inspection that the steel contains no detrimental discontinuities and that it meets the requirements of ASTM Designation A6 unless otherwise specified.

b) Repair of Defects. Rejection or repair of laminar discontinuities discovered in the edges of plate up to 4 inch maximum thickness or shapes is described in Table 505, Visual Inspection and Repair of Edges of Plates and Shapes. Laminar defects in the edges of shapes discovered by visual examination will be subject to repair or replacement as determined by the DCES. Acceptance, rejection, or repair of steel greater than four inches thick that contains visible discontinuities in edges or ends will be determined under provisions established by the DCES.

505.2 Laminar Defects at Tension Groove Welds

a) Detection of Defects. The following sequence will be used to determine if rejectable laminar defects are present at the boundary of tension groove welds:

1) If during visual inspection, laminar defects are discovered at any location in a plate or shape, the end two feet adjacent to the tension groove weld and the edge to be welded will be subject to magnetic particle inspection.

2) If during the magnetic particle inspection any laminar defects are discovered, ultrasonic testing will be used to search the end 6 inches of the plate or shape adjacent to the tension groove weld.

3) When ultrasonic testing is required, the test procedure described in Article 1708.4 shall be used to determine if the laminar defects are rejectable. This UT inspection shall be performed by the Contractor and witnessed by the Inspector.

4) If the plate is found acceptable by ultrasonic testing, and it is found during magnetic particle inspection that the sum of laminar defect lengths at the boundary of the tension
b) Repair of Defects. When the above inspection procedures reveal rejectable defects at the boundary of a tension groove weld, one of the following methods of repair may be approved in lieu of replacement of the entire plate.

1) When the sum of the length of all laminar defects is between 15% and 30% of the length of the joint, and when the end 6 inches of the plate is not rejectable by ultrasonic testing, the defective portion of the end of the plate may be excavated by air carbon arc gouging and the laminated steel replaced by sound weld metal.

The cavity in the edge or end of the plate and any excavation from a plate surface shall have a minimum radius of 1/4 inch at the root and the sides shall slope back to provide a minimum angle of 20° at the sides of the excavation and 45° at the ends. An approved welding procedure shall be used to fill the repair excavation and the excess weld metal shall be ground flush. At the completion of welding, the end six inches shall be retested by the ultrasonic test procedure described in this Manual to insure the complete removal of the laminar defects. The area repaired by welding shall also be inspected for weld defects by radiographic inspection.

The repair procedure shall be submitted to the DCES for approval prior to the initiation of repairs.

2) When the sum of the length of all laminar defects exceeds 30% of the length of the joint, the end portion of the plate may be removed and replaced to eliminate the defective portion of the plate. The replacement material may be obtained from stock if the heat identity is known and acceptable mill test reports are available. The minimum length of added plate shall be 5 feet unless otherwise approved by the DCES. A longer plate may be required to insure an area free of laminations at the boundary of the additional tension groove weld. The additional butt weld resulting from the added plate shall be subject to radiographic inspection in addition to the originally detailed weld inspection required by the Specifications. The direction of rolling of the replacement plate shall be parallel to the length of the member. The repair procedure shall be submitted to the DCES for approval and shall be shown as a revision to the approved shop drawings prior to the final acceptance of the repair.

506. STRAIGHTENING MATERIAL PRIOR TO FABRICATION

All deformed structural material shall be properly straightened prior to being laid out and worked in the shop. Sharp kinks and bends shall only be straightened with the approval of the DCES. Main material i.e., components of principal supporting members subject to calculated stress, shall not be bent cold without the approval of the DCES. Heat straightening shall be done in accordance with the provisions of Section 15, Heat Curving, Cambering, and Straightening.

507. DIRECTION OF ROLLING

All primary stress carrying material shall be ordered and prepared so that the direction of rolling is parallel to the direction of the main stress (compression or tension) in the member. This requirement shall apply to the following elements:

a) Flange and web plates of all stringers, girders, box girders, towers, arches and truss members.
b) Splice plates and truss gusset plates.
c) Lateral connection plates welded to flanges and webs of stringers, girders or box girders.
TABLE 505 — VISUAL INSPECTION AND REPAIR OF EDGES OF PLATES AND SHAPES (4" AND UNDER IN THICKNESS)

<table>
<thead>
<tr>
<th>Description of Discontinuity</th>
<th>Repair Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any discontinuity 1&quot; in length or less</td>
<td>None — need not be explored</td>
</tr>
<tr>
<td>Any discontinuity over 1&quot; in length and 1/8&quot; maximum depth</td>
<td>None — depth shall be explored by random spot grinding well faired in order not to create notches in the plate edge</td>
</tr>
<tr>
<td>Any discontinuity over 1&quot; in length with depth over 1/8&quot; but not greater than 1/4&quot;</td>
<td>Remove by grinding or air carbon arc gouging followed by grinding. The excavation shall be well faired in order not to create notches in the plate edge</td>
</tr>
<tr>
<td></td>
<td>If the removal of a discontinuity reduces the net cross section area of the plate by more than 5%, the resultant cavity shall be filled by welding**</td>
</tr>
<tr>
<td></td>
<td>Aggregate length of welding shall not exceed 20%* of plate edge length being repaired</td>
</tr>
<tr>
<td>Any discontinuity over 1&quot; in length with depth over 1/4&quot; but not greater than 1&quot;</td>
<td>Completely remove and weld. Aggregate length of welding shall not exceed 20%* of plate edge length being repaired**</td>
</tr>
<tr>
<td>Any discontinuity over 1&quot; in length with depth greater than 1&quot;</td>
<td>Subject to approval by the DCES. Gouge out to 1&quot; and block off by welding.</td>
</tr>
<tr>
<td></td>
<td>Aggregate length of welding shall not exceed 20%* of plate edge length being repaired.**</td>
</tr>
</tbody>
</table>

*Defects exceeding this length require the approval of the DCES before being repaired.
**Repair welding of tension members will be subject to radiographic inspection.

NOTES:
1. This specification applies only to edges which will not be joined by welds subject to calculated stress. This specification does not apply to any plate or shape that is subject to stress across its thickness (i.e., in “Z” direction).

2. Length of a defect is the visible long dimension on an edge. Depth is the distance that the defect extends into the plate or shape from the edge.

3. All manual welding shall be performed by qualified welders using low-hydrogen electrodes. Submerged Arc Welding and Flux Cored Arc Welding with external gas shielding may also be used with approved procedures. Cavities resulting from the removal of discontinuities shall be prepared prior to repair welding with a minimum radius of 1/4 inch and a minimum included angle of 20 degrees. When plate thickness is not sufficient for such preparation, repair welding will not be permitted.
SECTION 6
PREPARATION OF BASE METALS

601. OXYGEN CUTTING - GENERAL

Steel and weld metal may be oxygen cut provided a smooth and regular surface, free from cracks and notches is obtained. All oxygen cut surfaces shall be produced using a mechanically guided torch unless otherwise approved by the DCES. Oxygen cut surfaces produced by a manually guided torch, when allowed, shall be smoothed by machining or grinding.

In all oxygen cutting, the cutting flame shall be adjusted and manipulated to avoid cutting beyond (inside) the prescribed lines. The roughness of oxygen cut surfaces shall not exceed the American National Standards Institute surface roughness value of 1000 microinches for material up to 4 inches thick and 2000 microinches for material 4 inches to 8 inches thick, except, at the dead ends of members where there is no calculated stress, the roughness shall not exceed 2000 microinches. Roughness exceeding these values and occasional notches or gouges no more than 1/4 inch deep on otherwise satisfactory surfaces shall be removed by machining or grinding. Cut surfaces and edges shall be free of slag. Correction of discontinuities shall be fairied to the oxygen cut surfaces with a slope not exceeding 1 in 10.

Occasional notches or gouges that exceed 1/4 inch shall be repaired by welding. The repair of notches or gouges over 7/16 inch deep shall be referred to the DCES prior to repair. Welding repairs shall be made by suitably preparing the discontinuity, welding with an approved process after preheating in accordance with Table 708 and grinding the completed weld smooth and flush with the adjacent surface to produce a workmanlike finish. All welded repairs to main material subject to tensile stress shall be tested by ultrasonic or radiographic inspection as determined by the DCES.

Reentrant corners shall be filleted to a radius of not less than 3/4 inch. On main material a 2 inch minimum radius shall be provided wherever possible. The radius and its contiguous cuts shall meet without offset or cutting past the point of tangency.

602. OXYGEN CUTTING OF HIGH STRENGTH STEEL (50,000 psi minimum yield strength)

The Contractor (Fabricator) shall take steps to insure that the flame cut edges of main material are not hardened by the cutting process. This may be achieved by preheating, post heating or control of the burning process. Flame cut edges found to have a Rockwell Hardness Value of C 30 or greater will be considered unacceptable. A portable Rockwell Hardness Tester will be employed by the Inspector to determine conformance with these requirements. Unacceptably hard surfaces shall be removed by grinding, machining, or approved heat treating procedures.

603. SURFACES AND EDGES TO BE WELDED

Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks and other discontinuities which would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to a weld shall also be free of loose or thick scale, slag, rust, moisture, grease and other foreign material that will prevent proper welding or produce objectionable fumes. Mill scale that withstands vigorous wire brushing, a thin rust inhibitive coating, or antispatter compound may remain except that all mill scale shall be removed from the surfaces on which flange-to-web welds are to be made by any of the approved welding processes. This provision shall apply to all girders, stringers, beams, bridge columns, bents, towers, rigid frames, arches, truss chords and truss web members. The provision for removal of all mill scale prior to making web-to-flange welds shall not apply to secondary members, building columns or to members subjected to general blast cleaning prior to welding, where essentially all mill scale has been removed and no harmful rusting has occurred subsequent to blast cleaning, as determined by the Inspector. No mill scale shall be permitted to remain in the boundary of a groove weld subject to tensile stresses resulting from the design loads.
Unless otherwise specified, edges of material thicker than specified in the following list shall be oxygen cut to produce a satisfactory welding edge wherever a weld along the edge is to carry calculated stress:

Sheared edges of material thicker than ................................................. 1/2 inch
Rolled edges of plates (other than
Universal Mill plates) thicker than ............................................. 3/8 inch
Toes of angles or rolled shapes (other than
wide flange sections) thicker than ......................................... 5/8 inch
Universal Mill plates or edges of flanges of
wide flange sections thicker than ........................................... 1 inch

The form of edge preparation for butt joints shall conform to the requirements of Article 703.3 except as modified by Article 702. Machining, air carbon arc gouging, oxygen cutting, chipping, or grinding may be used for joint preparation, back gouging, or the removal of defective work or material. All air carbon arc gouged surfaces shall be ground after gouging to remove any carbon pick-up.

604. FLANGE PLATES

All flange plates shall be furnished with either oxygen cut edges which have the corners chamfered at least 1/16 inch by grinding or Universal Mill plates unless oxygen cut edges are required by the Contract Documents under the provisions of Section 9, Fracture Control Plan.

605. WEB PLATES

Web plates of built-up beams and girders, box girders and box arches shall be oxygen cut to produce the prescribed camber. The fabricator shall cut sufficient extra camber into the webs to provide for all camber losses due to welding, cutting, heat curving, etc.

606. TRUSS MEMBERS

All plates in welded sections of truss web and chord members shall have their longitudinal edges prepared by oxygen cutting. Edges of plates not joined by welding shall have the corners chamfered at least 1/16 inch by grinding.

607. STIFFENERS AND CONNECTION PLATES

Stiffeners and connection plates welded transverse to girder webs and flanges may be furnished with sheared edges provided their thickness does not exceed 3/4 inch. Universal Mill plate may be used provided its thickness does not exceed 1.0 inch. All other stiffeners and connection plates shall be furnished with oxygen cut edges. Stiffeners and connection plates shall be prepared with clipped corners (snipes) to provide clearance for the web to flange fillet welds. The dimension of the snipe in the vertical direction shall be 5 times the web thickness. In the horizontal direction, the snipe shall generally be 1 ½ inch maximum.

608. LATERAL GUSSET PLATES

Gusset plates and other connections welded parallel to lines of stress in tension members shall have the sides parallel to the lines of stress oxygen cut whenever their thickness exceeds 3/8 inch. Bolted lateral gusset plates may be furnished with sheared edges provided the thickness does not exceed 3/4 inch.

609. SPLICE PLATES AND GUSSET PLATES

Girder and stringer splice plates and truss gusset plates shall be furnished with oxygen cut edges.
610. SHEARED EDGES

Unless otherwise specified, sheared edges of plates thicker than 3/4 inch shall be removed to a depth of 1/4 inch beyond the original sheared edge or beyond any reentrant cut produced by shearing. This may be accomplished by oxygen cutting or edge planing.

611. BENDING OF STRUCTURAL STEEL

Unless otherwise approved by the DCES, there shall be no cold or low heat bending of main material. To facilitate bending, the steel shall be heated between 1100° and 1200° F over the entire area and cross section to be bent. Heating methods and equipment shall be as described in Section 15, Heat Curving, Cambering, and Straightening.

When flange plates are required to be bent to a radius of 2 feet or less, the area to be bent shall be heated for the full width of the flange and for a length of at least six times the thickness of the flange. No bending force shall be applied until this entire area is heated to a temperature between 1100° and 1200°F. After bending is complete, and the temperature of the plate has cooled to ambient temperature, all surfaces of the heated area shall be magnetic particle inspected in accordance with Section 18.

612. MACHINING OF CONTACT SURFACES

612.1 Bearing Surfaces. The surface finish of bearing and base plates and other bearing surfaces which are to come in contact with each other or with concrete shall meet the American National Standard for Surface Roughness as defined in ANSI B46.1, Surface Roughness, Waviness and Lay, Part 1.

Steel slabs or plates in contact with a concrete surface: ANSI 2000

Heavy plates in contact as part of bearing assemblies which are welded: ANSI 1000

Ends of compression members, bearing stiffeners and fillers in compression: ANSI 500

Rollers and rockers: ANSI 250

Pins, pin holes, rotating portion of top of rockers and rocker sockets in sole plates: ANSI 125

Sliding bearing - steel to copper alloys or steel to stainless steel: ANSI 125

Sliding bearing - stainless steel to polytetrafluoroethylene (PTFE): ANSI 5

(No. 8 bright mirror finish)

Sliding bearings with a surface roughness greater than ANSI 60 shall be machined so that the lay of the cut is parallel to the direction of movement.

Machined surfaces shall be plane and true conforming accurately to the dimensions shown on the plans.

Machined surfaces designed to be flat shall be flat within 0.010 inch.

Parts in bearing shall have uniform even contact with the adjacent bearing surface when assembled. The maximum gap between bearing surfaces shall be 0.040 inches unless a closer tolerance is specified. Base and sole plates which are plane and true and which have a surface roughness not exceeding the above tabulated values need not be machined, except that, sliding surfaces of base plates must be machined.

Surfaces of fabricated members shall not be machined until all fabrication on that particular assembly or subassembly is complete. Metal components that are to be heat treated shall be machined after heat treatment.
612.2 Abutting Joints. Abutting compression members shall be machined as specified above unless the Contract Documents indicate otherwise. Ends of abutting tension members shall be machined or machine burned to an ANSI surface roughness value not exceeding 1000 microinches to secure close and neat but not contact fitting joints. When the design is based upon transmitting all stress through the fasteners, the Contract Documents may detail all joints open 1/4 inch maximum, in which case ends of members will be treated as abutting tension members regardless of direction of stress.

612.3 End Connection Angles. End connection angles of floor beams and stringers shall be flush with each other and accurately set as to position and length of member. In general, end connection angles shall not be finished unless required by the Contract Documents. However, faulty assembling and connecting may be cause for requiring them to be milled, in which case their thickness shall not be reduced by more than 1/16 inch, nor shall their fastener bearing value be reduced below design requirements. End connection angles shall be milled after assembly to floor beams when called for on the Plans.

613. BOLT AND RIVET HOLES IN PRIMARY STRESS CARRYING MEMBERS

613.1 General. All holes in the following components of main members shall be subpunched and reamed, subdrilled and reamed, or drilled from the solid:

a) Webs and flanges of girders, box girders, stringers, floor beams, arches, towers, bents and rigid frames.

b) Lateral connection plates that are welded to tension flanges of the members listed above.

c) Hangers, connection plates, splice plates and gusset plates which support the members listed above.

613.2 Holes in Trusses. Unless otherwise stated in the Contract Documents, all trusses, regardless of type or size, shall be subject to general reaming.

When general reaming is required, all rivet or bolt holes in main members shall be subpunched and reamed, subdrilled and reamed, or drilled from the solid. This requirement shall not apply to holes in top and bottom chord lateral members, truss sway bracing, and lateral plates, connection angles, etc., connecting these members to main members of the structure. Connection plates or other parts acting both as main member material and secondary member material (lateral, sway bracing, etc.) shall have subpunched or subdrilled and reamed or drilled holes in locations engaging similar holes in main members.

Reaming or drilling shall be done after mating pieces are assembled to the control lines approved on the Shop Drawings and firmly bolted together. Reamed or drilled parts shall not be interchanged.

613.3 Drilled Holes. Drilled holes shall be 1/16 inch larger than the nominal diameter of the fastener. Burrs on the surfaces shall be removed by a method which leaves the hole free of burrs inside and out. The method shall not dish-out (reduce its thickness) the metal in the vicinity of the hole.

613.4 Reaming of Subsize Holes. After reaming is completed, the holes shall be 1/16 inch larger than the nominal diameter of the fastener. The size of the subsize hole shall be as follows:

a) For bolts or rivets greater than 3/4 inch diameter, the subsize hole shall be 3/16 inch smaller than the nominal diameter of the fastener (1/4 inch smaller than the final hole diameter).

b) For bolts or rivets of 3/4 inch diameter or less, the subsize hole shall be 1/16 inch less than the nominal diameter of the fastener (1/8 inch smaller than the final hole diameter).
For subpunched holes, the diameter of the die shall not exceed the diameter of the punch by more than 1/16 inch. The subpunched hole shall be clean cut, without torn or ragged edges.

When members are required to be reamed assembled, the subsize holes shall be so accurately done that, after assembling the component parts of a member or an assembly of connecting members and before reaming, a cylindrical pin 1/8 inch smaller than the nominal diameter of the punched hole may be passed through at least 75% of any group of contiguous holes in the same surface. If this requirement is not fulfilled, the pieces shall be rejected. If any such hole will not pass a pin 3/16 inch smaller than the nominal diameter of the subsize hole, this shall be cause for rejection. The requirement for the fitting of subsize pins during assembly is to insure that when reaming is performed, all cold worked (punch sheared) material will be removed from surfaces of the hole and to provide the hole quality required by these specifications. For subpunched holes, the depth of removal shall be 1/16 inch minimum. If the accuracy of subpunched work will not guarantee this hole quality when reamed, the size of the subpunched hole shall be reduced so that reaming will remove all cold worked material.

Reamed or drilled parts shall not be interchanged. Burrs resulting from reaming shall be removed as stated in Article 613.3. Reaming of fastener holes shall be done with twist drills or with tapered reamers. Reamers preferably shall not be guided by hand. No oil or grease shall be used as a lubricant unless all such material is removed by solvent cleaning before final assembly, painting and shipment. Any drift pinning done during assembly shall be only the minimum necessary to bring the parts into position, and not sufficient to enlarge the holes or distort the metal.

Holes drilled from the solid shall be accurately placed, perpendicular to the faying surface, cylindrical, and shall show no offset between adjacent plies.

Holes which are to be reamed shall have been accurately subpunched or subdrilled and the assembled parts, before reaming, shall conform to the requirements specified above. After reaming, the holes shall be perpendicular to the faying surface and 75% of any group of contiguous holes in the same surface shall show no elongation of the hole greater than 1/32 inch. The remainder of the holes shall not be elongated greater than 1/16 inch.

614. BOLT AND RIVET HOLES IN SECONDARY MEMBERS AND COMPONENTS

614.1 General. Secondary members and components are those members that are not described as primary stress carrying members in Articles 613.1 and 613.2 and do not support main members. Holes in secondary members may be made by any method described in Article 613.1 or they may be punched full size when the thickness of the steel does not exceed 3/4 inch. For punched holes, the diameter of the die shall not exceed the diameter of the punch by more than 1/16 inch. Holes must be clean cut without torn or ragged edges.

614.2 Size of Holes in Secondary Members. Standard size holes may be used in all plies of secondary members. Oversize holes may be used at locations described in Article 203.10. The diameter of oversize holes shall be 3/16 inch larger than bolts 7/8 inch and less in diameter, 1/4 inch larger than bolts inch in diameter, and 5/16 inch larger than bolts 1 1/8 inch and greater in diameter.

615. PINS AND ROLLERS

615.1 General. The material furnished for pins and rollers shall conform to the requirements of Article 503 unless otherwise specified in the Contract Documents. Pins and rollers shall be accurately manufactured to the dimensions shown on the plans. The surface finish shall be as required by the Specifications. Pins larger than 9 inches in diameter shall have a hole not less than 2 inches in diameter bored longitudinally through their centers. The hole shall be bored before the pin is subjected to heat treatment. Boring shall be conducted in a manner that will prevent injury to the pin. Pins which contain interior defects shall be rejected. The minimum radius on any reentrant cut machined in a pin or roller shall be 1/4 inch.
615.2 **Boring Pin Holes.** Holes for pins shall be bored true to detail dimensions, smooth and straight, normal to the axis of the member and parallel with any other pin hole in the same member unless otherwise required. A finishing cut shall always be made. The length outside to outside of holes in tension members and inside to inside of holes in compression members shall not vary from detailed dimensions more than 1/32 inch. Boring of holes in fabricated members shall be done after the riveting, bolting or welding is completed.

615.3 **Pin Clearances.** The diameter of the pin hole shall not exceed that of the pin by more than 0.020 inch for pins 5 inches or less in diameter, or 0.035 inch for larger pins.

615.4 **Pin Threads.** Pin threads shall make close fits in the nuts and shall meet the American National Standards Institute requirements for unified screw threads (ANSI B1.1) except that for diameters greater than 1 1/2 inches, pins shall be made with 6 threads per inch.

615.5 **Pilot and Driving Nuts.** Two pilot nuts and two driving nuts shall be furnished for each size of pin, unless otherwise specified.

616. BRONZE SURFACED EXPANSION BEARINGS

Bronze surfaced bearings shall be fabricated as follows. The bronze surfacing shall be deposited on the steel base plate by the oxy-acetylene or the manual shielded metal arc welding process. The bronze electrodes and/or filler metal shall be of a size and type approved by the DCES. Electrodes conforming to AWS A5.6, Specification for Copper and Copper Alloy Covered Electrodes, Classification E CuAl-A2 and E CuAl-B are acceptable for SMAW welding.

A suitable flux shall be used when the oxy-acetylene welding process is utilized. The type of flux shall be as approved by the DCES. The surface of the steel base plate that is to receive the bronze deposit shall be thoroughly cleaned of all dirt, oil, grease, mill scale and oxides by grinding or sandblasting prior to making the deposit.

A sufficient thickness of bronze shall be deposited to allow machining to a minimum retained thickness of 3/32 inch. Upon completion of machining and polishing, the finished surface of the bronze shall show no evidence of cracks, slag, or porosity exceeding the limits specified herein. Unmachined low spots and porosity not to exceed 0.050 inch in diameter will be allowed in the finished surface provided that the total area of such defects does not exceed 0.05 percent of the total area of bronze on any one plate and further provided that the total area of such defects in any square inch of the finished surface shall not exceed 0.01 square inches. Low spots, porosity, voids or holidays larger or more numerous than stated above may be repaired by grinding to sound metal and depositing additional bronze in the area, followed by remachining to the required dimensions. Warping of the plate may be counteracted by bending the steel plate in the opposite direction to which warping may take place prior to making the deposit. Any warp remaining in the piece after welding and cooling shall be removed prior to machining.

The bronze surface shall be machined as a sliding bearing under the provisions of Article 612, Machining of Contact Surfaces.

At the Contractor's option, bronze surfaced expansion bearings may be fabricated by welding 1/4 inch thick bronze plate or 1/8 inch thick bronze sheet to metal backing. The bronze shall conform to ASTM B100, Copper Alloy No. 510 or 511, or ASTM B22, Copper Alloy No. 911 or 913 unless otherwise specified. Attachment shall be by fillet welds or a combination of fillet welds and plug welds or by brazing as approved by the DCES. If the bronze surface is plane and true within 0.010 inch after welding, there need be no machining of the bronze surface. Machining shall not reduce the bronze thickness to less than 3/32 inch at any location.
701. EFFECTIVE DESIGN DIMENSIONS

701.1 Groove Welds.

701.1.1 Effective area. The effective area of any groove weld is the effective weld length multiplied by the effective throat.

701.1.2 Effective length. The effective weld length for any groove weld, square or skewed, is the width of the part joined, perpendicular to the direction of stress.

701.1.3 Effective throat. The effective throat of a complete joint penetration groove weld is the thickness of the thinner part joined with no increase for weld reinforcement.

The effective throat (E) of a partial joint penetration groove weld shall be the depth of chamfer (S), when the included angle at the root is 60 degrees or greater.

The effective throat (E) of a partial joint penetration groove weld shall be the depth of chamfer (S), less 1/8 inch, when the included angle at the root is between 45 degrees and 60 degrees.

The minimum effective throat of a partial joint penetration groove weld shall be as specified in Table 703.4.

The effective throat for flare groove welds when filled flush to the surface of the solid section of the bar shall be as shown in Table 701.1 and tested as follows:

a) Random sections of production welds for each welding procedure, or such test sections as required by the DCES, shall be used to verify that the effective throat is consistently obtained.

b) For a given set of parameters, if the Contractor has demonstrated that he can consistently provide larger effective throats than those shown in Table 701.1, he may establish the larger effective throats by qualification. Qualification shall consist of sectioning the radiused member, normal to its axis, at midlength and terminal ends of the weld. Such sectioning shall be made on a number of material sizes representative of the range used by the Contractor in construction or as required by the DCES.

<table>
<thead>
<tr>
<th>TABLE 701.1 — EFFECTIVE THROATS OF FLARE GROOVE WELDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flare-bevel-groove welds</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>All diameter bars</td>
</tr>
<tr>
<td>5/16 R</td>
</tr>
<tr>
<td>Note: R = radius of bar</td>
</tr>
</tbody>
</table>
701.2 Fillet Welds.

701.2.1 Effective area. The effective area is the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load.

701.2.2 Effective length. The effective length of a fillet weld is the overall length of the full-size fillet, including end returns. No reduction in effective length shall be made for either the start or crater of the weld if the weld is full size throughout its length.

The effective length of a curved fillet weld shall be measured along the center line of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area indicated in Article 701.3, then the area calculated by Article 701.3 shall be used as the effective area of the fillet weld.

The minimum effective length of a fillet weld shall be at least four times the nominal weld size, or 1 1/2 inches, whichever is greater.

701.2.3 Effective throat. The effective throat is the shortest distance from the root to the face of the diagrammatic weld.

701.3 Plug and Slot Welds.

701.3.1 Effective area. The effective area is the nominal area of the hole or slot in the plane of the faying surface.

701.3.2 Effective throat. The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the root to the face of the diagrammatic weld minus 1/8 inch for any groove detail requiring such reduction.

701.4 Seal Welds. Seal welding shall preferably be accomplished by a continuous weld combining the functions of sealing and strength. Seal welds should be detailed as fillet or groove welds on the shop drawings.

702. JOINT QUALIFICATION

Joints meeting the following requirements are designated as prequalified:

a) Conformance with the details in Article 703.

b) Use of one of the following welding processes in accordance with the requirements of Part B: manual shielded metal arc, submerged arc, or flux cored arc welding.

Joint details may depart from the details described in Article 703 only if the contractor submits to the DCES his proposed joints and joint welding procedures and at his own expense demonstrates their adequacy. Joints welded by procedures that do not conform to all provisions of Section 7, Welding, shall be subject to complete procedure qualification testing under the provisions of Section 8, Qualification. The joint details used in the qualification test shall be identical to those proposed for use in the work.
703. WELDING DETAILS

703.1 Fillet Welds. Fillet welds made by manual shielded metal arc, submerged arc and flux cored arc processes are considered prequalified when performed in accordance with the following. The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 703.1.

The maximum fillet weld size permitted along edges of material shall be:

a) The thickness of the base metal for metal less than 1/4 inch thick (See Figure 703.1, detail A).
b) 1/16 inch less than the thickness of base metal for metal 1/4 inch or more in thickness (See Figure 703.1, detail B), unless the weld is designated on the plans to be full throat thickness.

In general, welds joining stiffeners or connection plates to compression flanges need not exceed 5/16 inch. When larger welds are required by applied stress, it shall be noted on the Plans.

Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the provisions of Article 701.2.2. Fillet welds in holes or slots are not to be considered plug or slot welds.

Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60 degrees nor more than 120 degrees (See Figure 703.1, details C and D).

The minimum length of an intermittent fillet weld shall be four times the weld size or 1 1/2 inches, whichever is greater.

---

**TABLE 703.1 — MINIMUM SIZE FILLET WELDS**

<table>
<thead>
<tr>
<th>Material thickness of thicker part joined (inches)</th>
<th>Minimum Size Fillet Weld (inches)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bridges</td>
</tr>
<tr>
<td>To 1/2 inclusive</td>
<td>5/16*</td>
</tr>
<tr>
<td>Over 1/2 to 3/4</td>
<td>5/16*</td>
</tr>
<tr>
<td>Over 3/4 to 1 1/2</td>
<td>5/16*</td>
</tr>
<tr>
<td>Over 1 1/2 to 2 1/4</td>
<td>3/8</td>
</tr>
<tr>
<td>Over 2 1/4 to 6</td>
<td>1/2</td>
</tr>
<tr>
<td>Over 6</td>
<td>5/8</td>
</tr>
</tbody>
</table>

*Single pass welds must be used. The minimum seal shall be a 1/4 inch fillet weld.

**Weld size is determined by the thicker of the two parts joined unless a larger size is required by calculated stress. The weld size need not exceed the thickness of the thinner part joined.
703.1 Base metal less than 1/4" thick

Max. Size of Fillet Weld Along Edges

703.2 Plug and Slot Welds. Plug and slot welds made by the manual shielded metal arc, and flux cored arc welding processes as described herein may be used without performing the joint welding procedure qualification test provided the technique meets the provisions of Part B, Workmanship and Technique.

The minimum diameter of the hole for a plug weld shall not be less than the thickness of the part containing it, plus 5/16 inch, rounded to the next greater odd 1/16 inch. The maximum diameter of the hole for a plug weld shall not be greater than 2-1/4 times the depth of the weld metal filling.

The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

The length of the slot for a slot weld shall not exceed ten times the thickness of the part containing it. The minimum width of the slot shall not be less than the thickness of the part containing it plus 5/16 inch, rounded to the next greater odd 1/16 inch, nor shall it be greater than 2-1/4 times the depth of the weld metal filling.

Plug and slot welds are not permitted in quenched and tempered steels, normalized steels and fracture critical members.

The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction on any line shall be two times the length of the slot.
The depth of plug or slot welds in metal 5/8 inch thick or less shall be equal to the thickness of the material. In metal over 5/8 inch thick, it shall be at least one-half the thickness of the material but no less than 5/8 inch.

703.3 Complete Joint Penetration Groove Welds - Prequalified Joint Details.

703.3.1 General. Complete joint penetration groove welds made by manual shielded metal arc, submerged arc, or flux cored arc welding in butt, corner, and tee-joints which may be used without performing the joint welding procedure qualification test described in Section 8, Qualification, are detailed in Figure 703.3.

For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting. It is preferred that members that will be subject to residual stress in the transverse, "z", direction be beveled to help avoid lamellar tearing.
### FIGURE 703.3 — PREQUALIFIED JOINT WELDING DETAILS

#### Square Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW/FCAW</td>
<td>B-L</td>
<td>1/4 max.</td>
<td>R = T₁/₂</td>
<td>All</td>
<td>A, C, I</td>
</tr>
<tr>
<td></td>
<td>B-L-F</td>
<td></td>
<td>R = +1/16, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>B-L-S</td>
<td>1/2 max.</td>
<td>R = 0</td>
<td>F</td>
<td>A, C, I</td>
</tr>
<tr>
<td>SMAW/FCAW</td>
<td>B-U</td>
<td>U</td>
<td>R = 0</td>
<td>All</td>
<td>B, C, I</td>
</tr>
<tr>
<td></td>
<td>B-U-F</td>
<td></td>
<td>R = +1/8, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>B-U-S</td>
<td>U</td>
<td>R = 0</td>
<td>F</td>
<td>B, C, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R = +1/16, -0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Square Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW/FCAW</td>
<td>T-L</td>
<td>1/4 max.</td>
<td>R = T₁/₂</td>
<td>All</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td></td>
<td>T-L-F</td>
<td></td>
<td>R = +1/16, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>T-L-S</td>
<td>3/8 max.</td>
<td>R = 0</td>
<td>F</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R = +1/16, -0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Square Groove Weld**

![Diagram of Square Groove Weld](image)

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW FCAW</td>
<td>C-L</td>
<td>1/4 max.</td>
<td>U</td>
<td>R = T₁/2</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>C-L-F</td>
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<td></td>
<td>R = + 1/16, -0</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td>SAW</td>
<td>C-L-F</td>
<td>3/8 max.</td>
<td>U</td>
<td>R = + 1/16, -0</td>
<td>F</td>
</tr>
</tbody>
</table>

**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE B:** Joints shall be prepared by butting two plates with zero root opening. The first side shall then be air carbon arc gouged to a depth of two thirds of the throat thickness. After welding the first side to a sufficient depth to prevent weld cracking, the second side shall be air carbon arc gouged to sound weld metal and then welded before completing the weld on the first side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum unless otherwise shown.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE D:** Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

**NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.

---

**FIGURE 703.3 (Continued)**

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39
### Square Groove Weld

#### Table 703.3 (Continued)

<table>
<thead>
<tr>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Lb</td>
<td>1/4 max.</td>
<td>R = T₁</td>
<td>All</td>
<td>C, E, I</td>
</tr>
<tr>
<td>B-Lb-F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMAW FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

#### Table 703.3 (Continued)

<table>
<thead>
<tr>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Lb</td>
<td>1/4 max.</td>
<td>R = T₁</td>
<td>All</td>
<td>C, E, I</td>
</tr>
<tr>
<td>C-Lb-F</td>
<td></td>
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<tr>
<td>SMAW FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes:

- **NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.
- **NOTE E:** Backing for skewed joints may require shaping, bending, or beveling to provide a maximum gap of 1/16 inch between faying surfaces.
- **NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.
### Single Vee Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW FCAW</td>
<td>B-LIV</td>
<td>2&quot; max.</td>
<td>R = 0</td>
<td>R = +3/16, -0</td>
<td>All</td>
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<tr>
<td></td>
<td>B-LIV-F</td>
<td></td>
<td>f = 1/3 T, α = 60°</td>
<td>f = ±1/8, α = +10°, -5°</td>
<td>A, C, I</td>
</tr>
<tr>
<td>SAW</td>
<td>B-LIV-S</td>
<td>2&quot; max.</td>
<td>R = 0</td>
<td>R = +1/16, -0</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>f = 1/3 T, α = 60°</td>
<td>f = +1/8, -0, α = +10°, -5°</td>
<td>A, C, I</td>
</tr>
</tbody>
</table>

**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE D:** Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

**NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.

**FIGURE 703.3 (Continued)**
### Single Vee Groove Weld

- **Welding Process**: SMAW, FCAW
  - **Joint Designation**: B-UIVb, B-UIVb-F
  - **Base Metal Thickness**: T, TI
  - **Groove Preparation**:
    - **Specified Dimensions**:
      - R = 1/4, α = 45°
      - R = 3/8, α = 30°
      - R = 1/2, α = 20°
    - **Fit-Up Tolerances**:
      - R = +1/4, -0
      - α = +10°, -5°
    - **Permitted Welding Positions**:
      - All
      - F, OH
    - **Notes**:
      - C, E, I

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW</td>
<td>B-UIVb</td>
<td>U</td>
<td>R = 1/4, α = 45°</td>
<td>All</td>
<td>C, E, I</td>
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<tr>
<td>SMAW</td>
<td>B-UIVb-F</td>
<td>U</td>
<td>R = 1/4, α = 45°</td>
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<td>C, E, I</td>
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<tr>
<td>SAW</td>
<td>B-LIVb-S</td>
<td>1/2 max.</td>
<td>R = 1/4, α = 30°</td>
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<tr>
<td>SAW</td>
<td>B-LIVb-S</td>
<td>1/2 max.</td>
<td>R = 5/8, α = 20°</td>
<td>F</td>
<td>C, E, I</td>
</tr>
</tbody>
</table>

### Single Vee Groove Weld

- **Welding Process**: SMAW, FCAW
  - **Joint Designation**: C-UIVb, C-UIVb-F
  - **Base Metal Thickness**: T, T2
  - **Groove Preparation**:
    - **Specified Dimensions**:
      - R = 1/4, α = 45°
      - R = 3/8, α = 30°
      - R = 1/2, α = 20°
    - **Fit-Up Tolerances**:
      - R = +1/4, -0
      - α = +10°, -5°
    - **Permitted Welding Positions**:
      - All
      - F, OH
    - **Notes**:
      - C, E, I

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<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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<td>U</td>
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<td>C-UIVb-F</td>
<td>U</td>
<td>R = 1/4, α = 45°</td>
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<td>C, E, I</td>
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<tr>
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<td>C-LIVb-S</td>
<td>1/2 max.</td>
<td>R = 1/4, α = 30°</td>
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<td>C, E, I</td>
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<tr>
<td>SAW</td>
<td>C-LIVb-S</td>
<td>1/2 max.</td>
<td>R = 5/8, α = 20°</td>
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<td>C, E, I</td>
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**FIGURE 703.3 (Continued)**

42
Double Vee Groove Weld

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<thead>
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<th>Welding Process</th>
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<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
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<tr>
<td>SMAW</td>
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<td>R = 0</td>
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<td>A, C, I</td>
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<td></td>
<td></td>
<td>T₂</td>
<td>f = 1/8</td>
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<td></td>
<td></td>
<td></td>
<td>α = 60°</td>
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<td>S₁ = 2/3(T₁ - 1/8)</td>
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<td>FCAW</td>
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<td>R = 0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>f = ±1/8</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>α = ±10°, ±5°</td>
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<tr>
<td>SAW</td>
<td>B-U2V-S</td>
<td>U</td>
<td>R = 0</td>
<td>F</td>
<td>A, C, I</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>f = +1/16, -0</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = +10°, -5°</td>
<td></td>
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<td></td>
<td>S₁ = 2/3(T₁ - 1/4)</td>
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<td>S₂ = 1/3(T₁ - 1/4)</td>
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</table>

**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE E:** Backing for skewed joints may require shaping, bending, or beveling to provide a maximum gap of 1/16 inch between faying surfaces.

**NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.

**FIGURE 703.3 (Continued)**
### Single Bevel Groove Weld

#### Groove Preparation

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
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<th>Notes</th>
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<td>U</td>
<td>Specified Dimensions</td>
<td>Fit-Up Tolerances</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-UIB-F</td>
<td></td>
<td>R = 0</td>
<td>R = +3/16, -0</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>f = 1/3 T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>f = ±1/8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = 45°</td>
<td>α = +10°, -5°</td>
<td></td>
</tr>
<tr>
<td>SMAW</td>
<td></td>
<td>U</td>
<td>H</td>
<td>A, C, F, I</td>
<td></td>
</tr>
</tbody>
</table>

#### Welding Process Notes

- **SMAW**: Shielded Metal Arc Welding
- **FCAW**: Flux-Cored Arc Welding
- **T-UIB-F**: Tapered Unibody Groove

### Single Bevel Groove Weld

#### Groove Preparation

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>SMAW FCAW</td>
<td>T-UIB</td>
<td>U</td>
<td>Specified Dimensions</td>
<td>Fit-Up Tolerances</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T-UIB-F</td>
<td>U</td>
<td>R = 0</td>
<td>R = +3/16, -0</td>
<td>All</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>f = 1/3 T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>f = ±1/8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>α = 45°</td>
<td>α = +10°, -5°</td>
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<tr>
<td>SAW</td>
<td>T-UIB-S</td>
<td>U</td>
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<td>R = +1/16, -0</td>
<td>F</td>
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<td></td>
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<td></td>
<td>f = 1/3 T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>f = ±1/8, -0</td>
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<td></td>
<td></td>
<td>α = 60°</td>
<td>α = +10°, -5°</td>
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</tr>
</tbody>
</table>

**FIGURE 703.3 (Continued)**
After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

Square face is lower edge for horizontal position.

For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting. When thickness permits, T₁ shall be beveled to reduce the possibility of base metal separation due to weld shrinkage stresses.

Any deviation from the details shown shall be subject to approval of the DCES.
### Single Bevel Groove Weld

![Diagram of Single Bevel Groove Weld](image)

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>SMAW</td>
<td>B-UIBb</td>
<td>T₁</td>
<td>Specified Dimensions: R = 1/4, α = 45°, R = 3/8, α = 30°</td>
<td>Fit-Up Tolerances: α = +1/4, -0, α = +10°, -5°</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>.B-UIBb-F</td>
<td>T₂</td>
<td></td>
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</table>

**Dimensions Tolerances Positions**

- **R = 1/4, α = 45°**
- **R = 3/8, α = 30°**
- **α = +1/4, -0**
- **α = +10°, -5°**

**Notes:**

- C, E, F, I

---

**Single Bevel Groove Weld**

![Diagram of Single Bevel Groove Weld](image)

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
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<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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<tbody>
<tr>
<td>SMAW</td>
<td>T-UIBb</td>
<td>U</td>
<td>Specified Dimensions: R = 1/4, α = 45°, R = 3/8, α = 30°</td>
<td>Fit-Up Tolerances: α = +1/4, -0, α = +10°, -5°</td>
<td>All</td>
</tr>
<tr>
<td>FCAW</td>
<td>T-UIBb-F</td>
<td>U</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>T-UIBb-S</td>
<td>U</td>
<td>Specified Dimensions: R = 1/4, α = 45°, R = 3/8, α = 30°</td>
<td>Fit-Up Tolerances: α = +1/4, -0, α = +10°, -5°</td>
<td>F</td>
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**Notes:**

- C, D, E, I

---

**FIGURE 703.3 (Continued)**

46
Single Bevel Groove Weld

NOTE C: The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

NOTE D: Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

NOTE E: Backing for skewed joints may require shaping, beading, or beveling to provide a maximum gap of 1/16 inch between faying surfaces.

NOTE F: Square face is lower edge for horizontal position.

NOTE G: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting. When thickness permits, T₁ shall be beveled to reduce the possibility of base metal separation due to weld shrinkage stresses.

NOTE I: Any deviation from the details shown shall be subject to approval of the DCES.

FIGURE 703.3 (Continued)
Double Bevel Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness T₁ T₂</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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<td>SMAW FCAW</td>
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<td>R = 0</td>
<td>H</td>
<td>A, C, F, I</td>
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<td>B-U2B-F</td>
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<td>f = 1/8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>α = 45°</td>
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<td></td>
<td></td>
<td></td>
<td>S₁ = 2/3(T₁ - 1/8)</td>
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<tr>
<td></td>
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<td></td>
<td>S₂ = 1/3(T₁ - 1/8)</td>
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Double Bevel Groove Weld

<table>
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<th>Permitted Welding Positions</th>
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<td>T-U2B</td>
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<td>R = 0</td>
<td>All</td>
<td>A, C, D, I</td>
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<td>T-U2B-F</td>
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<td>f = 1/8</td>
<td></td>
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<td></td>
<td>α = 45°</td>
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<td>S₁ = 2/3(T₁ - 1/8)</td>
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<td>S₂ = 1/3(T₁ - 1/8)</td>
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SAW B-U2B-S U U R = 0 f = 1/4 α = 60° S₁ = 2/3(T₁ - 1/4) S₂ = 1/3(T₁ - 1/4) R = + 1/16, - 0 f = + 1/8, - 0 α = + 10°, - 5° F A, C, D, I

FIGURE 703.3 (Continued)
Double Bevel Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
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<td>U U</td>
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<td>Fit-Up Tolerances</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>R = 0</td>
<td>R = +3/16, -0</td>
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<td></td>
<td></td>
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<td>f = 1/8, ±1/8</td>
<td>f = +10°, -5°</td>
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<td></td>
<td></td>
<td>α = 45°, 10°</td>
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<td>S₁ = 2/3(T₁ - 1/8)</td>
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<td>S₂ = 1/3(T₁ - 1/8)</td>
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**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE D:** Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

**NOTE F:** Square face is lower edge for horizontal position.

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**NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.

**FIGURE 703.3 (Continued)**
### Single U Groove Weld

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<th>Permitted Welding Positions</th>
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<tr>
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<td>FCAW</td>
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</tr>
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<td>B-UIU-S</td>
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<td>specified</td>
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### Joint Designation

- **B-UIU**
- **B-UIU-F**
- **B-UIU-S**
- **C-UIU**
- **C-UIU-F**
- **C-UIU-S**

**Notes**

- **A**
- **C**
- **D**
- **H**
- **I**

**Specified Dimensions**

- \( R = 0 \)
- \( f = \frac{1}{3} T \)
- \( \alpha = 20^\circ \)
- \( r = \frac{1}{4} \)

**Fit-Up Tolerances**

- \( R = \pm \frac{3}{16} \)
- \( f = \pm \frac{1}{8} \)
- \( \alpha = \pm 10^\circ \)
- \( r = \pm \frac{1}{8} \)

**Permitted Welding Positions**

- All

**Notes**

A, C, H, I

---

**FIGURE 703.3 (Continued)**

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### Double U Groove Weld

**Welding Process**
- SMAW
- FCAW
- SAW

**Joint Designation**
- B-UZU
- B-UZU-F
- B-UZUS

**Base Metal Thickness**
- T₁
- T₂

**Groove Preparation**
- Specified Dimensions
- Fit-Up Tolerances
- Permitted Welding Positions
- Notes

<table>
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<th>Welding Process</th>
<th>Joint Designation</th>
<th>T₁</th>
<th>T₂</th>
<th>Specified Dimensions</th>
<th>Fit-Up Tolerances</th>
<th>Permitted Welding Positions</th>
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<td>α = 20°</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S₂ = 1/3(T₁ - 1/8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>B-UZUS</td>
<td></td>
<td></td>
<td>R = 0</td>
<td>R = +1/16, -0</td>
<td>F</td>
<td>A, C, H, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>f = 1/4</td>
<td>f = +1/8, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>α = 20°</td>
<td>α = +10°, -5°</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>r = 1/4</td>
<td>r = +1/8, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S₁ = 2/3(T₁ - 1/8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>S₂ = 1/3(T₁ - 1/8)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE D:** Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

**NOTE H:** Joints may be prepared before or after fit-up. When the joints are prepared after fit-up, NOTE B shall apply.

**NOTE I:** Any deviation from the details shown shall be subject to the approval of the DCES.
Single J Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW</td>
<td>B-UIJ</td>
<td>U</td>
<td>Specified Dimensions</td>
<td>Fit-Up Tolerances</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>B-UIJ-F</td>
<td>T_1</td>
<td>R = 0</td>
<td>R = ±3/16, -0</td>
<td>A, C, E, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T_2</td>
<td>f = 1/3 T_1</td>
<td>f = ±1/8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = 45°</td>
<td>α = ±10°, -5°</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r = 3/8</td>
<td>r = ±1/8, -0</td>
<td></td>
</tr>
<tr>
<td>FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Single J Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW</td>
<td>T-UIJ</td>
<td>U</td>
<td>Specified Dimensions</td>
<td>Fit-Up Tolerances</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>T-UIJ-F</td>
<td>U</td>
<td>R = 0</td>
<td>R = ±3/16, -0</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>f = 1/3 T_1</td>
<td>f = ±1/8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = 30°</td>
<td>α = ±10°, -5°</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>r = 3/8</td>
<td>r = ±1/8, -0</td>
<td></td>
</tr>
<tr>
<td>FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| SAW             | T-UIJ-S           | U                    | Specified Dimensions | Fit-Up Tolerances | F    |
|                 |                   |                      | R = 0             | R = ±1/16, -0             | A, C, D, I |
|                 |                   |                      | f = 1/3 T_1       | f = ±1/8, -0             |       |
|                 |                   |                       | α = 45°           | α = ±10°, -5°             |       |
|                 |                   |                       | r = 3/8            | r = ±1/8, -0              |       |

FIGURE 703.3 (Continued)
NOTE A: After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

NOTE C: The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

NOTE D: Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

NOTE F: Square face is lower edge for horizontal position.

NOTE G: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting. When thickness permits \( T_1 \) shall be beveled to reduce the possibility of base metal separation due to weld shrinkage stresses.

NOTE I: Any deviation from the details shown shall be subject to approval of the DCES.

FIGURE 70.3 (Continued)
### Double J Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW FCAW</td>
<td>B-U2J</td>
<td>U</td>
<td>R = 0</td>
<td>H</td>
<td>A, C, F, I</td>
</tr>
<tr>
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<td>B-U2J-F</td>
<td></td>
<td>f = 1/8</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = 45°</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r = 3/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S₁ = 2/3(T₁ - 1/8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S₂ = 1/3(T₁ - 1/8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R = +3/16, -0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>f = ±1/8</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td>α = +10°, -5°</td>
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<td></td>
<td></td>
<td></td>
<td>r = +1/8, 0</td>
<td></td>
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</tr>
</tbody>
</table>

### Double J Groove Weld

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW FCAW</td>
<td>T-U2J</td>
<td>U</td>
<td>R = 0</td>
<td>All</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td></td>
<td>T-U2J-F</td>
<td></td>
<td>f = 1/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>α = 30°</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>r = 3/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S₁ = 2/3(T₁ - 1/8)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>S₂ = 1/3(T₁ - 1/8)</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>R = +3/16, -0</td>
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<td>f = ±1/8</td>
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<td></td>
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<td>α = +10°, -5°</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>r = +1/8, 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td>T-U2J-S</td>
<td>U</td>
<td>R = 0</td>
<td>F</td>
<td>A, C, D, I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>f = 1/4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td>α = 45°</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>r = 3/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S₁ = 2/3(T₁ - 1/4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S₂ = 1/3(T₁ - 1/4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R = +1/16, -0</td>
<td></td>
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<td></td>
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<td></td>
<td>f = ±1/8</td>
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<tr>
<td></td>
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<td>α = +10°, -5°</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>r = +1/8, 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 703.3 (Continued)**
## Double J Groove Weld

### Welding Joint Designation
- **SMAW**
- **FCAW**

### Thickness
- **T₁**
- **I₁**

### Permitted Groove Preparation

<table>
<thead>
<tr>
<th>Specified Dimensions</th>
<th>Fit-Up Tolerances</th>
<th>Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S₁ = 2/3(T₁ - 1/8)</strong></td>
<td><strong>R = 0</strong></td>
<td><strong>R = ± 1/8, -0</strong></td>
<td><strong>All</strong></td>
</tr>
<tr>
<td><strong>S₂ = 1/3(T₁ - 1/8)</strong></td>
<td><strong>f = 1/8</strong></td>
<td><strong>f = ± 1/8</strong></td>
<td><strong>A, C, D, G, I</strong></td>
</tr>
<tr>
<td><strong>α = 30°</strong></td>
<td><strong>α = ± 10°, -5°</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>r = 3/8</strong></td>
<td><strong>r = ± 1/8, -0</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fit-Up Tolerances

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Joint Designation</th>
<th>Base Metal Thickness</th>
<th>Groove Preparation</th>
<th>Permitted Welding Positions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMAW</strong></td>
<td>C-U2J</td>
<td>U</td>
<td>U</td>
<td><strong>R = 0</strong></td>
<td><strong>R = ± 1/8, -0</strong></td>
</tr>
<tr>
<td><strong>FCAW</strong></td>
<td>C-U2J-F</td>
<td>U</td>
<td>U</td>
<td><strong>f = 1/8</strong></td>
<td><strong>f = ± 1/8</strong></td>
</tr>
<tr>
<td><strong>SMAW</strong></td>
<td>C-U2J-S</td>
<td>U</td>
<td>U</td>
<td><strong>α = 45°</strong></td>
<td><strong>α = ± 10°, -5°</strong></td>
</tr>
</tbody>
</table>

**NOTE A:** After welding the first side, air carbon arc gouge the root to sound weld metal before welding the second side. The radius of the gouge shall be 1/4 inch minimum and the sides shall slope back with a total included angle of 20 degrees minimum.

**NOTE C:** The orientation of the members in the joints may vary provided that the basic joint configuration remains the same and the design throat thickness is maintained.

**NOTE D:** Groove welds in tee and corner joints shall be reinforced with fillet welds equal to T/4, but not more than 3/8 inch.

**NOTE F:** Square face is lower edge for horizontal position.

**NOTE G:** For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting. When thickness permits T₁ shall be beveled to reduce the possibility of base metal separation due to weld shrinkage stresses.

**NOTE I:** Any deviation from the details shown shall be subject to approval of the DCES.

---

**FIGURE 703.3 (Continued)**
SYMBOLS FOR JOINT DESIGNATIONS

Joint Type
B — Butt
T — Tee
C — Corner

Joint Thickness Limitation
L — Limited
U — Unlimited

Groove Preparation
1 — Single
2 — Double
— Square
V — Vee Groove
B — Bevel Groove
U — U Groove
J — J Groove

Root Treatment
— Back gouging required
b — Back up bar required

Welding Process
— SMAW — Shielded Metal Arc Welding
F — FCAW — Flux Cored Arc Welding
S — SAW — Submerged Arc Welding

Example

FIGURE 703.3 (Continued)
703.4 Partial Joint Penetration Groove Welds.

703.4.1 General. Partial joint penetration groove welds made by manual shielded metal arc welding, submerged arc welding, or flux cored arc welding in butt, corner and tee joints may not be used unless specifically approved by the DCES. When the joint is approved, the minimum effective throat (E) shall be in accordance with Table 703.4

703.4.2 Definition. Groove welds without steel backing, welded from one side, and groove welds welded from both sides but without back gouging are considered partial joint penetration groove welds.

Table 703.4 — Minimum Effective Throat for Partial Joint Penetration Groove Welds

<table>
<thead>
<tr>
<th>Material thickness of thicker part joined (inches)</th>
<th>Minimum effective throat (E) (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To 1/4 incl.</td>
<td>1/4*</td>
</tr>
<tr>
<td>Over 1/4 to 1/2 incl.</td>
<td>5/16*</td>
</tr>
<tr>
<td>Over 1/2 to 1 1/2 incl.</td>
<td>5/16</td>
</tr>
<tr>
<td>Over 1 1/2 to 2 1/4 incl.</td>
<td>3/8</td>
</tr>
<tr>
<td>Over 2 1/4 to 6 incl.</td>
<td>1/2</td>
</tr>
<tr>
<td>Over 6</td>
<td>5/8</td>
</tr>
</tbody>
</table>

*Except the effective throat need not exceed the thickness of the thinner part.

703.5 Detailing To Reduce Residual Stresses. Joints shall be welded so as to minimize stresses due to the contraction of the weld metal and adjacent base metal upon cooling. When weldments are subject to unusual restraint or when plate thickness becomes excessive, the Contractor may submit revised joint details to limit the size of the weld nugget and thereby reduce residual stresses and distortion caused by welding. The State will approve these weld details provided it is adequately demonstrated that there is access for welding and that the details, welding procedure and inspection methods used will insure satisfactory results in the work. Peening may be approved by the DCES to control shrinkage stresses. All peening shall be performed in accordance with Article 719. Also see Article 718, Control of Distortion and Shrinkage Stresses.

703.6 Butt Joint Transitions. When butt joints are used to join material of different thicknesses or widths, there shall be a smooth transitional slope between the offset surfaces or edges. This slope shall not exceed that shown in Figure 703.6. The transition of thickness may be accomplished by sloping weld faces, chamfering the thicker part, or a combination of the two methods. The transition of width shall be accomplished by sloping the edges of the wider part. If it becomes necessary to have butt joints at locations other than shown on the Contract Plans, the butt joints must be so detailed on the shop drawings and approved by the DCES.

703.7 Prohibited Types of Joints and Welds. The following types of joints and welds are prohibited in bridges:

a) Butt joints not fully welded throughout their cross section, unless otherwise specified.

b) Groove welds made from one side only unless completely fused to a steel backing as specified in Article 716 or specified as a partial penetration groove weld in accordance with Article 703.4.

c) Intermittent groove welds.

d) Intermittent fillet welds, unless otherwise specified.

NOTE: This does not prohibit the use of partial penetration tee and corner welds for bridges and buildings when detailed on the plans.
Sloping Weld Surface

Remove after welding

Transition by Sloping Weld Surface

Chamfer before welding

Transition by Chamfering Thicker Part

Centerline Alignment (Particularly applicable to web plates)

Offset Alignment (Particularly applicable to flange plates)

*Groove may be of any permitted or qualified type and detail. Transition slopes shown are the maximum permitted.

Transition of Thickness

Transition of Width

FIGURE 703.6 – TRANSITION AT BUTT WELDS
704. GENERAL

The requirements of this section provide for welding of structural steels that have a minimum specified yield point not greater than 50 ksi. The steels to be welded are listed in Section 5, Base Metals. Higher strength steel or steels not listed in Section 5 will be subject to additional requirements as listed in the Contract Documents. When the Contractor proposes the use of a steel not listed in Section 5, additional requirements may be specified by the DCES during review and approval of the welding procedure specification.

All welders, welding operators and tackers shall be qualified by tests prescribed in Section 8, Qualification.

All welding shall be performed in accordance with the provisions of a written procedure specification as shown in Figure 704. The welding procedure specifications shall be prominently displayed at the welding station. Joint welding procedures not prequalified shall be qualified by Welding Procedure Qualification Tests in accordance with the provisions of Section 7A, Design of Welded Connections.

Welders shall be provided firm footing at all times. When it is necessary to weld from platforms above the ground, such platforms shall be rigidly braced to prevent movement of the platform during the welding operation.

All welding and oxygen cutting equipment shall be designed and manufactured and shall be in suitable condition to enable qualified welders, welding operators, and tackers to follow the procedures and obtain the results required by these specifications.

Welding shall not be done when the ambient temperature is lower than 0° F*, when surfaces are wet or exposed to rain, snow or high wind, or when welders or welding operators are exposed to inclement conditions.

The sizes and lengths of welds shall be no less than those specified by the plans and shop drawings, nor shall they be substantially in excess of those requirements without approval of the DCES. The location of welds shall not be changed without prior approval.

705. APPROVED WELDING PROCESSES

The following welding processes may be used for the fabrication of bridges and buildings:

- Manual Shielded Metal Arc Welding (SMAW)
- Submerged Arc Welding (SAW)
- Flux Cored Arc Welding (FCAW)
- Electroslag Welding (ESW)
- Electrogas Welding (EGW)

Section 4, General Fabrication Requirements, specifies fully automatic and semiautomatic welding for many applications. These requirements may preclude the use of specific welding processes in certain areas.

*The reference to 0° F does not mean the ambient environmental temperature but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0° F provided a heated structure or shelter around the area being welded maintains the air and base metal temperature adjacent to the weldment at 0° F or higher.
### WELDING PROCEDURE SPECIFICATION

- Material specification
- Welding process
- Manual, semiautomatic or automatic
- Position of welding
- Filler metal specification AWS
- Filler metal classification
- Electrode and manufacturer
- Flux and manufacturer
- Shielding gas
- Dew point
- Flow rate
- Single or multiple pass
- Single or multiple arc
- Welding current
- Polarity
- Welding progression
- Root treatment
- Preheat and interpass temperature
- Postheat treatment

### WELDING PROCEDURE

<table>
<thead>
<tr>
<th>Pass no.</th>
<th>Electrode size</th>
<th>Welding parameters</th>
<th>Travel speed</th>
<th>Joint detail</th>
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<tr>
<td></td>
<td></td>
<td>Ampères</td>
<td>Volts</td>
<td></td>
</tr>
</tbody>
</table>

Sequence of weld passes shall be shown diagrammatically

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in Section 8A.

Procedure no. __________________________ Fabricator or Erector __________________________

Revision no. __________________________ Authorized by __________________________

Date __________________________

**FIGURE 704 – SAMPLE WELDING PROCEDURE SPECIFICATION**
of the fabrication. All welding processes except manual shielded metal arc must be qualified by tests performed by the Contractor as required by Section 8, Qualification.

Electroslag welding and electrogas welding may be used to make compression welds in bridges and both tension and compression welds in buildings provided the welds are subjected to both radiographic testing and ultrasonic testing in accordance with the provisions of this manual. Electroslag and electrogas welding shall not be permitted for tension welds in bridges.

All SMAW shall be performed using low hydrogen electrodes as described in this Manual. When FCAW is used, carbon dioxide gas shielding shall be used unless otherwise approved by the DCES.

706. FILLER METAL REQUIREMENTS

706.1 General. All complete joint penetration groove welds joining base metals listed in Section 5 shall be made using electrodes, electrode flux combinations or grades of weld metal that produce filler metal mechanical properties as specified in Table 706.1.

Partial penetration welds, fillet welds and complete joint penetration welds subject only to shear stresses may be produced using filler metals that have a yield stress less than the base metal provided the Charpy V-Notch toughness of the filler metal and the ductility of the filler metal meet all the requirements for complete joint penetration groove welds. The filler metal shall meet all stress requirements as determined by the DCES.

Under some conditions, filler metal with improved ductility is preferred to filler metal with yield stress that matches the base metal. Overmatching filler metal, i.e., where the filler metal is significantly stronger than the base metal, is undesirable. Overmatching filler metal can be one of the major contributors to lamellar tearing when weld residual stresses act upon the base metal in the short transverse, "z", direction. The DCES may disapprove welding electrodes, electrode flux combinations and grades of weld metal that will cause significant over matching in his opinion.

All electrodes, wire and flux shall be packaged, dried and stored in accordance with the provisions of Articles 711 through 714. After filler metal has been removed from its original package or container, it shall be protected and stored so that its characteristics and welding properties are not affected.

706.2 Requirements for Weathering Steels. Weathering steels, ASTM A242 and A588, shall be welded using electrodes, electrode flux combinations, or grades of weld metal that produce filler metal mechanical properties as shown in Table 706.1 and chemical properties as shown in Table 706.2, except as provided in Article 707, Welding Weathering Steels.

706.3 Manufacturer's Certification. The DCES maintains a file of manufacturers' certified test results of filler metal qualification tests qualifying electrodes and flux for SAW, FCAW, ESW, EGW and SMAW.

If the electrode or wire and flux combination to be used is not listed in this manufacturer's certification file or if the data contained therein is more than one year old because the manufacturer has failed to voluntarily submit the required certified tests results, the Contractor will be required to furnish the Inspector with manufacturers' certified test results for each lot of electrode and flux used in the work.

This certification provides only for the acceptance of the electrode and flux. The welding procedure shall be qualified in accordance with the provisions of Section 8, Qualification.

When requested by the DCES or required by the Contract Documents, the Contractor or Fabricator shall furnish manufacturers' certifications that the electrodes, electrode flux combination or grades of weld metal furnished meets the requirements of the Contract Documents.
### Table 706.1 — Mechanical Requirements for Filler Metal

<table>
<thead>
<tr>
<th>Electrode Specification (AWS)</th>
<th>Yield Strength (ksi)</th>
<th>Tensile Strength (ksi)</th>
<th>Elongation in 2&quot; (min.)</th>
<th>CVN</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWS A5.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7016</td>
<td>60 min.</td>
<td>72 min.</td>
<td>22</td>
<td>20°F - 20°F</td>
</tr>
<tr>
<td>E7018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7028</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWS A5.5</td>
<td></td>
<td>68 - 80</td>
<td>24</td>
<td>20°F - 40°F</td>
</tr>
<tr>
<td>E8018-C3</td>
<td></td>
<td>80 min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWS A5.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A0-XXXX</td>
<td>58 min.</td>
<td>70 - 95</td>
<td>22</td>
<td>20°F - 0°F</td>
</tr>
<tr>
<td>F7A2-XXXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A4-XXXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A5-XXXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A6-XXXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWS A5.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A0-EXXX-X</td>
<td>58 min.</td>
<td>70 - 95</td>
<td>22</td>
<td>20°F - 0°F</td>
</tr>
<tr>
<td>F7A2-EXXX-X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7A4-XXXX-X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCAW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AWS A5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7XT-1</td>
<td>60 - 84</td>
<td>72 - 95</td>
<td>22</td>
<td>20°F - 0°F</td>
</tr>
<tr>
<td>E7XT-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESW &amp; EGW</td>
<td>57 min.</td>
<td>70 min.</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

*CVN tests do not provide a reliable measurement of ESW and EGW weld metal toughness. Crack opening displacement test results or other measurements of weld metal toughness shall be as determined by the DCES.
### TABLE 706.2 — CHEMICAL REQUIREMENTS FOR FILLER METAL USED FOR WEATHERING STEELS

<table>
<thead>
<tr>
<th>AWS Classification</th>
<th>Chemical Composition %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon C</td>
</tr>
<tr>
<td>SMAW</td>
<td></td>
</tr>
<tr>
<td>E8018-C3</td>
<td>0.12</td>
</tr>
<tr>
<td>SAW</td>
<td></td>
</tr>
<tr>
<td>F7AX-EXXX-B1</td>
<td>0.12</td>
</tr>
<tr>
<td>F7AX-EXXX-B2</td>
<td>0.15</td>
</tr>
<tr>
<td>F7AX-EXXX-Ni1</td>
<td>0.12</td>
</tr>
<tr>
<td>F7AX-EXXX-Ni2</td>
<td>0.12</td>
</tr>
<tr>
<td>F7AX-EXXX-Ni3</td>
<td>0.12</td>
</tr>
<tr>
<td>F7AX-EXXX-W</td>
<td>0.12</td>
</tr>
<tr>
<td>FCAW</td>
<td></td>
</tr>
<tr>
<td>F7XT-1</td>
<td>As Approved by DCES.</td>
</tr>
<tr>
<td>F7XT-5</td>
<td>As Approved by DCES.</td>
</tr>
</tbody>
</table>

Note: All requirements are maximum unless a range is indicated.
707. WELDING WEATHERING STEELS

All filler metal shall meet the requirements of Article 706 with the following exceptions:

a) In multiple-pass welds, the weld metal may be deposited so that at least two layers on all exposed surfaces and edges are deposited with a filler metal meeting the chemical requirements in Table 706.2. The remainder of the weld may be deposited using any one of the filler metals specified in Table 706.1.

b) For single pass welding other than electroslag or electrogas welding of weathering steel, the filler metal shall conform to the requirements of Table 706.2. Manual shielded metal arc welds, consisting of single pass fillet welds up to 1/4 inch maximum and 1/4 inch groove welds made in a single pass or a single pass each side, may be made using any electrode specified in Table 706.1.

c) Submerged arc welds consisting of single pass fillet welds 5/16 inch maximum and groove welds made with a single pass or single pass each side may be made using any electrode and flux combinations specified in table 706.1.

d) Flux cored arc welds consisting of single pass fillet welds up to 5/16 maximum and groove welds made with a single pass or single pass each side may be made using the electrodes specified in Table 706.1.

e) Electroslag and electrogas welding of weathering steel shall require weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal. The mechanical properties of the weld metal shall meet the requirements of Table 706.1 and the chemical composition shall meet the requirements of Table 706.2.

708. PREHEAT AND INTERPASS TEMPERATURE

708.1 General Requirements. All welding processes with the exception of electroslag and electrogas welding shall require that the steel be preheated and that interpass temperatures be maintained in accordance with Table 708. When welding a combination of base metals, the minimum preheat and interpass temperature shall be governed by the higher strength steel.

When the base metal is below the temperature listed for the thickness and grade of steel being welded, it shall be preheated. For modification of preheat requirements for submerged arc welding with multiple electrodes, see Article 712.5. The preheat and interpass temperature shall be maintained so that the surfaces of the parts on which weld metal is deposited are at or above the minimum specified temperature for a distance equal to the thickness of the part being welded but not less than 3 inches both laterally and in advance of the welding, and in the thru thickness, "z", direction.

Preheat and interpass temperatures shall be sufficient to prevent crack formation. Temperatures above the minimum shown in Table 708 may be required for highly restrained welds.

Preheat and interpass temperatures combined with heat input during welding shall be such that the hardness of the heat affected zones does not exceed a Rockwell Hardness of C27.

All field welding shall be done with a preheat and interpass temperature of 250° F unless higher preheat and interpass temperatures and required by Table 708. Preheat requirements shall be waived for the welding of permanent metal forms, and stud shear connectors to portions of girder flanges subject only to compressive stress.

Lateral gusset plates shall be welded to girder flanges using a minimum preheat and interpass temperature of 250° F, unless higher temperatures are required by Table 708.
Crack repair procedures shall provide for higher preheat temperatures, controlled interpass temperatures and post heating as approved by the DCES.

The preheat requirement for the welding of transverse stiffeners to web plates of A588 steel up to 3/4 inch in thickness may be reduced from the 100°F temperature required by Table 708 to 50°F provided welding is done by a fully automatic submerged arc process. The minimum welding heat input shall be 50 kilojoules per inch. When submerged arc welding equipment is used that welds both sides of a stiffener or a connection plate simultaneously, the total heat input from both welding arcs shall be 100 kilojoules per inch minimum.

708.2 Preheating for Tack Welding. There shall be no tack welding on steel that is not preheated to the minimum specified preheat and interpass temperature required by Table 708 unless the tack weld and the adjacent heat affected zones are completely remelted and incorporated in a subsequent submerged arc weld. When required by the DCES, the Contractor shall furnish macroetched specimens to demonstrate conformance with this requirement.

All temporary tack welds that are not remelted and incorporated into permanent welds shall be removed by grinding. The areas where tack welds are removed shall be magnetic particle inspected by the Contractor in accordance with the provisions of Section 18, Magnetic Particle Inspection. The Inspector may perform hardness tests to determine that areas harder than a Rockwell hardness of C27 are not allowed to remain in the work.

### TABLE 708 — MINIMUM PREHEAT AND INTERPASS TEMPERATURE

<table>
<thead>
<tr>
<th>Thickness of Thickest Part at Point of Welding (inches)</th>
<th>ASTM A36, A53, A252, A441, A500, A501, A572</th>
<th>ASTM A588, A242</th>
</tr>
</thead>
<tbody>
<tr>
<td>To 3/4, inclusive</td>
<td>50°F</td>
<td>100°F</td>
</tr>
<tr>
<td>Over 3/4 to 1 1/2, inclusive</td>
<td>70°F</td>
<td>200°F</td>
</tr>
<tr>
<td>Over 1 1/2 to 2 1/2, inclusive</td>
<td>150°F</td>
<td>300°F</td>
</tr>
<tr>
<td>Over 2 1/2</td>
<td>225°F</td>
<td>350°F</td>
</tr>
</tbody>
</table>

709. HEAT INPUT REQUIREMENT FOR A588 STEEL

The minimum heat input during welding of A588 steel shall be 35 kilojoules per inch for material from 3/8 inch to 3/4 inch in thickness and 50 kilojoules per inch for material over 3/4 inch in thickness. The Contractor shall calculate the minimum and maximum welding heat inputs for various welding procedures and submit these values to the DCES for approval as part of his welding procedure specification.

710. STRESS RELIEF HEAT TREATMENT

Where required by the Contract Documents or approved as a part of a weld repair procedure welded assemblies shall be stress relieved by heat treating. Finish machining shall be done after stress relief. Stress relief heat treatment shall conform to the following requirements:

a) The temperature of the furnace shall not exceed 600°F at the time the welded assembly is placed in it.

b) Above 600°F, the rate of heating shall not be more than 400°F per hour divided by the maximum metal thickness of the thicker part in inches, but in no case more than 400°F per hour. During the heating period, variations in temperature throughout the portion of the part being heated shall not be greater than 200°F within any 15 foot interval of length.
c) After a mean temperature range between 1100°F and 1200°F is reached, the temperature of the assembly shall be held within the specified limits for a time not less than specified in Table 710a, based on weld thickness. When the specified stress relief is for dimensional stability, the holding time shall not be less than specified in Table 710a based on the thickness of the thicker part. During the holding period there shall be no difference greater than 150°F between the highest and lowest temperature throughout the portion of the assembly being heated.

d) Above 600°F cooling shall be done in a closed furnace or cooling chamber at a rate no greater than 500°F per hour divided by the maximum metal thickness of the thicker part in inches, but in no case more than 500°F per hour. From 600°F, the assembly may be cooled in still air.

e) When it is impractical to post heat to the temperature limitations stated in Table 710a, welded assemblies may be stress relieved at lower temperatures for longer periods of time as shown in Table 710b.

*The rates of heating and cooling need not be less than 100°F per hour. However, in all cases, consideration of closed chambers and complex structures may indicate reduced rates of heating and cooling to avoid structural damage due to excessive thermal gradients.

**TABLE 710a — MINIMUM HOLDING TIME**

<table>
<thead>
<tr>
<th>1/4 inch or less</th>
<th>Over 1/4 inch through 2 inches</th>
<th>Over 2 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 minutes</td>
<td>1 hour/inch</td>
<td>2 hours plus 15 minutes for each additional inch over 2</td>
</tr>
</tbody>
</table>

**TABLE 710b — ALTERNATIVE STRESS-RELIEF HEAT TREATMENT**

<table>
<thead>
<tr>
<th>Decrease in temperature below minimum specified temperature (°F)</th>
<th>Minimum holding time at decreased temperature, (hours per inch of thickness)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>150</td>
<td>5</td>
</tr>
<tr>
<td>200</td>
<td>10</td>
</tr>
</tbody>
</table>
711. REQUIREMENTS FOR MANUAL SHIELDED METAL ARC WELDING

711.1 Electrodes for Manual Shielded Metal Arc Welding. Electrodes for manual shielded metal arc welding (SMAW) shall conform to the requirements of the latest edition of AWS A5.1, Specification for Mild Steel Covered Arc Welding Electrodes, or to the requirements of AWS A5.5, Specification for Low Alloy Steel Covered Arc Welding Electrodes. Only classifications E7016, E7018, E7028, or E8018-C3 shall be used without the prior approval of the DCES.

All SMAW electrodes shall be furnished in hermetically sealed containers and shall be dried for at least 2 hours, but not to exceed 4 hours, between 450°F and 500°F before they are used. After drying, electrodes shall immediately be placed in a storage oven held continuously at a temperature of at least 250°F until used in the work. One oven may be used as both a drying and storage oven provided proper temperature controls are maintained.

E70XX electrodes not used within 4 hours and E80XX electrodes not used within 2 hours from the time they are removed from the drying or storage oven shall be redried for 1 hour minimum at a temperature between 700°F and 800°F, or shall be discarded and not used in the work. If the relative humidity is greater than 70%, the limits of 4 hours and 2 hours shall be reduced to 2 hours and 1 hour respectively.

Redrying of electrodes will only be permitted if the Contractor has the proper equipment for controlled drying at the temperatures specified above. Electrodes which have been wet shall not be redried or used under any condition. Electrodes redried once and then exposed to atmospheric conditions for a time greater than stated above shall be discarded and not used in the work.

711.2 Procedures for Manual Shielded Metal Arc Welding

711.2.1 General. The work shall be positioned for flat position welding whenever practical. The classification and size of electrodes, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances pertinent to the work. Welding current shall be within the range recommended by the electrode manufacturer.

711.2.2 Size of Electrodes. The maximum diameter of electrodes shall be as follows:

a) 1/4 inch for all welds made in the flat position, except root passes.

b) 1/4 inch for horizontal fillet welds.

c) 3/16 inch for root passes of groove welds made in the flat position with backing and with a opening of 1/4 inch or more.

d) 5/32 inch for welds made with low-hydrogen electrodes in the vertical and overhead positions.

e) 3/16 inch for root passes of groove welds and for all other welds not included above.

711.2.3 Size of Weld Passes. The minimum size of a root pass shall be sufficient to prevent cracking. The maximum thickness of root passes in groove welds shall be 1/4 inch. The maximum size of single pass fillet welds and root passes of multiple pass fillet welds shall be:

a) 3/8 inch in the flat position.

b) 5/16 inch in the horizontal or overhead positions.

c) 1/2 inch in the vertical position.

The maximum thickness of layers subsequent to root passes of groove and fillet welds shall be:

a) 1/8 inch for subsequent layers of welds made in the flat position.

b) 3/16 inch for subsequent layers of welds made in the vertical, overhead, or horizontal positions.
711.2.4 Direction of Welding. The progression for all passes in vertical position welding shall be upward. However, when tubular products are welded, the progression of vertical welding may be upward or downward but only in the direction or directions for which the welder is qualified using the electrode classification and size approved by the DCES.

711.2.5 Gouging Root of Weld. Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound weld metal and ground before welding is started from the second side.

711.2.6 Restrictions. E7028 electrodes shall not be permitted for use in the root pass of groove welds in any position.

712. REQUIREMENTS FOR SUBMERGED ARC WELDING

712.1 General. All welding procedures for submerged arc welding shall be qualified in accordance with the provisions of Section 8, Qualification. Submerged arc welding may be performed with one of more single electrodes, one or more parallel electrodes, or combinations of single and parallel electrodes. The spacing between arcs shall be such that the slag cover over the weld metal produced by a leading arc does not cool sufficiently to prevent the proper weld deposit of a following electrode. Submerged arc welding with multiple electrodes may be used for any groove or fillet weld pass.

The following paragraphs governing the use of submerged arc welding apply to any steel included in Section 5, Base Metals. Consideration shall be given to the additional heat input produced by simultaneous welding on two sides of a common member. Electrode spacing, orientation, and weld travel speed shall be regulated to prevent bridging (undesirable base metal melting beyond the weld) and attendant hot cracking.

The diameter of electrodes shall not exceed 1/4 inch.

Surfaces on which submerged arc welds are to be deposited and adjacent faying surfaces shall be clean and free of moisture as specified in Section 6, Preparation of Base Metal.

All welds for bridges detailed as complete joint penetration groove welds and not required to be fused into steel backing shall have the root of the initial (first side) weld air carbon arc gouged to sound weld metal and ground before welding the second side.

When welds for buildings or welds designed to transmit only shear stresses in bridges require a specific root penetration, the Contractor shall make a sample joint and provide a macroetched cross section to demonstrate that the proposed welding procedure will obtain the required root penetration without back gouging. The DCES, at his discretion, may accept a radiograph of a test joint or recorded evidence in lieu of the test specified in this paragraph. Nondestructive tests may be employed to assure penetration is achieved in the work.

Roots of groove welds and fillet welds may be backed by temporary steel bars meeting the requirements of Section 5, Base Metal, if necessary to prevent melting through. The DCES will consider joint design changes that make temporary steel backing unnecessary. Roots of groove and fillet welds may be sealed by means of root passes deposited with SMAW low hydrogen electrodes or by other approved welding processes. All temporary backing shall be removed and the surfaces finished flush unless otherwise approved by the DCES.

Neither the depth nor the maximum width in the cross section of weld metal deposited in each weld pass shall exceed the width of the surface of the weld pass (See Figure 712.1). This requirement may be waived only if the testing of a welding procedure has demonstrated to the satisfaction of the DCES that such welds are free from cracks. The welding procedure and the electrode flux combination used in the tests shall be the same as that used in construction.
Tack welds which will be incorporated in fillet welds 3/8 inch or smaller or in the root of joints requiring specific root penetration shall be sufficiently small to insure that they do not produce objectionable changes in the appearance of the weld surface or result in a decrease in penetration. If it is anticipated that either situation may occur, they shall be removed or reduced in size in accordance with Article 726, Repairs, prior to welding.

Tack welds in the root of a joint with steel backing less than 5/16 inch thick shall be removed or made continuous for the full length of the joint using low hydrogen electrodes.

**FIGURE 712.1 — WELD PASS RATIO**

**712.2 Electrodes and Fluxes for Submerged Arc Welding.** The bare electrodes and fluxes used in combination for submerged arc welding shall conform to the requirements of the latest edition of AWS A5.17, Specification for Bare Carbon Steel Electrodes and Fluxes for Submerged Arc Welding or to the requirements of the latest edition of AWS A5.23, Specification for Bare Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding.

The classification shall be as listed in Table 706.1.

A shop welded procedure qualification test described in Section 8, Qualification shall demonstrate that the electrode flux combination will produce the required weld metal properties as listed in Table 706.1.

When weathering steels are used, chemical analysis of the deposited weld metal shall verify conformance with the requirements of Table 706.2.

If required by Article 706.3, the Contractor shall furnish manufacturer’s certifications or certified copies of the test results performed by the manufacturer that demonstrate the electrode and flux combination meets the requirements of the Contract Documents.

Flux used for submerged arc welding shall be non-hygrosopic, dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages capable of being stored under normal conditions for at least 6 months without affecting its welding characteristics or weld properties.

Flux from damaged packages shall be dried before use at a minimum temperature of 250°F for not less than one hour, or discarded. Flux shall be placed in dispensing systems immediately upon opening a package. If flux is used from an open package or stored in an open and unheated flux hopper.
for more than 72 hours, 1 inch minimum of the surface flux shall be discarded before the remainder is used. Flux that has been wet shall not be used. Flux fused in welding shall not be reused. Fluxes may be recycled provided they are protected from contamination by moisture, dirt, mill scale or other foreign materials that may affect welding characteristics or weld properties. Fluxes shall not be recycled a sufficient number of times to permit segregation of the flux or loss of component sizes such that welding characteristics or weld properties may be modified.

712.3 Procedures for Submerged Arc Welding with a Single Electrode. Single electrode means one electrode connected exclusively to one power source which may consist of one or more power units.

All submerged arc welds except fillet welds shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single pass fillet welds made in the horizontal position shall not exceed 5/16 inch.

The thickness of weld layers, except root and surface layers, shall not exceed 1/4 inch. When the root opening is 1/2 inch or greater, a multiple pass, split-layer technique shall be used. The split-layer technique shall also be used in making multiple pass welds when the width of the layer exceeds 5/8 inch.

The welding current, arc voltage, and travel speed shall be such that each pass shall have complete fusion with the adjacent base metal and weld metal and there will be no overlap or undue undercutting. The maximum welding current to be used when making any pass of a groove weld that has fusion to both faces of the groove shall be 600 amps, except that the final layer may be made using a higher current. The maximum current to be used when making fillet welds in the flat position shall be 1000 amps.

712.4 Procedures for Submerged Arc Welding with Parallel Electrodes. Parallel electrodes means two electrodes connected electrically in parallel exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. The welding current shall be the total for the two electrodes.

Submerged arc welds made with parallel electrodes, except fillet welds, shall be welded in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single pass fillet welds made in the horizontal position shall not exceed 5/16 inch.

The thickness of weld layers is not limited. Single or parallel electrodes may be used for the root pass of groove welds. Backing bars or root faces shall be of adequate thickness to prevent melting thru.

When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 1/2 inch, parallel electrodes shall be displaced laterally or a split layer technique used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 5/8 inch, a split layer technique with electrodes in tandem shall be used.

The welding current, arc voltage, travel speed, and relative location of electrodes shall be such that each pass will have complete fusion with the adjacent base metal and weld metal, and there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in the roots of joints under restraint.

The maximum welding current for making groove welds shall be:

a) 700 amps for parallel electrodes when making the root layer in a groove having no root opening, and which does not fill the groove.
b) 900 amps for parallel electrodes when making the root pass in a groove having steel backing.
c) 1200 amps for parallel electrodes for all other passes except the final layer.
d) For the final layer, there is no restriction on welding current.
Weld procedures using more than 1200 amps in the final pass will be subject to qualification testing as determined by the DCES.

The maximum welding current to be used in making a fillet weld shall be 1200 amps for parallel electrodes.

Preheat and interpass temperatures for parallel electrode submerged arc welding shall conform to the provisions of Table 708.

The DCES may approve reductions in preheat for certain applications of parallel electrode submerged arc welding provided acceptable weld and heat affected zone hardness test results are obtained during qualification testing and in verification testing during the work. The total welding heat input shall be computed based on all welding variables and the number of arcs operating simultaneously. The combination of preheat, interpass temperature and welding heat input shall be such that tests demonstrate that no portion of the heat affected zone has a Rockwell hardness greater than C25 or a Vickers hardness number greater than 266. Determination of the heat affected zone hardness shall be made on the initial macroetched cross sections of sample test welds and on the surface of weldments during the progress of the work. * Surfaces shall be ground to a finish of 60 microinches or smoother in areas that are to be hardness tested. Tests shall be made on the thicker metal in each weld joint at a rate of not less than one test per weldment, or one test each 50 feet of groove weld, each pair of fillet welds made simultaneously, or each fillet weld. Hardness testing may be reduced in frequency or discontinued after the procedure has been established to the satisfaction of the DCES.

No reduction of the preheat requirements listed in Table 708 will be permitted for fillet or groove welds 3/8 inch and under in size.

712.5 Procedures for Submerged Arc Welding with Multiple Electrodes. Multiple electrodes are defined as the combination of two or more single or parallel electrode systems. Each of the component systems has its own independent power source and its own electrode feeder.

Submerged arc welds with multiple electrodes, except fillet welds, shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single pass multiple electrode fillet welds made in the horizontal position shall not exceed 1/2 inch.

The thickness of weld layers is not limited. A single or multiple electrode may be used to make the root pass of groove welds. Backing bars or root faces shall be of adequate thickness to prevent melting thru. When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 1/2 inch, a split layer technique shall be used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 1 inch, and only two electrodes are used, a split layer technique with electrodes in tandem shall be employed.

The welding current, arc voltage, travel speed and relative location of electrodes shall be such that each pass will have complete fusion with the adjacent base metal and weld metal and there will be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in roots of joints under restraint.

The maximum welding current when making a groove weld shall be:

a) 700 amps for any single electrode or for parallel electrodes when making the root layer in a groove having no root opening and which does not fill the groove.

* The Vickers hardness number shall be determined in accordance with the requirements of ASTM E92. Rockwell hardness numbers shall be determined in accordance with the provisions of ASTM E18.
b) 750 amps for any single electrode or 900 amps for parallel electrodes when making the root pass in a groove weld having steel backing.

c) 1000 amps for any single electrode or 1200 amps for parallel electrodes for all other passes except the final layer.

d) For the final layer, there is no restriction on welding current.

Welding procedures using currents higher than listed in c) above shall be subject to qualification testing as determined by the DCES. The maximum welding current to be used for making a fillet weld shall be 1000 amps for any single electrode or 1200 amps for parallel electrodes. Preheat and interpass temperatures for multiple electrode submerged arc welding shall conform to the provisions of Table 708.

The DCES may approve reductions in preheat for certain applications of multiple electrode submerged arc welding, provided acceptable weld and heat affected zone hardness test results are obtained during qualification testing and in verification testing during the work. The total welding heat input shall be computed based upon all welding variables and the number of arcs operating simultaneously. The combination of preheat, interpass temperature and welding heat input shall be such that tests demonstrate that no portion of the heat affected zone has a Rockwell hardness greater than C 25 or a Vickers hardness number greater than 266. Determination of the heat affected zone hardness shall be made on the initial macroetched cross sections of sample test welds and on the surface of weldments during the progress of the work. Surfaces shall be ground to a finish of 60 microinches or smoother in areas that are to be hardness tested. Tests shall be made on the thicker metal in each weld joint at a rate of not less than one test per weldment, or one test each 50 feet of groove weld, each pair of fillet welds made simultaneously, or each fillet weld. Hardness testing may be reduced in frequency or discontinued after the procedure has been established to the satisfaction of the DCES.

No reduction of the preheat requirements listed in Table 708 will be permitted for fillet welds or groove welds 3/8 inch and under in size.

713. REQUIREMENTS FOR FLUX CORED ARC WELDING

713.1 Electrodes for Flux Cored Arc Welding. Electrodes for flux cored arc welding shall conform to the requirements of the latest edition of AWS A5.20, Specification for Carbon Steel Electrodes for Flux Cored Arc Welding. The classification of the electrode shall meet the requirements of Table 706.1.

The shielding gas or gas mixture used for flux cored arc welding shall be of a welding grade having a dew point of -40°F or lower. The Contractor shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and will meet the dew point requirement.

713.2 Procedures for Flux Cored Arc Welding with a Single Electrode. A shop welded procedure qualification test described in Section 8, Qualification, shall demonstrate that the electrode-shielding gas combination will produce the required weld metal properties as listed in Tables 706.1 and 706.2.

The shielding shall be carbon dioxide gas unless otherwise approved by the DCES.

The electrodes shall be received in suitable containers to insure that they are dry and in suitable condition for use. The maximum electrode diameter shall be 5/32 inch for welding in the flat and horizontal positions, 3/32 inch for welding in the vertical position, and 5/64 inch for welding in the overhead position.

The maximum size fillet weld to be made in one pass shall be 1/2 inch for flat and vertical welding, 3/8 inch for welding in the horizontal position, and 5/16 inch for welding in the overhead position.
The thickness of weld layers, except root and surface layers, shall not exceed 1/4 inch.

When the root opening of a groove weld is 1/2 inch or greater, a multipass split layer technique shall be used. The split layer technique shall also be used in making all multiple pass welds when the width of the layer exceeds 5/8 inch for flat, horizontal and overhead welding or 1 inch for vertical welding. The welding current, arc voltage, gas flow rate, mode of metal transfer, and travel speed shall be adjusted so that each pass will have complete fusion with adjacent base metal and weld metal and meet the requirements of this Manual.

The progression of all passes for vertical welding shall be upward. In tubular structures, the progression of passes for vertical welding may be upward or downward, but only in the direction for which the welder and welding process is qualified.

Flux cored arc welding shall not be done in a draft or wind unless the weld is protected by a shelter. The shelter shall be suitably constructed to reduce the velocity of the wind in the vicinity of the weld to a maximum of five miles per hour.

To prevent melting thru, roots of groove or fillet welds may be backed by steel bars if necessary as described in Article 712.1. Roots of groove or fillet welds may be sealed by means of root passes deposited by manual shielded metal arc welding using E 7016 or E 7018 electrodes.

714. REQUIREMENTS FOR ELECTROSLAG AND ELECTROGAS WELDING

714.1 Qualification of Process, Procedures, and Joint Details. Prior to use, the contractor shall prepare a procedure specification and qualify each procedure for each process to be used according to the requirements in Section 8, Qualification. The procedure specification shall include the joint details, filler metal type and diameter, amperage, voltage (type and polarity), speed of vertical travel if not an automatic function of arc length or deposition rate, oscillation (traverse speed, length, and dwell time), type of shielding including flow rate and dew point of gas or type of flux, type of molding shoe, postweld heat treatment if used, and other pertinent information.

The electroslag and electrogas welding processes shall not be used for welding heat treated steel or for welding bridge members subject to tensile stresses or reversal of stress.

Dynamic toughness impact tests shall be included in the welding procedure qualification. The test requirements and procedure shall be as approved by the DCES.

The DCES, at his discretion, may accept evidence of previous qualification of the joint welding procedures to be employed.

714.2 Mechanical Test Requirements. Prior to use, the contractor shall demonstrate that each combination of shielding and filler metal will produce weld metal having the mechanical properties specified in the latest edition of AWS A5.25, Specification for Consumables Used for Electroslag Welding of Carbon and High Strength, Low Alloy Steels, or the latest edition of AWS A5.26, Specification for Consumables Used for Electrogas Welding of Carbon and High Strength, Low Alloy Steels, as applicable, when welded in accordance with the procedure specification described in Section 8, Qualification.

Qualification tests shall verify that the welding procedure produces filler metal meeting the requirements of Table 706.1.
714.3 Chemical Requirements. The results of chemical analysis of deposited filler metal shall be subject to the approval of the DCES.

714.4 Condition of Electrodes and Guide Tubes. Electrodes and consumable guide tubes shall be dry, clean, and in suitable condition for use.

714.5 Shielding Gas. A gas or a gas mixture used for shielding for electrogas welding shall be of a welding grade and have a dew point of -40°F or lower. When requested by the DCES, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and will meet the dew point requirements.

714.6 Condition of Flux. Flux used for electroslag welding shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without affecting its welding characteristics or weld properties. Flux from damaged packages shall be dried at a minimum temperature of 250°F for one hour before use, or discarded. Flux that has been wet shall not be used. If flux is used from an open package or container, 1 inch minimum of the surface flux shall be discarded before the remainder is used.

714.7 Procedures for Electroslag and Electrogas Welding. Gas to be used for shielding shall be of a welding grade and shall meet all requirements of the procedure specification. When mixed at the welding site, suitable meters shall be used for proportioning the gases. The percentage of gases shall conform to the requirements of the procedure specification.

Electrogas welding shall not be done in a draft or wind greater than five miles per hour unless the weld is protected by a shelter. This shelter shall be suitably constructed to reduce wind velocity in the vicinity of the weld surface to a maximum of five miles per hour.

The type and diameter of the electrodes used shall meet the requirements of the procedure specification.

Welds shall be started in such a manner as to permit sufficient heat buildup to insure complete fusion of the weld metal to the groove faces of the joint. Welds which have been stopped at any point in the weld joint for a sufficient amount of time for the slag or weld pool to begin to solidify may be restarted and completed, provided the completed weld is examined by ultrasonic testing for a minimum of 6 inches on each side of the restart and, unless prohibited by joint geometry, also examined by radiographic testing. All such restart locations shall be recorded and reported to the Inspector.

Because of the high heat input characteristic of these processes, preheating is not normally required. However, no welding shall be performed until the base metal is preheated sufficiently to insure that moisture does not condense or remain on joint surfaces.

The temperature of cooling water in water cooled shoes shall be controlled to prevent condensation of moisture within the joint.

Welds having defects prohibited by Articles 724 and 725 shall be repaired as permitted by Article 726 using a qualified welding process, or the entire weld shall be removed and replaced.

715. EXTENSION BARS AND RUNOFF PLATES

Welds shall be terminated at the end of a joint in a manner that will insure sound welds. Whenever possible, this shall be done by the use of extension bars and runoff plates placed in a manner that will duplicate the joint detail being welded.
Extension bars and runoff plates used in bridge construction shall be removed upon completion of the weld joint.

Extension bars and runoff plates used in building construction shall be removed at the completion of welding unless otherwise approved by the Engineer. Extension bars and runoff plates shall conform to the requirements of Article 504.

716. GROOVE WELD BACKING

Unless otherwise approved by the DCES, only steel may be used as groove weld backing. Groove welds made with the use of steel backing shall have the weld metal thoroughly fused to the backing. The steel backing shall be made continuous for the full length of the weld. All necessary joints in the steel backing shall be complete joint penetration groove welds meeting all the workmanship requirements of this Section. Weld backing shall conform to the requirements of Article 504.

716.1 Bridge Structures. On bridge structures, steel backing of welds transverse to the direction of computed stress shall be removed and the joints shall be ground flush. Steel backing of welds that are parallel to the direction of stress or not subject to computed stress need not be removed unless specified in the Contract Documents or ordered by the DCES.

When the steel backing of longitudinal welds in bridge structures is permitted to be externally attached to the base metal by welding, the welds shall be continuous for the length of the backing. Backing may be left in place on tee and corner welds unless otherwise specified.

716.2 Buildings and Tubular Structures. Steel backing of welds used in buildings or tubular structures need not be removed unless specified in the Contract Documents or ordered by the DCES.

717. TEMPORARY AND TACK WELDS

Temporary and tack welds shall be subject to the same quality requirements as final welds except:

a) Preheat is not mandatory for single pass welds which are completely remelted with their attendant heat affected zones and incorporated into final submerged arc welds.

b) Discontinuities such as undercut, unfilled craters and minor porosity need not be removed before the final submerged arc weld, if such welds are to be remelted.

c) The minimum length of the tack welds shall be at least four times the nominal weld size, or 1 1/2 inches, whichever is greater, unless otherwise approved by the DCES.

Tack welds which are incorporated into final welds shall be made with electrodes approved for use in the approved welding procedure specification.

Tack welds shall be thoroughly cleaned before final welding. Multiple pass tack welds shall have cascaded ends.

Tack welds larger than permitted in Article 712.1 shall be reduced in size by grinding before final welding is begun.

Temporary or tack welds which are not incorporated into the final weld shall be removed and the surface shall be finished flush with the original surface. The areas where the welds were removed shall be magnetic particle inspected by the Contractor in accordance with the provisions of Section 18, Magnetic Particle Inspection.

The Inspector shall perform hardness tests on the weld removal areas. Areas found to be harder than Rockwell hardness C 27 will not be accepted. Localized hard spots may be removed by grinding as approved by the DCES.
There shall be no temporary attachments by welding to tension areas of any structural steel unless approved by the DCES.

All temporary welds, when approved, shall meet all quality requirements of the specifications for permanent welds including preheat, interpass temperature, and minimum heat input controls. Temporary welds shall be removed and the surface finished flush as described in this Section.

Tack welds, when approved to attach permanent metal forms to compression areas of girder flanges, shall be subject to the above requirements, except that preheat is not mandatory. Tack welds will not be permitted on girder flanges, in areas subject to tension or reversal stress. Areas of tension or reversal stress will generally be shown on the plans. (See Article 203.4 for definition of stress reversal zone.)

718. CONTROL OF DISTORTION AND SHRINKAGE STRESSES

When assembling and joining parts of structures, built-up members, or welding reinforcing parts to members, the procedure and sequence shall minimize distortion and shrinkage stresses. All welds shall be deposited in a sequence that will balance the applied heat of welding and shrinkage stresses while the welding progresses. Complete welding of the first side of a groove weld preparation before welding the second side may cause unacceptable distortion.

The Contractor shall develop welding procedures which, in conjunction with the overall fabrication methods, will produce members and structures that meet the dimensional and quality requirements of the Contract Documents. These procedures and any revisions necessary in the course of the work shall be sent for information and comment to the DCES.

The direction of the general progression of welding on a member shall be from points where the parts are relatively fixed in position with respect to each other toward points where they have a greater relative freedom of movement. Joints expected to have significant shrinkage should usually be welded before joints expected to have less shrinkage. Joints should be welded with as little restraint as possible.

All shop splices in each component part of a cover plated beam or builtup member shall be made before the component part is welded to other parts of the member. Long girders may be made by shop splicing subsections made in accordance with this paragraph.

Welds made under conditions of severe external shrinkage restraint shall be welded continuously to completion or to a point that will insure freedom from cracking before the joint is allowed to cool below the minimum specified preheat and interpass temperature.

Joint details may be modified to reduce total shrinkage and control distortion in accordance with Article 702.

719. PEENING

With approval of the DCES, peening will be permitted on intermediate weld layers of large multipass welds and repair welds to control shrinkage stresses and prevent cracking. No peening shall be done on the root or surface layer of the weld. The peening tool shall be rounded to a 1/4 inch minimum radius at the striking end. The Contractor shall submit his peening procedure to the DCES for approval before beginning the work. Care shall be taken to prevent overlapping or cracking of the weld or base metal. No procedure or equipment will be permitted that will allow moisture, oil, or other materials to contaminate the weld joint. All peening energy shall be directed against the convex surface of the weld beads. No peening of base metal or of the fusion boundaries will be permitted. Peening may only be done when the weld is between 150°F minimum and 550°F maximum.
720. ARC STRIKES

Arc strikes outside the area of permanent welds shall be avoided. Blemishes caused by arc strikes shall be ground flush and smooth. The area shall be visually inspected and magnetic particle or dye penetrant tested to insure soundness. Cracks shall be reported to the DCES and repaired as described in Article 726. The Inspector shall perform hardness tests in arc strike areas. Areas found harder than a Rockwell hardness of C 27 shall be repaired as approved by the DCES.

721. CAULKING

Caulking is defined as the plastic deformation of weld and base metal surfaces by mechanical means to seal or obscure discontinuities. Caulking shall not be permitted.

722. WELD CLEANING

722.1 In Process Cleaning. All slag shall be removed and the weld and adjacent base metal shall be brushed clean before welding over previously deposited metal. This requirement shall apply not only to successive layers, but also to successive beads and to the crater area when welding is resumed after any interruption. The provisions of this section shall not restrict the welding of plug and slot welds, when required by the plans and performed in accordance with procedures approved by the DCES.

722.2 Cleaning of Completed Welds. Slag shall be removed from all completed welds, and the weld and the adjacent base metal shall be cleaned of all weld spatter, fume deposits and other surface contaminates. Welded joints that are to be painted shall not be painted until the work has been completed and accepted.

723. WELD PROFILES AND FILLET WELD SIZES

The faces of fillet welds may be slightly convex, flat or slightly concave as shown in Figure 723 (A) & (B). Profiles shown in Figure 723 (C) shall not be allowed.

Fillet welds shall be permitted to underrun the nominal fillet size specified by 1/16 without correction provided the undersize portion of the fillet welds does not exceed 10% of the length of the weld. On web to flange welds of plate girders, no underrun is permitted at the ends for a length equal to the depth of the girder.

Oversize fillet welds are not considered unacceptable unless they produce excessive distortion or will produce undesirable residual stress in the opinion of the DCES. Corrections, when necessary, will be limited to reducing the weld size as described in Article 726.2 and/or correcting the distortion. The soundness of the weld and adjacent base metal shall be evaluated by magnetic particle testing after repairs are completed.

All butt welded joints subject to radiographic inspection as described in Section 16 shall be ground smooth four sides before being radiographed. Welds in joints 3/4 inch or less in thickness shall be ground flush. Other joints to be radiographed may be finished leaving some reinforcement provided all surface lines have been removed by grinding and reinforcement does not exceed the requirements of Table 723.

The finish grinding need not be parallel to the direction of stress in the joint provided the surface roughness is less than ANSI 125.

The reinforcement need not be equally distributed on each side of the joint provided it does not exceed the amount shown in Table 723. No weld reinforcement will be permitted on the side of a joint that is a faying surface, contact surface, or exposed web surface of a fascia girder. All butt welds not subject to radiographic inspection or grinding to produce flush surfaces shall be made with slight or minimum reinforcement and shall have none of the defects shown in Figure 723(E). The height of reinforcement shall not exceed 1/8 inch on any side of a joint and shall have a gradual transition to the base metal surface.
Care shall be taken to insure that welds in shapes and plates are not ground below the ordered thickness. Small localized reductions in section thickness not to exceed 10% of the length of the weld will be permitted provided the reduction is not more than 5% of the ordered thickness of the thinner piece. General undergrinding shall not exceed 0.010 inches below the ordered thickness. Sections ground below these limits shall be rewelded and if the original weld joints calls for radiographic inspection, they shall be reradiographed.

Undercut shall not be greater than 0.010 inch deep when its direction is transverse to the direction of primary stress in the part that is undercut. Undercut shall not exceed 1/32 inch deep when its direction is parallel to the direction of primary stress in the part that is undercut. The DCES may approve localized undercut greater than 1/32 inch deep in parts not subjected to calculated stress.

Welds shall be free from overlap.

TABLE 723 — WELD REINFORCEMENT

<table>
<thead>
<tr>
<th>Plate Thickness (inches)</th>
<th>Thickness of Reinforcement (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To 3/4, inclusive</td>
<td>none, grind flush</td>
</tr>
<tr>
<td>Over 3/4 to 1, inclusive</td>
<td>3/64 each side or 3/32 total</td>
</tr>
<tr>
<td>Over 1 to 2, inclusive</td>
<td>1/16 each side or 1/8 total</td>
</tr>
<tr>
<td>Over 2 to 3, inclusive</td>
<td>3/32 each side or 3/16 total</td>
</tr>
<tr>
<td>Over 3</td>
<td>1/8 each side or 1/4 total</td>
</tr>
</tbody>
</table>

724. QUALITY OF WELDS (Bridges)

724.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if:

a) The weld has no cracks.
b) Thorough fusion exists between adjacent layers and passes of weld metal and between weld metal and base metal.
c) All craters are filled to the full cross section of the weld.
d) Weld profiles are in accordance with the provisions of Article 723.
e) Undercut is less than described in Article 723.
f) Porosity does not exceed the provisions of Article 724.3.
g) The size of fillet welds meet the requirements of Article 723.

Visual inspection of welding shall be performed before, during, and after completion of the welding.

724.2 Other Nondestructive Inspection. Welds that are subject to nondestructive testing other than visual inspection of the weld in process, on the surface of the completed weld, or in the cross section of a milled end required by design, shall meet all the requirements for welds visually inspected as described above and shall also conform to the standards of acceptance described in Section 16, Radiographic Testing, Section 17, Ultrasonic Testing, Section 18, Magnetic Particle Inspection, or Section 19, Dye Penetrant Inspection, as provided in the Contract Documents. Testing may begin immediately after the completed welds have cooled to ambient temperatures unless otherwise specified.
Note: Convexity, C, of a weld or individual bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 0.06 inches.

(A) Desirable fillet weld profiles

(B) Acceptable fillet weld profiles

(C) Unacceptable fillet weld profiles

Note: Reinforcement R shall not exceed 1/8 inch.

(D) Acceptable butt weld profile

(E) Unacceptable butt weld profiles

FIGURE 723 – ACCEPTABLE AND UNACCEPTABLE WELD PROFILES
724.3 **Limits of Porosity.**

a) Fillet Welds. The frequency of piping porosity in the surface of fillet welds shall not exceed one in four inches or six in four feet of weld length and the maximum diameter shall not exceed 3/32 inch.

Since piping porosity does not have to extend to the surface of the weld to present a serious structural defect, a subsurface inspection for porosity shall be required by the Inspector whenever piping porosity 3/32 inch or larger in diameter extends to the surface at intervals of 12 inches or less over a distance of four feet, or when the condition of electrodes, flux base metal, or the presence of weld cracking indicates that there may be a problem with piping or gross porosity. This subsurface inspection shall be a visual inspection of 12 inch long sections of the fillet weld throat after it has been ground or removed by air carbon arc gouging to a depth of one-half the design throat. When viewed at the mid throat of the weld, the sum of the diameters of all porosity shall not exceed 3/8 inch in any linear inch of weld or 3/4 inch in any 12 inch length of weld.

b) Groove Welds. Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds the frequency of piping porosity shall not exceed one in four inches or six in four feet of weld length and the maximum diameter shall not exceed 3/32 inch.

Groove welds displaying piping porosity at the surface which exceeds the values permitted under paragraph a) above shall be excavated by air carbon arc gouging or grinding to one-half the depth of the groove preparation that was welded. When viewed at the mid groove depth, the sum of the diameters of all porosity shall not exceed 3/16 inch in any linear inch of weld or 3/8 inch in any 12 inch length of weld.

725. **QUALITY OF WELDS (Buildings)**

All welds shall be visually inspected. A weld subject only to visual inspection that meets the visual inspection requirements for bridge welds shall be acceptable.

In general, undercut twice the amount allowed in bridge welds will be permitted. The DCES may approve undercut greater than 1/16 inch deep in members not subject to calculated stress or subject only to compressive stress.

Welds subject to radiographic testing shall meet the building quality requirements of Section 16. Welds subject to ultrasonic testing shall meet the minimum acceptance levels for welds in buildings as listed in Section 17. Welds subject to magnetic particle or dye penetrant testing shall conform to the requirements of Section 18 & 19 respectively.

Visual inspection of welding shall be performed before, during, and after completion of the welding. Other nondestructive testing of welds may begin immediately after the completed welds have cooled to ambient temperature unless otherwise specified.

726. **REPAIRS**

726.1 General. The removal of weld metal or portions of the base metal may be done by machining, grinding, chipping, or air carbon arc gouging. It shall be done in such a manner that the remaining weld metal or base metal is not nicked or undercut. Unacceptable portions of the weld shall be removed without substantial removal of the base metal.
Additional weld metal, to compensate for any deficiency in size, shall be deposited using an electrode preferably smaller than that used to make the original weld but not less than 5/32 inch in diameter. The surfaces shall be cleaned thoroughly before welding. Minimum preheat and interpass temperatures, and minimum welding heat input requirements shall be observed.

When air carbon arc gouging is used, it shall be followed by grinding to remove carbon pickup.

726.2 Written Repair Procedures. Written repair procedures shall be submitted on full size drawings* to fully describe the deficiency and the proposed method of repair. The drawings shall be prepared by the Contractor and submitted to the DCES for approval, when any of the following conditions exist:

a) Defective base metal, including lamellar tears.

b) Excessive number of weld defects listed in Article 726.2 in any one member, as determined by the DCES.

c) Any delayed or cold crack in weld or base metal.

d) Any weld or base metal crack other than an occasional root pass crack that occurred before it was possible to make the next weld pass.

e) Heat-shrink procedures used to increase the camber of welded plate girders. (See Article 1502.3).

f) Repairs to electroslag or electrogas welds with internal defects.

g) Revised design to compensate for deficiencies.

h) Members repair welded or modified to correct fabrication errors in cutting, punching, drilling, fitting, etc.

i) Members which must be cut apart and rewelded or modified in any way due to fit-up or welding errors.

726.3 Methods of Repair. The Contractor shall have the option of either repairing an unacceptable weld, removing and replacing the entire weld when approved by the DCES, or replacing the entire weldment. The repaired or replaced weld or replaced weldment shall be tested by the method originally used. The same technique and quality acceptance criteria shall be applied.

If the Contractor elects to repair the weld, it shall be repaired as follows:

a) Overlap or excessive convexity shall be repaired by removing excess weld metal by grinding.

b) Excessive concavity of welds or craters, undersize welds, or undercutting shall be repaired by cleaning and depositing additional weld metal after heating to the minimum preheat temperature.

c) Excessive weld porosity, excessive slag inclusions, incomplete fusion or overlap not correctable by grinding shall be repaired by removing defective portions and rewelding.

*In lieu of full size drawings, the DCES may approve repair sketches. When ordered by the DCES, the Contractor shall reproduce approved repair sketches on full size drawings so that they may be filed with the As-Built Plans.
d) Cracks in weld or base metal shall be repaired by the following procedure: Determine the extent of the crack by use of magnetic particle testing or other equally positive means approved by the DCES. Remove the crack and sound metal two inches beyond each end of the crack and reweld in accordance with the approved repair procedure.

e) Members distorted by welding may be straightened by heat-shrink straightening procedures as described in Section 15.

f) Where work performed subsequent to making a defective weld has rendered the weld inaccessible or has caused new conditions which would make the correction of the deficiency dangerous or ineffective, the original condition shall be restored by removing welds, members, or both before making corrections, or the deficiency shall be compensated for by additional work done in accordance with a design revision approved by the DCES.
727. SCOPE
This section contains provisions for the installation and inspection of steel studs welded to structural steel. The term "steel studs" is used to describe concrete anchors, shear connectors used in composite steel-concrete construction, threaded studs and similar end welded attachments.

728. GENERAL
Studs shall be of a design suitable for arc welding to steel members with automatically timed stud welding equipment. The type, size or diameter, and length of stud shall be as specified by the drawings, specifications, or special provisions as approved by the DCES. Dimensions and tolerances for standard type shear connectors are shown in Figure 728.

```
<table>
<thead>
<tr>
<th>Shank Diameter (C)</th>
<th>Length Tolerances (L)</th>
<th>Head Diameter (H)</th>
<th>Minimum Head Height (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 +0.000</td>
<td>± 1/16</td>
<td>1 ± 1/64</td>
<td>9/32</td>
</tr>
<tr>
<td>5/8 +0.000</td>
<td>± 1/16</td>
<td>1 1/4 ± 1/64</td>
<td>9/32</td>
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<tr>
<td>3/4 +0.000</td>
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<td>7/8 +0.000</td>
<td>± 1/16</td>
<td>1 3/8 ± 1/64</td>
<td>3/8</td>
</tr>
</tbody>
</table>
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Note: \( L = \text{manufactured length equals length specified plus burn-off.} \)

FIGURE 728 – STANDARD TYPE SHEAR CONNECTOR
An arc shield (ferrule) of heat-resistant ceramic or other suitable material shall be furnished with each stud.

A suitable deoxidizing and arc stabilizing welding flux shall be furnished with each stud of 5/16 inch diameter or larger. Studs less than 5/16 inch in diameter may be furnished with or without flux.

Studs shall be produced by cold heading, cold rolling, or machining. Finished studs shall be of uniform quality and condition, free of injurious laps, fins, seams, cracks, twists, bends, or other injurious discontinuities. A stud with radial cracks or bursts in the head shall not be the cause for rejection provided the cracks or bursts do not extend more than 1/2 the distance from the head periphery to the shank, as determined by visual inspection.

Additional camber shall be provided in the fabrication of the structural members to compensate for a reduction of camber due to welding of the studs.

729. MATERIAL REQUIREMENTS

Studs shall be furnished in accordance with the materials section, entitled "Stud Shear Connectors" of the Standard Specifications.

730. OPERATOR QUALIFICATION

The initial test required by Article 732 shall also serve to qualify the stud welding operator. Operators not involved in the initial procedure qualification shall be qualified before any production studs are welded. The operator shall have the first two welded studs tested in accordance with the provisions of Article 732. When the two welded studs have been tested and found satisfactory, the operator may then weld production studs.

731. WELDING PROCEDURES

Studs shall be welded to steel members with automatically timed stud welding equipment connected to a suitable power source. It two or more stud welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time, and so that the power source has fully recovered from making one weld before another weld is started. While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

At the time of welding, the studs shall be free from rust, pits, scale, oil or other deleterious matter that would adversely affect the welding operation. The stud base shall not be painted, galvanized, or cadmium plated prior to welding.

The areas on the member where studs are to be welded shall be free of scale, rust, dirt, paint, grease, or other injurious material as necessary to obtain satisfactory welds. These areas may be cleaned by blast cleaning, wire brushing, peening, prick punching, or grinding.

If the Contractor elects to use a rust preventive lacquer coating on the steel surfaces, this coating will be allowed to remain during the welding of studs provided acceptable stud welds are uniformly produced.

Welding shall not be done when the base metal temperature is less than 0°F, or when the surface is wet or exposed to falling rain or snow. When the temperature of the base metal is below 32°F, one stud in each 100 studs welded shall be tested by the methods specified in Article 733, as applicable, in addition to the first two tested as specified in Article 732.

Longitudinal and lateral spacings of stud shear connectors with respect to each other and to edges of beam or girder flanges may vary a maximum of 1 inch from the location shown on the drawings, provided the adjacent studs are not closer than 2 1/2 inches center to center. The minimum distance from the edge
of a stud base to the edge of a flange shall be the diameter of the stud plus 1/8 inch, but preferably not less than 1 1/2 inches. Other types of studs shall be so located as to permit a workmanlike assembly of attachments without alterations or reaming.

After welding, arc shields shall be broken free from all studs unless otherwise approved by the DCES.

The studs, after welding, shall be free from any defect or substance that would interfere with their intended function.

When approved by the DCES, studs may be fillet welded by the manual shielded metal arc process, provided the following requirements are met:

a) The fillet weld size shall be a minimum of 5/16 inch.

b) Welding shall be done with E7018 electrodes, 5/32 inch in diameter.

c) The stud base shall be prepared so that the outside circumference of the stud fits tightly against the base metal.

d) All rust and mill scale at the location of the stud shall be removed from the base metal by blast cleaning or grinding. The end of the stud shall also be clean.

e) The base metal to which the studs are welded shall be preheated in accordance with the requirements of Table 708.

f) The fillet welds meet all the weld quality requirements of Articles 724 and 725.

732. QUALITY CONTROL

732.1 Shear Connectors. The first two stud shear connectors welded on each member, after being allowed to cool, shall be tested by bending to an angle of 30 degrees from their original axes by striking the studs with a two pound hammer. If failure occurs in the weld zone of either stud, the procedure shall be corrected and two more studs shall be welded to the member and tested. If either of the second two studs fail, additional welding shall be continued on separate plates of the same thickness as the member and in the same general position until two consecutive studs are tested and found to be satisfactory. Two consecutive studs shall then be welded to the member, tested and found to be satisfactory before any more production studs are welded to the member.

For members having less than 20 stud shear connectors, the stud welding procedure may be tested at the start of each day's production welding period in lieu of testing in accordance with the previous paragraph.

A new production period begins with the welding of a given size and type stud with a given welding procedure or with the beginning of each day's production.

Before use in production, each welding unit shall be used to weld two stud shear connectors to separate test material in the same general position (i.e., flat, vertical, overhead, sloping) and of a similar thickness. After being allowed to cool, they shall be bent as described above. If failure occurs, the procedure shall be corrected and two consecutive studs shall be welded to the test material, tested and found to be satisfactory before any production studs are welded to the member.

The foregoing testing shall be performed after any change in the welding procedure.

If failure occurs in the stud shank, an investigation shall be made to ascertain and correct the cause before more studs are welded.
732.2 **Applications Other Than Shear Connectors.** Before starting the welding operations or at the request of the EIC or Inspector, two stud connectors shall be welded to separate material in the same general position (i.e., flat, vertical, overhead, sloping) and of a thickness and material similar to the member. After being allowed to cool, the studs shall be bent to an angle of 30 degrees from their original axes by striking the studs with a two pound hammer. If failure occurs in the weld zone of either stud, the procedure shall be corrected and two more studs shall be welded and tested before any studs are welded to the member. The foregoing testing shall be performed after any change in the welding procedure.

If failure occurs in the stud shank, an investigation shall be made to ascertain and correct the cause before more studs are welded.

733. **INSPECTION REQUIREMENTS**

If visual inspection reveals any stud shear connector that does not show a full 360 degree flash, any stud that has been repaired by welding, or any stud in which the reduction in length due to welding is less than normal, that stud shall be struck with a two pound hammer and bent to an angle of 15 degrees from its original axis. For studs showing less than a 360 degree weld fillet, the direction of bending shall be opposite the missing weld fillet. Studs that crack in the weld, the base metal, or the shank under inspection or subsequent straightening shall be replaced. Non-fusion on the vertical leg of the flash and small-shrink fissures are acceptable.*

For studs other than shear connectors, at least one stud in every 100 shall be bent to an angle of 15 degrees from its original axis by striking with a two pound hammer. If threaded, the stud shall be tested with a calibrated torque wrench to the value shown in Table 733 for the diameter and thread of the stud, in a device similar to that shown in Figure 733. If the stud fails, the procedures shall be checked in accordance with Article 732.2 and two more of the existing studs shall be bent or torque-tested. If either of these two studs fail, all studs represented by the tests shall be torque-tested, bend-tested, or rejected. For critical structural connections, the DCES shall designate the type and extent of additional inspection in the Contract.

Non-fusion on the vertical leg of the flash and small-shrink fissures are acceptable.*

The Inspector, where conditions warrant, may select a reasonable number of additional studs to be subjected to the tests specified above.

The bent stud shear connectors and concrete anchors that show no sign of failure shall be acceptable for use and left in the bent position if no portion of the stud is less than 1 inch from a proposed concrete surface. All required bending and straightening shall be done, without heating, before completion of the stud welding operation on the job, except as otherwise provided in the Contract.

If studs welded during the progress of the work are not in accordance with the provisions of this Manual, the Contractor shall make changes (such as welding procedure, welding equipment, and stud base) necessary to ensure that studs subsequently welded meet the requirements of this Manual.

- The expelled metal around the base of the stud is designated as flash in accordance with the definition of flash in AWS A3.0, Terms and Definitions, and Appendix D of this Manual. It is not a fillet weld such as those formed by conventional arc welding. The expelled metal, which is excess to the weld required for strength, is not detrimental, but, on the contrary, is essential to provide a good weld. The containment of this excess molten metal around a welded stud by the ferrule (arc shield) assists in securing sound fusion of the entire cross section of the stud base. The stud weld flash may have non-fusion in its vertical leg and overlap on its horizontal leg, and it may contain occasional small-shrink fissures or discontinuities that usually form at the top of the weld flash with essentially radial or longitudinal orientation, or both, to the axis of the stud. Such non-fusion on the vertical leg of the flash and small-shrink fissures are acceptable. The fillet weld profiles shown in Figure 723 do not apply to the flash of automatically timed stud welds.
If ordered by the DCES, the Contractor shall submit studs of the types used for the Contract for testing by the Department Laboratory to determine conformance with the requirements of the Standard Specifications.

![Diagram](image)

Dimensions are appropriate to the size of the stud. Threads of the stud shall be clean and free of lubricant other than the residue of cutting oil.

**FIGURE 733 – TESTING DEVICE**

<table>
<thead>
<tr>
<th>Nominal Diameter of Studs (inches)</th>
<th>Threads Per Inch and Series Designated</th>
<th>Testing Torque (foot pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>28 UNF</td>
<td>5.0</td>
</tr>
<tr>
<td>1/4</td>
<td>20 UNC</td>
<td>4.2</td>
</tr>
<tr>
<td>5/16</td>
<td>24 UNF</td>
<td>9.5</td>
</tr>
<tr>
<td>5/16</td>
<td>18 UNC</td>
<td>8.6</td>
</tr>
<tr>
<td>3/8</td>
<td>24 UNF</td>
<td>17.</td>
</tr>
<tr>
<td>3/8</td>
<td>16 UNC</td>
<td>15.</td>
</tr>
<tr>
<td>7/16</td>
<td>20 UNF</td>
<td>27.</td>
</tr>
<tr>
<td>7/16</td>
<td>14 UNC</td>
<td>24.</td>
</tr>
<tr>
<td>1/2</td>
<td>20 UNF</td>
<td>42.</td>
</tr>
<tr>
<td>1/2</td>
<td>13 UNC</td>
<td>37.</td>
</tr>
<tr>
<td>9/16</td>
<td>18 UNF</td>
<td>60.</td>
</tr>
<tr>
<td>9/16</td>
<td>12 UNC</td>
<td>54.</td>
</tr>
<tr>
<td>5/8</td>
<td>18 UNF</td>
<td>84.</td>
</tr>
<tr>
<td>5/8</td>
<td>11 UNC</td>
<td>74.</td>
</tr>
<tr>
<td>3/4</td>
<td>16 UNF</td>
<td>147.</td>
</tr>
<tr>
<td>3/4</td>
<td>10 UNC</td>
<td>132.</td>
</tr>
<tr>
<td>7/8</td>
<td>14 UNF</td>
<td>234.</td>
</tr>
<tr>
<td>7/8</td>
<td>9 UNC</td>
<td>212.</td>
</tr>
<tr>
<td>1</td>
<td>12 UNF</td>
<td>348.</td>
</tr>
<tr>
<td>1</td>
<td>8 UNC</td>
<td>318.</td>
</tr>
</tbody>
</table>

**TABLE 733 – REQUIRED TORQUE FOR TESTING THREADED STUDS**
734. REPAIR PROCEDURES

Studs on which a full 360 degree flash is not obtained shall be replaced or, at the option of the stud welding contractor, be repaired by adding a 5/16 inch fillet weld in place of the missing flash. All welding shall be performed using 5/32 inch diameter E7018 electrodes. All welding procedures and preheat requirements shall be as described in this Manual. The repair weld shall extend at least 3/8 inch beyond each end of the discontinuity being repaired. The repair weld shall be fused at all boundaries, have full throat throughout its length and all craters shall be filled.

If an unacceptable stud has been removed from a component subjected to tensile stresses, then the area from which the stud was removed shall be made smooth and flush. Where base metal has been pulled out in the course of stud removal, manual shielded metal arc welding with low hydrogen electrodes in accordance with the requirements of this manual shall be used to fill the pockets and the weld surface shall be ground flush.

In compression areas of members, if stud failures are confined to shanks or fusion zones of studs, a new stud may be welded adjacent to each unacceptable area in lieu of repair and replacement of the existing weld area. If metal is torn from the base metal of such areas, the repair provisions shall be the same as for tension areas except that when the depth of discontinuity is less than 1/8 inch or 7% of the base metal thickness, the discontinuity may be faired by grinding in lieu of filling the unacceptable area with weld metal. Where a replacement stud is to be placed in the unacceptable area, the above repair shall be made prior to welding the replacement stud. Replacement shear connector studs shall be tested by bending to an angle of 15 degrees from their original axes. The areas of components exposed to view in completed structures shall be made smooth and flush where a stud has been removed. If studs are welded, without authorization, to areas of webs and flanges subject to calculated tensile stress, they shall be removed and the removal sites shall be repaired and tested as follows:

1) Oxygen cut 1/8 inch above the base metal surface.
2) Grind flush.
3) Hardness test to determine that no remaining portion of the weld or base metal is harder than Rockwell hardness C27.
4) Stud removal sites in tension areas which require repair welding will be subject to nondestructive testing as determined by the DCES.
735. GENERAL

Reinforcing steel shall not be subject to any welding unless specifically shown on the plans or approved by the DCES. Welding shall not be permitted where impact properties are a requirement of the design specification. All welding shall be performed in conformance with a welding procedure specification and joint detail approved by the DCES. Tack welding of reinforcing steel outside the approved weld joint and arc strikes are prohibited.

The American Welding Society, Structural Welding Code-Reinforcing Steel, AWS D1.4 may be used as a reference in preparing welding procedure specifications and joint details for approval.

736. BASE METAL

Reinforcing steel shall conform to requirements of the Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, ASTM A615, Grades 40 or 60, or the Specification for Cold-Drawn Steel Wire for Concrete Reinforcement, ASTM A82. Other base metals shall conform to the requirements of Section 5, Base Metal, or shall be listed in the approved welding procedure specification.

737. WELD PROCESSES

All welding of reinforcing steel shall be performed using the manual shielded metal arc welding process or the flux cored arc welding process in conformance with all applicable requirements of this manual.

738. FILLER METAL

When reinforcing steel is to be welded by the manual shielded metal arc process, E7018 electrodes shall be used unless otherwise specified. When matching filler metal strength is required for welding direct butt splices of A615, Grade 60 bars, the DCES may approve the use of E9018 electrodes. When welding is to be performed by the flux cored arc welding process, E7XT-1 or E7XT-5 electrodes shall be used.

739. PERMISSIBLE STRESSES

Base metal stresses shall be as specified in the applicable design specification. The permissible stresses for bevel and V-groove butt splices in tension or compression shall be the same as the corresponding allowable unit stresses for the base metal in the applicable reinforcing steel design specification, provided it does not exceed 20 ksi for E70XX weld metal or 25.6 ksi for E90XX weld metal. Shear stresses shall not exceed 0.3 times the minimum specified ultimate tensile strength for building welds or 0.27 times the minimum specified ultimate tensile strength for bridge welds. When Class E70 electrodes are used, the maximum shear stress for building and bridge welds shall be 21 ksi and 18.9 ksi respectively.

740. EFFECTIVE DESIGN DIMENSIONS

740.1 Direct Butt Splices. The effective weld area shall be the nominal cross sectional area of the bar being spliced. If different size bars are being spliced, the effective weld area shall be the nominal cross sectional area of the smaller of the two bars at the splice.

740.2 Flare-Bevel and Flare-V-Groove Welds. The effective weld area shall be the effective weld length multiplied by the effective weld throat thickness. The effective weld length of flare-bevel and flare-V-groove welds shall be the overall length of the full sized flare-bevel or flare-V-groove weld. No deduction in effective length shall be made for either the start or the crater of the weld if the weld is full size throughout its length.
The minimum effective weld length of a flare-bevel or a flare-V-groove weld shall not be less than two times the bar diameter for equal bars, or two times the smaller bar diameter for two unequal bars.

The effective throat of a flare-bevel or a flare-V-groove weld when filled flush to the solid section of the bar shall be 0.4 and 0.6 respectively of the radius of the bar as shown in Figure 740. Larger effective throats may be used provided the welding procedure for indirect butt splices is qualified by test as approved by the DCES. When bars of unequal diameter are joined, the effective throat shall be based on the radius of the smaller bar.

**FIGURE 740 — EFFECTIVE THROATS FOR FLARE-GROOVE WELDS**

741. **JOINT DETAILS**

741.1 General. Joints shall be detailed as direct butt splices, indirect butt splices or lap welded splices. Welding symbols shall be as designated in AWS A2.4, Symbols for Welding and Nondestructive Testing. Special conditions shall be fully explained by added notes or details.
741.2 Direct Butt Splice Details. A direct butt splice is defined as a splice between two bars whose axes are approximately colinear with the bars being joined by a complete joint penetration groove weld made from both sides or from one side with backing.

A direct butt splice between two bars whose axes are in an approximately horizontal position shall be made preferably with either single-or double-V-groove welds with each bar beveled to provide a groove angle or angles of between 45° and 60° as shown in Figure 741.2 A and B. A direct butt splice between bars whose axes are in an approximately vertical position shall be made preferably with either single- or double-bevel groove welds with the end of the lower bar cut approximately 90° to the bar axis and the upper bar beveled to a groove angle or angles of approximately 45° as shown in Figure 741.2 C and D. Direct butt splices in bars No. 8 and smaller using a single-V-groove or single-bevel-groove shall be made with the appropriate backing as shown in Figure 741.2 E and F.

741.3 Indirect Butt Splice Details. An indirect butt splice is defined as a splice between two bars whose axes are approximately colinear, where the bars are welded to a common splice member by either single-or double-flare-bevel or flare-V-groove welds and the cross section of the bars remains unwelded. The splice member may be plate, angle, bar, or other shape as approved by the DCES. The cross sectional area of the splice member shall develop the strength of the bars being spliced. Double-flare-bevel-groove welds shall be used when the splice member is an angle, plate, or flat bar as shown in Figure 741.3 A and B. Double-flare-V-groove welds shall be used when the splice member is a round bar as shown in Figure 741.3 C. Single-flare-bevel and V-groove welds shall be used only when access is limited to one side of the joint.

741.4 Direct Lap Splice Details. A direct lap splice is defined as a splice between two bars whose axes are approximately parallel and approximately in the same plane, where bars in contact are welded together by either single-or double-flare-V-groove welds as shown in Figure 741.4. Double-flare-V-groove welds shall be used for direct lap welded splices unless the joint is accessible only from one side, in which case a single-flare-V-groove weld may be used.

741.5 Indirect Lap Splice Details. An indirect lap splice is defined as a splice between two bars laterally and welded to a common splice plate by single-or double-flare-bevel-groove welds as shown in Figure 741.5. The cross sectional area of the splice plate shall develop at least the strength of the bars being spliced. The bars shall be substantially in contact with the splice plate as described in Article 744. This splice shall be designed considering the effects of eccentricity and provisions for restraint.
A - Single vee-groove weld

B - Double vee-groove weld

Note 1: Chip, grind, or gouge to sound weld metal before welding other side

C - Single bevel groove weld

D - Double bevel groove weld

E - Single vee-groove weld

F - Single bevel groove weld with split pipe backing

Detail A, B, C and D for bars No. 9 and larger.
Detail E and F for bars No. 8 and smaller.

FIGURE 741.2 - DIRECT BUTT SPLICES
Double-flare-bevel-groove weld

Spacing of bars (similar for detail B)

A – Indirect butt splice using a plate

Flare-bevel-groove weld

B – Indirect butt splice using an angle

SECTION C - C

Double-flare-V-groove weld

C – Indirect butt splice using two bars

741.3 – INDIRECT BUTT SPLICES
FIGURE 741.4 – DIRECT LAP SPLICE DETAILS

SECTION A - A

SECTION B - B

Double-flare-V-groove weld
Note: The effects of eccentricity shall be considered or restraint provided in the design of the splice.
742. **PREHEAT AND INTERPASS TEMPERATURES**

Preheat and interpass temperatures shall be based on the carbon equivalent of the reinforcing steel bars and/or the splice material, whichever number is higher (see Table 742). The carbon equivalent number shall be calculated using the chemical composition as shown on the mill test report which represents the material to be welded. The following carbon equivalent formula shall be used:

\[
\text{C.E.} = \% C + \frac{\% \text{Mn}}{6} + \frac{\% \text{Cu}}{40} + \frac{\% \text{Ni}}{20} + \frac{\% \text{Cr}}{10} - \frac{\% \text{Mo}}{50} - \frac{\% \text{V}}{10}
\]

If mill test reports are not available, chemical analysis may be made on bars representative of the bars to be welded. When the mill test report does not establish the value for Molybdenum (Mo) and Vanadium (V), the carbon equivalent shall be determined by using Carbon (C), Manganese (Mn), Copper (Cu), Nickel (Ni), and Chromium (Cr). If the chemical composition of the bars is not known, or not obtained, the carbon equivalent shall be assumed to be above 0.75 for that material.

### TABLE 742 – MINIMUM PREHEAT AND INTERPASS TEMPERATURES

<table>
<thead>
<tr>
<th>Carbon equivalent range, %</th>
<th>Size of reinforcing bar</th>
<th>Degrees F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40 max.</td>
<td>up to 11 inclusive</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>14 and 18</td>
<td>50</td>
</tr>
<tr>
<td>0.41-0.45 inclusive</td>
<td>up to 11 inclusive</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>14 and 18</td>
<td>100</td>
</tr>
<tr>
<td>0.46-0.55 inclusive</td>
<td>up to 6 inclusive</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>7 to 11 inclusive</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>14 and 18</td>
<td>200</td>
</tr>
<tr>
<td>0.56-0.65 inclusive</td>
<td>up to 6 inclusive</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>7 to 11 inclusive</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>14 and 18</td>
<td>300</td>
</tr>
<tr>
<td>0.66-0.75</td>
<td>up to 6 inclusive</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>7 to 18 inclusive</td>
<td>400</td>
</tr>
<tr>
<td>above 0.75</td>
<td>up to 18 inclusive</td>
<td>500</td>
</tr>
</tbody>
</table>

Notes:

1) When reinforcing steel is to be welded to main structural material, the preheat requirements of the structural material shall also be considered (see Table 708). The minimum preheat requirement to apply in this situation shall be the higher requirement of the two tables.

2) Welding shall not be done when the ambient temperature is lower than 0°F. When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated in such a manner that the cross section of the bar for not less than 6 in. on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperatures must be sufficient to prevent crack formation.

3) After welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited.

4) Where it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75.
743. PREPARATION OF MATERIAL

Surfaces to be welded shall be smooth, uniform, and free from fins, tears, cracks and other defects which would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to a weld shall also be free from loose or thick scale, slag, rust, moisture, grease, paint, epoxy covering, zinc coating, or other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that withstands vigorous wire brushing, a thin rust inhibitive coating, or antispatter compound may remain.

The ends of reinforcing bars in direct butt splices shall be trimmed back and shaped to form the welding groove by oxygen cutting, air carbon arc cutting, or by sawing. Roughness of the cut surface shall not be greater than 2000 microinches. Defects in cut surfaces may be repaired as described in Article 601.

744. ASSEMBLY

Joint details shall be arranged to provide the most favorable position for welding. Each joint shall have adequate clearance and accessibility for welding as required by the process being used. The members to be joined shall be aligned to minimize eccentricity.

Bars in direct butt splices shall not be offset at the joint by more than the following:

- Bar sizes No. 10 or smaller .................................................... 1/8 inch
- Bar sizes No. 11 and No. 14 .................................................... 3/16 inch
- Bar size No. 18 ................................................................. 1/4 inch

For indirect butt splices, the maximum gap between the bar and splice member shall not exceed one quarter of the bar diameter or more than 3/16 inch.

For direct lap splices, the maximum gap between the bars shall not exceed one quarter of the bar diameter or more than 1/4 inch with bar bars remaining in approximately the same plane.

For indirect lap splices, the maximum gap between the bar and the splice plate shall not exceed one quarter of the bar diameter or more than 3/16 inch.

Welding shall not be performed within two bar diameters of any portion of a bar that has been cold bent. Welding of crossing bars shall not be permitted during assembly of reinforcement unless approved by the DCES.

745. QUALITY OF WELDS

Fillet welds shall meet the profile requirements shown in Figure 745A, with no deficiencies as shown in Figure 745B.

Groove welds shall be made with some reinforcement unless otherwise provided. The reinforcement shall not exceed 1/8 inch in height measured from the main body of the bar and shall have gradual transition to the plane of the base metal surface as shown in Figure 745A, with none of the deficiencies shown in Figure 745B.

There shall be complete fusion between weld metal and base metal and between successive passes in the weld. Welds shall have no cracks in either the weld metal or the heat affected zone. All craters shall be filled to the full cross section of the weld. Welds shall be free of overlap. Undercutting deeper than 1/32 inch shall not be allowed regardless of the direction of stress except that at points where welds intersect the raised patterns (deformations), undercutting less than 1/16 inch deep shall be acceptable. The sum of diameters of piping porosity in flare-bevel-groove, flare-V-groove and fillet welds shall not exceed 3/8 inch in any linear inch of weld and shall not exceed 9/16 inch in any 6 inch length of weld. Welds that do
not meet the quality requirements stated herein shall be repaired in accordance with the provisions of Article 726.

![Diagram of acceptable and unacceptable weld profiles](image)

A – Acceptable groove weld profiles

<table>
<thead>
<tr>
<th>Flare-bevel grooves</th>
<th>Flare-V grooves</th>
<th>Direct butt splices</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Acceptable profiles" /></td>
<td><img src="image" alt="Unacceptable profiles" /></td>
<td><img src="image" alt="Profiles" /></td>
</tr>
</tbody>
</table>

B – Unacceptable groove weld profiles

FIGURE 745 – ACCEPTABLE AND UNACCEPTABLE WELD PROFILES

746. QUALIFICATION

Welders shall be qualified in accordance with Section 8B of this manual. Additional reinforcing steel welding qualification tests may be ordered by the DCES.

747. INSPECTION

The provisions of Section 3, Inspection, shall apply. Welds shall be accepted or rejected based upon visual inspection, unless otherwise stated in the Contract Documents. Inspection shall be performed before, during and after welding to insure compliance with this specification.
Approved welding procedures shall consist of approved joint welding details which are welded using approved welding procedure specifications. The procedures for manual shielded metal arc welding shall be considered prequalified and exempt from procedure qualification testing when operated within the limits recommended by the electrode manufacturers. Welding shall be performed in accordance with the provisions of Section 7, Welding. The DCES reserves the right to order a SMAW procedure qualification test when, in his opinion, the joint welding procedure(s) or welding consumables, used or to be used, justify such a test. The test(s), if ordered, shall be as directed by the DCES. All other welding procedures shall be qualified by tests described herein.

The Contractor shall submit his proposed welding procedure to the DCES for review. The welding parameters for this procedure shall be shown on a form similar to Figure 801a. This information will be used to determine the procedure qualification test(s) required.

A complete procedure qualification test shall be performed for each electrode or electrode flux combination. For SAW and FCAW, the complete qualification tests shall be performed on the test plate described in Figure 801b. For ESW and EGW, the qualification tests shall be performed on the test plate described in Figure 801c. Additional tests may be required as determined by the DCES.

A modified procedure qualification test may be performed on the test plate described in Figure 801d for SAW and FCAW if the proposed procedure includes an electrode or electrode flux combination which is on record with the DCES and has produced satisfactory test results using welding parameters within the limitation of variables described in Article 805.

When joint welding details to be used in the work are not prequalified under the provisions of Article 703, the joint details and welding procedure shall be subject to complete qualification testing using a test plate conforming to Figure 801b, but modified to duplicate the weld joint details and thickness. The number of weld passes and operating variables shall be identical to those to be used in the work. Approval of unusual details and unusual procedures for operating SMAW, SAW, FCAW, ESW, or EGW may be denied on the basis of concern for increased weld defects on diminished weld properties. Approval of such procedures may require nondestructive tests of production welds at the Contractor's expense. Tee and corner weld details and procedures shall be tested as butt welds as determined by the DCES. When the qualification test plate thickness is less than one inch to duplicate a production weld, the DCES may modify or delete specific test specimens.

The DCES may order modification of any of the above tests as necessary to establish the acceptability of the welding procedure specification.

Any variation from the approved welding procedure, beyond the limits described in Article 805, Limitation of Variables, shall require approval of the DCES.

All approved welding procedure specifications shall be subject to verification testing at intervals not exceeding three years. The modified procedure qualification test shall be used for requalification of SAW and FCAW processes unless otherwise specified. The DCES may order additional qualification testing whenever there appear to be deficiencies in production welding.

Unless otherwise specified, fillet welding procedures shall be qualified by testing in a groove weld configuration as described in Figures 801b or 801d. These tests shall be performed using the fillet welding parameters (amps, volts, travel speed, etc.) listed in the fillet welding procedure specification.

Care should be taken in all weld testing to avoid unnecessary build-up of interpass temperature which is not representative of actual conditions in the work. Unnecessary temperature build-up may adversely affect notch toughness test results.
NEW YORK STATE
DEPARTMENT OF TRANSPORTATION
WELDING PROCEDURE QUALIFICATION RECORD

Fabricator: ___________________________ Test Date ___________________________

Process ___________________________ Filler Metal Classification ___________________________

Electrode(s) ___________________________ Flux ___________________________

<table>
<thead>
<tr>
<th>(1) Diameter</th>
<th>Amps</th>
<th>Volts</th>
<th>Current &amp; Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) _______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
<tr>
<td>(3) _______</td>
<td>______</td>
<td>______</td>
<td>______</td>
</tr>
</tbody>
</table>

Shielding Gas ___________________________ Flow Rate ___________________________

Travel Speed ___________________________ Material Specification & Thickness ___________________________

Preheat Temp. ___________________________ Interpass Temp. ___________________________

<table>
<thead>
<tr>
<th>SPECIMEN</th>
<th>TESTS RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Weld Metal Tension (AWMT)</td>
<td>Tensile Strength (psi) ________</td>
</tr>
<tr>
<td></td>
<td>Yield Strength (psi) ________</td>
</tr>
<tr>
<td></td>
<td>Elongation in 2&quot; (%) ________</td>
</tr>
<tr>
<td></td>
<td>Reduction in Area (%) ________</td>
</tr>
<tr>
<td>Side Bends</td>
<td>1. ______ 2. ______ 3. ______ 4. ______</td>
</tr>
<tr>
<td>Reduced Section Tension</td>
<td>Tensile Strength 1. ______ 2. ______ Location of Break 1. ______ 2. ______</td>
</tr>
<tr>
<td>Charpy Impact (Weld Metal)</td>
<td>Avg. Ft. Lbs. ______ @ ______°F</td>
</tr>
<tr>
<td></td>
<td>Avg. Ft. Lbs. ______ @ ______°F</td>
</tr>
<tr>
<td>ESW &amp; EGW</td>
<td>______ ______ ______ ______ Avg. Ft. Lbs. ______ @ ______°F</td>
</tr>
<tr>
<td>Chemistry</td>
<td>C. ______ Mn. ______ P. ______ S. ______ Si. ______</td>
</tr>
<tr>
<td></td>
<td>Ni. ______ Cr. ______ Mo. ______ V. ______ Cu. ______</td>
</tr>
</tbody>
</table>

REMARKS:

Test Witness: ___________________________ Agency ___________________________

Results Reviewed: ___________________________ DOT Acceptance ___________________________ Date ___________________________

FIGURE 801a — SAMPLE WELDING PROCEDURE QUALIFICATION RECORD
1. The type of steel used in this test shall be approved by the DCES.
2. Minimum preheat shall be in accordance with Table 708.
3. Welding and machining shall be witnessed by a State representative.
4. Test specimens and the Welding Procedure Qualification Record showing all welding parameters used for the test shall be submitted to the DCES for testing and review.
5. When required, macroetch specimens 3/8" thick and "T" wide shall be removed for testing. At least one cut face of each specimen shall be polished and etched for macroscopic examination by the DCES.

FIGURE 801b — COMPLETE PROCEDURE QUALIFICATION TEST PLATE FOR SAW & FCAW
### NOTES:

1. The type of steel used in this test shall be approved by the DCES.
2. Minimum preheat shall be in accordance with Table 708.
3. Welding and machining shall be witnessed by a State representative.
4. Test specimens and the Welding Procedure Qualification Record showing all welding parameters used for the test shall be submitted to the DCES for testing and review.
5. Macroetch specimens 3/8" thick and "T" wide shall be removed for testing. At least one cut face of each specimen shall be polished and etched for macroscopic examination by the DCES.

---

**FIGURE 801c — COMPLETE PROCEDURE QUALIFICATION TEST PLATE FOR ESW & EGW**

---

```plaintext
<table>
<thead>
<tr>
<th>Discard.</th>
<th>Macroetch Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Bend</td>
<td>See Figure 804b</td>
</tr>
<tr>
<td>Reduced Section</td>
<td>See Figure 804a</td>
</tr>
<tr>
<td>Tension</td>
<td></td>
</tr>
</tbody>
</table>

**Impact Block**

Submit full size for machining and testing at State's expense.

**Macroetch Specimen**

See Note 5

**All Weld Metal**

Tension

See Figure 804c

**Side Bend**

Reduced Section

Tension

**Side Bend**

Discard

Macroetch Specimen

12" min.  12" min.

Joint preparation shall be the same as used in the work.

T = thickness to be welded but need not exceed 2"
```
NOTES:
1. The type of steel used in this test shall be approved by the DCES.
2. Minimum preheat shall be in accordance with Table 708.
3. Welding and machining shall be witnessed by a State representative.
4. Test specimens and the Welding Procedure Qualification Record showing all parameters used for the test shall be submitted to the DCES for testing and review.

FIGURE 801d — MODIFIED PROCEDURE QUALIFICATION TEST PLATE FOR SAW AND FCAW
802. BASE METAL AND ITS PREPARATION

The base metal and its preparation for welding shall comply with the procedure specification. For all types of welded joints except electroslag and electrogas welds, the length of the weld and the dimensions of the base metal shall be in accordance with Figures 801b and 801d. Electroslag and electrogas welds shall be tested using the full procedure qualification test plate described in Figure 801c.

Qualification of a welding procedure specification established with a base metal listed in Section 5, Base Metals, having a minimum specified yield point of 50 ksi or less, shall qualify the procedure for welding any other base metal or combination of base metals listed in Section 5 which have a minimum specified yield point equal to or less than that of the base metal used in the test.

803. TEST POSITIONS

Submerged arc welding tests shall be performed in the flat position using the test plates shown in Figures 801b or 801d, as determined by the DCES.

Flux cored arc welding tests shall be performed in the position to be used in the work as defined in Figure 810. Tests for the flat, vertical, and overhead positions shall be welded using the test plates shown in Figures 801b or 801d, as determined by the DCES. The test for the horizontal position shall be welded using a plate similar to Figure 801b or 801d, except the joint configuration shall be B-U1Bb-F.

Electroslag and Electrogas welding tests shall be welded in the vertical position.

804. TEST SPECIMENS

The types of specimens outlined below are used to determine the mechanical properties, degree of soundness and chemical composition of welded joints made with specific weld procedure specifications.

a) Reduced Section Tension Specimens to determine tensile strength (See Figure 804a).
b) Side Bend Specimens to determine soundness (See Figure 804b).
c) All Weld Metal Tension Specimen to determine mechanical properties (See Figure 804c).
d) Charpy V-Notch Impact Specimens to determine toughness (See ASTM A370).
e) Chemical Analysis to determine weathering properties (See ASTM A751).
f) Radiographic Test to determine soundness. All test welds shall be subject to radiographic testing as described in Section 16. Machining of test specimens shall not begin until radiographic tests have verified that the test weld meets the weld quality requirements for bridges or buildings as applicable.
g) Fillet Weld Macroetch Test to determine weld fusion, weld bead size, and layer depth. A fillet weld tee test as shown in Figure 804d shall be made when ordered by the DCES. The maximum size single pass fillet weld and the minimum size multiple pass fillet weld used in construction shall be tested. These two fillet weld tests may be combined in a single test plate. The test plate shall be cut perpendicular to the direction of welding at three locations. Specimens representing one face of each of the three cuts shall be polished and etched to clearly define the weld metal and heat affected zones. A clear protective coating shall be applied to prevent corrosion. The specimens shall be submitted to the DCES for examination.
h) Groove Weld Macroetch Tests to determine weld fusion, weld bead size, layer depth and effective throat. When required by the DCES, the test weld(s) shall be cut perpendicular to the direct-
tion of welding and the cut surfaces shall be polished and etched to clearly define the weld metal and heat affected zones. A clear protective coating shall be applied to prevent corrosion. The specimens shall be submitted to the DCES for examination.

All specimens except the impact block shall be machined by the Contractor and submitted to the DCES for testing. The impact block shall be submitted full thickness with the weld reinforcement ground flush and shall measure 6 inches by 6 inches minimum. Five Charpy V-Notch specimens shall be machined and tested by the State.

When weathering steel is to be used, the chemistry of the weld metal shall be determined by chemical analysis of portions of Charpy V-Notch or all weld metal tension specimens after they have been mechanically tested.

All mechanical testing and chemical analysis of specimens furnished by the Contractor under the provisions of this section shall be tested by the State without charge.

FIGURE 804a — REDUCED SECTION TENSION SPECIMEN
Radius all corners 1/8" max.

If flame cut, not less than 118" shall be removed from edge by machining.

T = 3/8"

6" min.

These edges may be flame cut and may or may not be machined.

W = 1 1/2"

Face and Root Bend Specimen

Radius all corners 1/8" max.

If flame cut, not less than 1/8" shall be removed from edges by machining.

W = 3/8"

10" min.

T = 1" to 1 1/2"

Weld reinforcement machined flush with base metal

Side Bend Specimen

FIGURE 804b — BEND SPECIMENS
NOTES:
1. The reduced section may have a gradual taper from the ends toward the center with the ends not more than 0.005 inch larger in diameter than the center.
2. Specimen taken from the center of a weld.

FIGURE 804c – STANDARD ROUND ALL WELD METAL TENSION SPECIMEN
Notes:
1. Where the maximum plate thickness used in production is less than the value shown in the table, the maximum thickness of the production pieces may be substituted for $T_1$ and $T_2$.
2. At the contractor's option, the maximum single pass fillet welds may be welded on one side of the joint, and the minimum multiple pass fillet weld may be welded on the other side.

FIGURE 804d —FILLET WELD SOUNDNESS TEST FOR PROCEDURE QUALIFICATION
805. LIMITATION OF VARIABLES

The variables described below shall be considered essential changes in a welding procedure and shall re-
quire establishing a new procedure specification. The Complete Procedure Qualification Test shall be
performed unless a Modified Procedure Qualification Test is approved under the provisions of Article
801.

When a combination of welding processes is used, the variables applicable to each process shall apply.

805.1 Submerged Arc Welding.

a) A change in electrode or flux.
b) A change increasing filler metal strength or toughness classification.
c) A change in electrode diameter when using an alloy flux.
d) A change in the number of electrodes used.
e) A change in the type of current (ac or dc) or polarity.
f) A change of more than 10% above or below the specified amperage for each electrode
diameter used.
g) A change of more than 7% above or below the specified arc voltage for each diameter elec-
trode used.
h) A change of more than 15% above or below the specified travel speed.
i) A change of more than 10%, or 1/8 inch, whichever is greater, in the longitudinal spacing of
 the arcs.
j) A change of more than 10%, or 1/16 inch, whichever is greater, in the lateral spacing of the
 arcs.
k) A change of more than ± 10 degrees in the angular position of any parallel electrode.
l) A change in the angle of electrodes in machine or automatic welding of more than

1) ± 3 degrees in the direction of travel.
2) ± 5 degrees normal to the direction of travel.

m) For a specified groove, a change of more than ± 25% in the specified number of passes. If
the area of the groove is changed, it is permissible to change the number of passes in propor-
tion to the area.
n) A change in position in which welding is performed as defined in Article 809.5a.
o) A change in the type of joint.
p) An increase in the diameter of the electrode used over that called for in the procedure
 specification.

805.2 Flux Cored Arc Welding.

a) A change in electrode or method of shielding.
b) A change increasing filler metal strength level, when permitted, but not vice versa.
c) An increase in the diameter of electrode.
d) A change in the number of electrodes used.
e) A change from a single gas to any other single gas or to a mixture of gases or a change in
 specified percentage composition of gas mixture, when permitted.
f) A change of more than 10% above or below the specified amperage for each size electrode
 used.
g) A change of more than 7% above or below the specified arc voltage for each size electrode
 used.
h) A change of more than 10% above or below the specified travel speed.
i) An increase of 25% or more or a decrease of 10% or more in the rate of flow of shielding gas
 or mixture.
j) For a specified groove, a change of more than ± 25% in the specified number of passes. If the area of the groove is changed, it is permissible to change the number of passes in proportion to the area.

k) A change in the position in which welding is performed as defined in Article 809.5a.

l) A change in the type of joint.

m) For vertical welding of tubular structures, a change in the progression specified for any pass from upward to downward or vice versa.

n) A change in type of welding current (ac or dc), polarity, or mode of metal transfer across the arc.

805.3 Electroslag and Electrogas Welding.

805.3.1 Changes Requiring Requalification by Complete Procedure Test.

a) A change in electrode, flux, or consumable guide metal composition.

b) A change in consumable guide metal core cross-sectional area exceeding 30%.

c) A change in flux system (cored, magnetic electrode, external flux, etc.).

d) A change in flux composition including consumable guide coating.

e) A change in shielding gas composition of any one constituent of more than 5% of the total flow.

f) A change in welding current exceeding 20% or a change in wire feed speed (rate) exceeding 40%.

g) A change in groove design, other than square groove, increasing groove cross-sectional area.

h) A change in joint thickness (T) outside the limits of 0.5T to 1.1T, where T is the thickness used for the procedure qualification.

i) A change in number of electrodes.

j) A change from single pass to multiple pass or vice versa.

k) A change to a combination with any other welding process or method.

l) A change in postweld heat treatment.

m) A change in design of molding shoes, either fixed or movable, as follows:

1) Nonfusing solid to water-cooled or vice versa.

2) Metallic to nonmetallic or vice versa.

3) Nonfusing to fusing or vice versa.

4) A reduction in any cross-sectional dimension or area of solid nonfusing shoe exceeding 25%.

805.3.2 Changes Requiring Requalification by Other Tests. The following changes in a qualified electroslag or electrogas procedure shall require requalification of the procedure by radiographic and ultrasonic testing in accordance with the requirements of Sections 16 and 17. The DCES may order additional tests to determine the effect, if any, on mechanical properties and chemical composition of the weld metal.

a) A change exceeding 1/32 inch filler metal diameter.

b) A change exceeding 10 inches per minute in filler metal oscillation traverse speed.

c) A change in filler metal oscillation traverse dwell time exceeding 2 seconds, except as necessary to compensate for variation in joint opening.

d) A change in filler metal oscillation traverse length which affects the proximity of filler metal to the molding shoes by more than 1/8 inch.

e) A change in flux burden exceeding 30%.

f) A change in shielding gas flow rate exceeding 25%.

g) A change in welding position from vertical by more than 10 degrees.

h) A change from ac to dc or vice versa, or a change in polarity for direct current.

i) A change in welding power volt-ampere characteristics from constant voltage to constant current or vice versa.
j) A change in voltage exceeding 10%.
k) A change exceeding 1/4 inch in square groove root opening.
l) A change in groove design other than square groove, reducing groove cross-sectional area.
m) A change in speed of vertical travel, if not an automatic function of arc length or deposition rate, exceeding 20% except as necessary to compensate for variation in joint opening.

806. METHOD OF TESTING SPECIMENS

Specimens shall be tested in accordance with the following specifications:

a) Reduced Section Tension Specimen .................................................. ASTM A370
b) Side Bend Specimens ................................................................. ASTM E190, E290

c) All Weld Metal Tension Specimen ............................................... ASTM A370
d) Charpy V-Notch Impact Specimen ............................................ ASTM A370
e) Chemical Analysis ................................................................. ASTM A751
f) Radiographic Test ..................................................................... SCM Section 16

g) Ultrasonic Test .......................................................................... SCM Section 17
h) Macroetch Specimen ............................................................... ASTM E340

807. TEST RESULTS

807.1 Reduced Section Tension Tests. The tensile strength shall not be less than the minimum specified tensile strength of the base metal.

807.2 Side Bend Tests. Side bend specimens shall be placed with the side showing the greater discontinuity, if any, directed toward the gap. The convex surface of the specimen shall be examined for the appearance of cracks or other open discontinuities. The specimen shall not have a crack or other open discontinuity exceeding 1/8 inch, measured in any direction. Cracks at the corners of the specimen shall not be considered except when they are longer than 1/4 inch, in which case the DCES may order additional bend tests and may determine that excessive cracking is cause for rejection of the specimen.

807.3 All Weld Metal Tension Test. Mechanical properties shall meet the requirements of Table 706.1 for the electrode or electrode flux classification specified.

807.4 Charpy V-Notch Impact Test. Five specimens shall be tested to determine the minimum Charpy V-Notch Impact Value. The extreme lowest and highest value obtained with the five specimens shall be discarded and the average value for the remaining three specimens shall be as specified in Table 706.1. If the energy value for more than one of the remaining three specimens is below the minimum average requirement, or if the energy value for one of the three specimens is less than two-thirds (2/3) of the specified minimum average requirement, a retest shall be made, and the energy value of all three retest specimens, after discarding the highest and lowest values, shall equal or exceed the specified minimum average requirement.

807.5 Chemical Analysis. Chemical analysis of filler metal used in weathering applications shall verify that the deposited weld meets the chemical requirements of any one of the electrode or electrode flux classifications shown in Table 706.2.

807.6 Radiographic Test. The radiograph shall be evaluated in accordance with Article 1605.

807.7 Macroetch Specimen. The macroetch specimen shall meet the dimensional and quality requirements of Section 7, Welding.
808. RETESTS

808.1 General. If any specimen other than an impact specimen fails to meet the test requirements, two retests for that particular specimen may be performed provided the specimens are cut from the same procedure qualification plate. The results of both retests must meet the test requirements.

808.2 Impact Specimens. If the energy value for more than one of the three specimens is below the minimum average requirement or if the energy value for one of the three specimens is less than two-thirds of the specified minimum average requirement, a retest shall be made and the energy value obtained from each of the three retest specimens shall equal or exceed the specified minimum average value.

808.3 Test Plates. If sufficient material is not available from the original qualification test weldment, a new test plate may be welded provided the parameters used in the retest are the same as those used to weld the original test plate. Any deviation from the original parameters other than those allowed under Article 805, Limitation of Variables, shall be cause to consider the new test plate as a separate qualification test.
809. GENERAL

Each welder, welding operator, and tacker who performs work on Contracts for the State must be qualified for each process and position used by tests described in this Section. The following job descriptions shall be used to determine the type of tests required:

a) Welder - A person who performs a manual or semiautomatic welding operation.

b) Welding Operator - A person who operates automatic welding equipment.

c) Tacker - A fitter, or someone under the direction of a fitter, who tack welds parts of a weldment to hold them in proper alignment until the final welds are made. Tackers shall be limited to performing work in the fabrication shop.

All qualification tests shall be witnessed by a State representative. At the completion of welding, the State representative shall die stamp the test plate number and identify the witnessing agency, i.e., D.O.T. Region No., or testing agency under contract to the State.

The base metal used for the test plates shall be structural steel of any weldable type that is internally sound and in good condition.

Qualification established by these procedures shall be considered as qualification to weld or tack weld any steel listed in Section 5, Base Metal.

A welder or welding operator who performs a successful procedure qualification test as described in Section 8A shall be considered qualified for that process and position.

A welder, welding operator, or tacker qualified with an approved electrode and shielding medium combination shall be considered qualified to weld or tack weld with any other approved electrode and shielding medium combination for the process used in the qualification test.

810. TEST POSITIONS

All welds shall be classified as being flat, horizontal, vertical, or overhead as described in Figure 810a. Based on this classification, the test plates shall be positioned as described herein.

810.1 Groove Welds. Groove weld qualification test plates shall be oriented in one of the positions described below and in Figure 810b.

a) Flat Position (1G). The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side.

b) Horizontal Position (2G). The test plates shall be placed in an approximately vertical plane with the welding groove approximately horizontal.

c) Vertical Position (3G). The test plates shall be placed in an approximately vertical plane with the welding groove approximately vertical.

d) Overhead Position (4G). The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the under side.

810.2 Fillet Welds. Fillet weld qualification test plates shall be oriented in one of the positions described below and in Figure 810c.

a) Flat Position (1F). The test plates shall be placed so that each fillet weld is deposited with its longitudinal axis approximately horizontal and its throat approximately vertical.
b) **Horizontal Position (2F).** The test plates shall be placed so that each fillet weld is deposited on the upper side of the horizontal surface and against the vertical surface.

c) **Vertical Position (3F).** The test plates shall be placed in an approximately vertical plane with the welding preparation approximately vertical.

d) **Overhead position (4F).** The test plates shall be placed in an approximately horizontal plane so that each fillet weld is deposited on the under side of the horizontal surface and against the vertical surface.

### Table of positions of groove welds

<table>
<thead>
<tr>
<th>Position</th>
<th>Diagram reference</th>
<th>Inclination of axis</th>
<th>Rotation of face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>A</td>
<td>0° to 15°</td>
<td>150° to 210°</td>
</tr>
<tr>
<td>Horizontal</td>
<td>B</td>
<td>0° to 15°</td>
<td>80° to 150°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210° to 280°</td>
</tr>
<tr>
<td>Overhead</td>
<td>C</td>
<td>0° to 80°</td>
<td>0° to 80°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>280° to 360°</td>
</tr>
<tr>
<td>Vertical</td>
<td>D, E</td>
<td>15° to 80°</td>
<td>80° to 280°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80° to 90°</td>
<td>0° to 360°</td>
</tr>
</tbody>
</table>

### Figure 810a – Positions of Groove Welds

Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).
Tabulation of positions of fillet welds

<table>
<thead>
<tr>
<th>Position</th>
<th>Diagram reference</th>
<th>Inclination of axis</th>
<th>Rotation of face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>A</td>
<td>0° to 15°</td>
<td>150° to 210°</td>
</tr>
<tr>
<td>Horizontal</td>
<td>B</td>
<td>0° to 15°</td>
<td>125° to 150°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>210° to 235°</td>
</tr>
<tr>
<td>Overhead</td>
<td>C</td>
<td>0° to 25°</td>
<td>0° to 125°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>225° to 360°</td>
</tr>
<tr>
<td>Vertical</td>
<td>D</td>
<td>15° to 80°</td>
<td>125° to 235°</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>80° to 90°</td>
<td>0° to 360°</td>
</tr>
</tbody>
</table>

Notes:
1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

FIGURE 810a (continued) – POSITIONS OF FILLET WELDS
NOTE: Test plates must remain in position until welding is complete.
811. WELDER QUALIFICATION

811.1 Welder Classification. Welders shall be classified as shop or field welders based on the following description:

a) Shop Welder—A person who is employed by the contractor/fabricator to perform welding at the fabrication plant. The shop welder must be qualified by tests conducted at the plant and witnessed by the Inspector.

b) Field Welder—A person who is employed by the contractor/erector to perform welding in the field. The field welder must be qualified by tests conducted at approved locations and witnessed by representatives of the State.

811.2 Tests Required. Welder qualification tests for manual and semiautomatic welding shall be performed using the applicable test plate as follows:

a) Groove weld test plate as described in Figure 811.2a.

b) Optional horizontal groove weld test plate as described in Figure 811.2b.

c) Fillet weld test plate as described in Figure 811.2c.
NOTES:
1. All plate surfaces within the area of the backing strip must be free of mill scale and surface depressions. This includes the top and bottom of the test plates and the backing strip.
2. After welding, the weld reinforcement shall be ground flush with the surface of the plate. Do not remove the backing strip.
3. See Table 811.3 for type and position limitations.
4. T = 3/8 inch qualifies for limited thickness welding up to 3/4 inch. T = 1 inch qualifies for unlimited thickness welding.

FIGURE 811.2a — WELDER QUALIFICATION TEST PLATE — GROOVE WELDS
NOTES:

1. All plate surfaces within the area of the backing strip must be free of mill scale and surface depressions. This includes the top and bottom of the test plates and the backing strip.
2. After welding, the weld reinforcement shall be ground flush with the surface of the plate. Do not remove the backing strip.
3. $T = 3/8$ inch qualifies for limited thickness welding up to $3/4$ inch.
4. $T = 1$ inch qualifies for unlimited thickness welding.

FIGURE 811.2b—OPTIONAL WELDER QUALIFICATION TEST PLATE—HORIZONTAL POSITION
NOTES:

1. All plate surfaces within the area of the backing strip must be free of mill scale and surface depressions. This includes the top and bottom of the test plates and the backing strip.
2. After welding, the weld reinforcement shall be ground flush with the surface of the plate. Do not remove the backing strip.
3. See Table 811.3 for type and position limitations.

FIGURE 811.2e — WELDER QUALIFICATION TEST PLATE — FILLET WELDS
811.3 Position Qualified. The type and position of welds qualified by each test plate position shall be as described in Table 811.3.

<table>
<thead>
<tr>
<th>Qualification Test</th>
<th>Type of Weld and Position of Welding Qualified*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Plate</strong></td>
<td><strong>Plate Position</strong></td>
</tr>
<tr>
<td>Figure 811.2a and b</td>
<td>1G Flat</td>
</tr>
<tr>
<td></td>
<td>2G Horizontal</td>
</tr>
<tr>
<td></td>
<td>3G Vertical</td>
</tr>
<tr>
<td></td>
<td>4G Overhead</td>
</tr>
<tr>
<td>Figure 811.2c</td>
<td>1F Flat</td>
</tr>
<tr>
<td></td>
<td>2F Horizontal</td>
</tr>
<tr>
<td></td>
<td>3F Vertical</td>
</tr>
<tr>
<td></td>
<td>4F Overhead</td>
</tr>
<tr>
<td></td>
<td>3F &amp; 4F</td>
</tr>
</tbody>
</table>

*Positions of Welding: F=Flat, H=Horizontal, V=Vertical, OH=Overhead

811.4 Welding Procedure. All manual shielded metal arc welder qualification tests shall be performed using 5/32 inch diameter electrodes conforming to the requirements of the latest edition of AWS A5.1, "Specification for Carbon Steel Covered Arc Welding Electrodes" or AWS A5.5, "Specification for Low-Alloy Steel Covered Arc Welding Electrodes", classification E7018. The welding parameters shall be in accordance with the manufacturer's recommendations.

Qualification of welders for semiautomatic processes shall be performed using the parameters specified in the approved welding procedure.

All welding shall be performed in accordance with the provisions of this manual.

811.5 Preparation of Test Specimens. The weld reinforcement shall be ground flush with the surface of the test plate. Machining may be used to remove excess weld metal, but the final surface must be produced by grinding. No surface depressions (lines, gouges, nicks, etc.) may remain. The surface roughness shall not exceed 125 microinches.

The thickness of test plates and welds shall not be reduced by more than 1/16 inch during the grinding process. Excessively ground test plates shall be rejected as unfit for testing.

No grinding, air carbon arc gouging, pneumatic chipping or machining of any type will be permitted between weld passes for any purpose. Weld cleaning may only be performed by means of a hand held, non-mechanical chipping hammer and/or wire brush during the weld test.

811.6 Method of Testing Specimens. Field welder test specimens shall be submitted to the Department of Transportation, Bureau of Materials for radiographic testing in accordance with the provisions of Section 16.

The contractor may radiograph shop welder test specimens in accordance with the provisions of Section 16, or may submit the test specimens to the Bureau of Materials for testing as described above.
811.7 Test Results. The entire weld shall be radiographed. Any three consecutive inches of the length of the test weld shall be evaluated in accordance with Article 1605 by a State representative. The area examined shall be in the center portion of the weld length, selected to avoid discontinuities associated with the start and stop of weld passes at the ends of the weld.

The welded test plates shall conform to Article 724, Quality of Welds.

811.8 Retests. If a welder fails to meet the test requirements, a retest may be made consisting of two test plates for each type which was failed. In lieu of the above, a single retest may be performed if the welder documents evidence of additional training.

All retest specimens must meet the requirements of the original test.

811.9 Period of Effectiveness.

a) Shop Welders. Shop welders shall be certified for a period of three years unless the individual is not engaged in welding by the process for which he has qualified for a period exceeding six months, or unless inspection of the work indicates a specific reason to question the welder's ability. Requalification of a welder whose certification has expired may be performed using 3/8 inch or one inch thick test plates. If certification was withdrawn because of unsatisfactory workmanship, requalification must be performed using the original test.

b) Field Welders. Field welders shall be certified for three years provided their work record is maintained as described on the certificate. The work record must be signed at least once every six months by an Engineer-in-Charge or by a licensed professional engineer to verify that the welder has performed acceptable work. The certificate may be revoked at any time by the DCES if inspection of the work indicates specific reason to question the welder's ability. At the end of the three year period, a new certificate will be issued by the DCES providing the welder has maintained the work record properly. If the welder is not engaged in welding for which he has qualified for a period exceeding six months, or if the work record is not maintained, requalification testing may be performed using 3/8 inch or one inch thick test plates. If certification was withdrawn because of unsatisfactory workmanship, requalification must be performed using the original test.

811.10 Records.

a) Shop Welders. Records of test results for shop welders shall be kept by the fabricator or contractor and shall be available to representatives of the State upon request.

b) Field Welders. Records of test results for field welders shall be kept by the DCES.

812. WELDING OPERATOR QUALIFICATION

812.1 Tests Required. The welding operator qualification tests for automatic welding processes shall be performed as follows:

a) The qualification test plates for automatic submerged arc welding or automatic flux cored arc welding shall be as shown in Figure 812.1a. This test shall qualify the welding operator for making groove welds in the flat position and fillet welds in the flat and horizontal position on material of unlimited thickness with the process tested.

b) The welding operator qualification test plates for the electroslag or electrogas process shall be as shown in Figure 812.1b. This test shall qualify the operator for making groove welds with the process tested on material of unlimited thickness.
NOTES:

1. All plate surfaces within the area of the backing strip must be free of mill scale and surface depressions. This includes the top and bottom of the test plates and the backing strip.
2. After welding, the weld reinforcement shall be ground flush with the surface of the plate. Do not remove the backing strip.
3. For flat position and material of unlimited thickness.

FIGURE 812.1a – WELDING OPERATOR QUALIFICATION TEST PLATE FOR AUTOMATIC SUBMERGED ARC AND AUTOMATIC FLUX CORED ARC WELDING
FIGURE 812.1b – WELDING OPERATOR QUALIFICATION TEST PLATE FOR ELECTROSLAG AND ELECTROGAS WELDING
812.2 **Welding Procedure.** Qualification of welding operators for automatic processes shall be performed using the parameters specified in the approved welding procedure.

All welding shall be performed in accordance with the provisions of this manual.

812.3 **Preparation of Test Specimens.** The weld reinforcement shall be ground flush with the surface of the test plate. Machining may be used to remove excess weld metal, but the final surface must be produced by grinding. No surface depressions (lines, gouges, nicks, etc.) may remain. The surface roughness shall not exceed 125 microinches.

The thickness of test plates and welds shall not be reduced by more than 1/16 inch during the grinding process. Excessively ground test plates shall be rejected as unfit for testing.

No grinding, air carbon arc gouging, pneumatic chipping or machining of any type will be permitted between weld passes for any purpose. Weld cleaning may only be performed by means of a hand held, non-mechanical chipping hammer and/or wire brush during the weld test.

812.4 **Method of Testing Specimens.** The test plate shall be radiographed by the Contractor or the State in accordance with the provisions of Section 16.

812.5 **Test Results.** The entire weld shall be radiographed. Any 12 consecutive inches of the length of the test plate shall be evaluated in accordance with Article 1605 by a State representative. The area examined shall be in the center portion of the weld length, selected to avoid discontinuities associated with the start and stop of weld passes at the ends of the weld.

The welded test plate shall conform to Article 724, Quality of Welds.

812.6 **Retests.** If a welding operator fails to meet the test requirements, a retest may be made consisting of two test plates for each type which failed. In lieu of the above, a single retest may be performed if the welder documents evidence of additional training.

All retest specimens must meet the requirements of the original test.

812.7 **Period of Effectiveness.** Welding operators shall be certified for three years unless the individual is not engaged in welding for which he has qualified for a period exceeding six months, or unless inspection of the work indicates a specific reason to question the welding operator’s ability. Requalification of a welding operator shall be performed using the test plate described for the original test.

812.8 **Records.** Records of test results shall be kept by the manufacturer or contractor and shall be available to representatives of the State upon request.

813. **TACKER QUALIFICATION**

813.1 **Tests Required.** The tacker qualification tests for manual and semiautomatic welding shall be performed as described in Figure 813.1. The tacker shall make a 1/4 inch maximum size tack weld approximately 2 inches long.
813.2 Positions Qualified. The positions qualified by each test plate position shown in Figure 813.2 shall be as described in Table 813.2.
TABLE 813.2 - TACKER QUALIFICATION - POSITION LIMITATIONS

<table>
<thead>
<tr>
<th>Test Position</th>
<th>Position Qualified*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1T Flat</td>
<td>F</td>
</tr>
<tr>
<td>2T Horizontal</td>
<td>F, H</td>
</tr>
<tr>
<td>3T Vertical</td>
<td>F, H, V</td>
</tr>
<tr>
<td>4T Overhead</td>
<td>F, H, OH</td>
</tr>
<tr>
<td>3T &amp; 4T</td>
<td>F, H, V, OH</td>
</tr>
</tbody>
</table>

*Positions of Welding: F = Flat, H = Horizontal, V = Vertical, OH = Overhead

813.3 Welding Procedure. All manual shielded metal arc tacker qualification tests shall be performed using 5/32 inch diameter electrodes conforming to the requirements of the latest edition of AWS A5.1, “Specification for Carbon Steel Covered Arc Welding Electrodes” or AWS A5.5, “Specification for Low-Alloy Steel Covered Arc Welding Electrodes”, classification E7018. The welding parameters shall be in accordance with the manufacturer’s recommendations.

Qualification of tackers using semiautomatic processes shall be performed using the parameters specified in the approved welding procedure.

All tacking shall be performed in accordance with the provisions of this manual.

813.4 Method of Testing Specimens. A force shall be applied to the specimen as shown in Figure 813.4 until rupture occurs. The force may be applied by any convenient method. The surface of the weld and the fracture shall be examined visually for defects.

813.5 Test Results Required. A visual inspection of the specimen before the tack weld has been ruptured shall show that the tack weld has a reasonably uniform appearance, free of overlap, cracks, and excessive undercut. There shall be no porosity visible on the surface of the tack weld.
The fractured surface of the tack weld shall show fusion at the root, but not necessarily beyond, and shall exhibit no incomplete fusion to the base metal or any inclusion or porosity larger than 3/32 inch in greatest dimension.

813.6 Retests. If the tacker fails to meet the test requirements, one retest may be made without additional training. If the tacker fails the retest, he will be required to show evidence of additional training or practice prior to performing an additional retest.
SECTION 9
FRACTURE CONTROL PLAN

901. GENERAL

Fracture critical members or member components (FCMs) are tension members, or tension components of members, whose failure would be expected to result in collapse of the structure.

Tension components of bridge members consist of components of tension members and those portions of flexural members that are subject to tensile stress. Any attachment that is welded to a tension component of a fracture critical member in the direction parallel to the tension stress shall be considered part of the tension component and therefore fracture critical.

Examples of FCM's are the tie girders of a tied-arch bridge, steel pier cap beams, the girders of a two-girder bridge, the tension web and chord members of trusses, suspended span hangers and other nonredundant parts supporting the superstructure.

Fracture critical members shall be identified on the plans by appropriate notations to call the Contractor's attention to special testing and fabrication requirements.

All provisions of the SCM shall apply to fracture critical members except as modified by this section and special notes that may be placed in the Contract Documents to reflect special requirements of individual structures.

902. SHOP DRAWING REVIEW

Shop drawings shall be reviewed as described in Section 2. The shop drawings shall list material requirements and show necessary details to ensure conformance with this Section and other provisions of the Contract Documents, if any.

The shop drawing for each FCM which is repaired in accordance with Category III as described in Article 909.2 shall be revised to include a note referring to the approved repair procedure.

903. FABRICATOR QUALIFICATION

The structural steel fabricator and erector shall be subject to approval by the DCES. Approval shall be based on an inspection/investigation by representatives of the Department to determine if the fabricator and erector have adequate personnel, organization, experience, procedures, knowledge, equipment and plant capable of producing quality workmanship. The AISC Quality Certification Program, Category III, Major Steel Bridges, shall be used as a guide in this determination.

904. BASE METAL REQUIREMENTS

904.1 General. All requirements of the Standard Specifications, Materials Section entitled Structural Steel, shall apply with modifications listed herein or in the Contract Documents.

Fracture critical plates and shapes shall be produced to fully killed fine grain practice.

All FCM plates shall be rolled on a "sheared-mill" and furnished with oxygen cut edges conforming with the requirements of Section 6, Preparation of Base Metals.

904.2 Toughness Requirements. Fracture critical plates and shapes shall be sampled and tested to determine the Charpy V-Notch Impact Toughness in accordance with the requirements of
ASTM A673. Sampling and testing shall be performed at the P Frequency, modified to include impact tests at each end of each plate. The CVN specimens shall be coded with the heat and plate number, and that code shall be recorded on the certified mill test report with the test results. If requested, the tested specimens shall be forwarded to the DCES for review. The impact test shall consist of three specimens taken from each test location. The average impact energy shall meet the minimum requirements of Table 904. If the energy value from more than one of three test specimens is below the specified minimum average, or, if the energy value for one specimen is less than or two-thirds (2/3) of the specified minimum, a retest of three additional specimens shall be made and the energy value from each specimen shall equal or exceed the specified minimum average. Longitudinal CVN tests shall be performed and reported for each shape or plate as-rolled or as-heat treated.

Heat treatment may be required to produce the toughness listed in Table 904 or specified in the Contract Documents. When not specified in the Contract Documents, the heat treatment, if any, necessary to produce the required CVN toughness, shall be the option of the Contractor.

Under special conditions, the DCES may specify CVN toughness values that, when tested at the lowest anticipated service temperature, are significantly greater than those listed in Table 904.

904.3 Blast Cleaning & Visual Inspection. All surfaces of fracture critical plates and shapes shall be subject to complete blast cleaning and visual inspection by the QC Inspector prior to assembly and welding. Blast cleaning shall be performed in the shop prior to assembly to aid the inspection of surfaces for injurious defects and to facilitate welding. Blast cleaning shall conform to the requirements of the Steel Structures Painting Council Surface Preparation No. 6 (SSPC-SP-6) - Commercial Blast Cleaning, as described in the Standard Specifications, Materials Section entitled Painting Metal Structures.

904.4 Repairs to Base Metal. There shall be no conditioning of fracture critical plates or shapes by welding at the mill. Repairs may be made by welding at the shop in the presence of the Shop Inspector. All repair welding shall be performed in accordance with Article 909.

All repair welds shall be subject to nondestructive tests and shall meet the requirements for quality of welds as described in this manual.

**TABLE 904 — FCM TOUGHNESS REQUIREMENT FOR BASE METAL**

<table>
<thead>
<tr>
<th>ASTM Designation</th>
<th>Thickness</th>
<th>Average Minimum Toughness and Test Temperature&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A36</td>
<td>up to 1 1/2 inches over 1 1/2 to 4 inches</td>
<td>25 ft/lbs at 40°F 25 ft/lbs at 20°F</td>
</tr>
<tr>
<td>A572 Grade 50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>up to 1 1/2 inches over 1 1/2 to 2 inches over 2 to 4 inches (mechanically fastened)</td>
<td>25 ft/lbs at 40°F 25 ft/lbs at 20°F 25 ft/lbs at 20°F</td>
</tr>
<tr>
<td>A588&lt;sup&gt;b&lt;/sup&gt;</td>
<td>up to 1 1/2 inches over 1 1/2 to 2 inches over 2 to 4 inches (mechanically fastened) over 2 to 4 inches (welded)</td>
<td>25 ft/lbs at 40°F 25 ft/lbs at 20°F 25 ft/lbs at 20°F 30 ft/lbs at 20°F</td>
</tr>
</tbody>
</table>

<sup>a</sup> Minimum service temperature from –1°F to –30°F

<sup>b</sup> If the yield strength of the steel exceeds 65 ksi, the temperature for the CVN test for acceptability shall be reduced by 15°F for each increment of 10 ksi above 65 ksi. The yield strength is the value given in the certified mill test report.
905. WELDING PROCESSES

The Manual Shielded Metal Arc Welding and the Submerged Arc Welding processes may be used for the fabrication of fracture critical members. The Flux Cored Arc Welding process may only be used with the prior written approval of the DCES. The Gas Metal Arc Welding, Electroslag and Electrogas welding processes shall not be used for the fabrication of fracture critical members. Welding processes approved for use in the construction of FCM's shall be qualified by tests described in this section.

906. WELDING

906.1 General. The welding requirements of this manual shall apply as modified herein. Field welding shall not be permitted unless approved by the DCES.

906.2 Preheat and Interpass Temperature. Preheat and interpass temperatures shall conform to the requirements of Article 708 except as modified in Table 906.2.

<table>
<thead>
<tr>
<th>Thickness of Thickest Part at Point of Welding (inches)</th>
<th>ASTM A36, A572</th>
<th>ASTM A588</th>
</tr>
</thead>
<tbody>
<tr>
<td>to 3/4, inclusive</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>over 3/4 to 1 1/2</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>over 1 1/2 to 2 1/2</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>over 2 1/2</td>
<td>300</td>
<td>350</td>
</tr>
</tbody>
</table>

906.3 Electrode and Flux Requirements. All manual shielded metal arc welding electrodes shall be of a low hydrogen classification. The maximum moisture content of the electrode covering shall not exceed 0.4% by weight when tested in accordance with the procedure described in AWS A5.5.

The diffusible hydrogen content of weld metal deposited by the SMAW, SAW and FCAW processes shall be measured by tests performed by the electrode, or electrode/flux manufacturer. Tests shall be conducted to determine the diffusible hydrogen content of weld metal produced using the consumables to be used in the work. The manufacturer shall provide the Fabricator with a written description of the storage and operating requirements that must be followed to keep the diffusible hydrogen content of the deposited weld metal below an average of 5 milliliters per hundred grams when measured as an average of three tests, and below a maximum single value of 6.3 milliliters per hundred grams. If the manufacturer's storage and operating requirements are less stringent than the requirements of this Manual, the more stringent requirements shall apply. Diffusible hydrogen shall be measured using the glycerin method as recommended by the International Institute of Welding. Saturated glycerin or saturated silicone oil tests may be performed by the same procedure or at elevated temperature. Saturated glycerin and/or saturated silicone oil tests are preferred to the standard glycerin tests since they more nearly equal the results obtained when testing by the mercury method.

906.4 Storage of Electrodes and Fluxes. SMAW electrodes shall be dried and stored in accordance with the provisions of Section 7B. FCAW electrodes shall be stored by procedures recommended by the manufacturers to insure their freedom from moisttrue pick-up and other contamination. Since FCAW electrodes may be more susceptible to contamination while on the welding machine, appropriate measures shall be taken to assure that they are not left unprotected when not in use and do not remain on the welding machine a sufficient time under adverse conditions, to promote unacceptable levels of hydrogen in the weld metal or cause other welding difficulties.
906.4

All submerged arc fluxes shall be baked at 550°F for two hours minimum and shall be stored at 250°F minimum after drying. The recycling of fluxes shall be controlled to avoid pickup of materials that may cause an increase in the hydrogen content of the deposited weld metal or otherwise interfere with the production of sound welds. The Contractor shall submit a description of his flux recycling program to the DCES for approval. Fluxes left unused in the welding machine hopper(s) more than eight hours shall be replaced with flux that has been baked as described above.

907. WELDING PROCEDURE QUALIFICATION

907.1 General. The welding procedure shall be qualified not more than six months prior to use by tests described in Figure 907. The base metal shall be of the same ASTM specification as that to be used in the FCM. Qualification of a welding procedure shall be accomplished using welding consumables supplied under the same AWS specification and shall be produced by the same manufacturer as those to be used in the FCMs. Each lot or heat of welding consumables shall be pretested in accordance with the applicable AWS specification and certified test results furnished. Lot and heat are as defined in Section III, NB2420 of the ASME Boiler and Pressure Vessel Code.

The DCES, at his discretion, may accept evidence of previous qualification of a welding procedure provided the qualification tests were performed in accordance with the requirements of this section.

Weld joint details that conform in all respects to the provisions of Section 7A are considered prequalified.

907.2 Weld Metal Toughness. The toughness requirements specified herein are mandatory minimum values for qualifying the welding procedures used in all welding of fracture critical members. The minimum average Charpy V-Notch impact strength of weld metal joining ASTM A36, A441, A572 Grade 50, and A588 steels shall be 25 foot-pounds when tested at minus 20°F.

907.3 Groove Welding Procedures. Qualification of groove welding procedures shall be based on the results of mechanical tests. A chemical analysis shall be performed when required for weathering steels. One test shall be made with "T" equal to one inch and one test shall be made with "T" equal to the maximum thickness to be welded in construction, provided the maximum is equal to or greater than one and one-half inches, except that the maximum test plate thickness need not exceed two inches. Test specimens shall be removed and prepared for testing as described in Figure 907. All mechanical testing shall conform to the requirements of Article 806.

907.4 Fillet Welding Procedures. Qualification of fillet welding procedures shall be as described in Figure 907, except the reduced section tensile test will not be required. The thickness of the weld procedure test plates may be 3/4 inch or 1 inch.

All weld passes used to make the fillet weld procedure qualification test shall be made using weld procedure variables that will produce the highest anticipated heat input to be used in the work, i.e., maximum amperage, maximum voltage and minimum travel speed.

The requirements of Article 805, Limitation of Variables, shall apply, except that any change in the welding procedure which increases the welding heat input shall require a new procedure test.

The Contractor may propose modifications to the test plate shown in Figure 907 that he feels may more nearly approximate the welding conditions to be encountered in the fabrication. The Contractor may propose to forced air cool fillet weld procedure qualification test plates if it is anticipated that the heat build-up between test weld passes will be significantly greater than the conditions to be encountered in fabrication. Any proposal to revise the Weld Procedure Qualification tests described in Figure 907 shall be submitted to the DCES for approval prior to beginning work.
### FIGURE 907 - PROCEDURE QUALIFICATION TEST PLATE (FCM)

<table>
<thead>
<tr>
<th>Direction of Rolling</th>
<th>Macroetch Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discard</td>
<td></td>
</tr>
<tr>
<td>Side Bend (A or B)</td>
<td>See Section C-C</td>
</tr>
<tr>
<td>Reduced Section Tension</td>
<td>See Note 8</td>
</tr>
<tr>
<td>Side Bend (A or B)</td>
<td></td>
</tr>
<tr>
<td>Impact Block</td>
<td>See Note 10</td>
</tr>
<tr>
<td>All Weld Metal Tension</td>
<td>See Section A-A &amp; Note 9</td>
</tr>
<tr>
<td>Macroetch Specimen</td>
<td></td>
</tr>
<tr>
<td>Discard</td>
<td></td>
</tr>
<tr>
<td>Side Bend (A or B)</td>
<td>12&quot; min. See Note 6</td>
</tr>
<tr>
<td>Reduced Section Tension</td>
<td>12&quot; min. See Note 6</td>
</tr>
<tr>
<td>Macroetch Specimen</td>
<td>23&quot; min.</td>
</tr>
</tbody>
</table>

**Note:**
- 13" min. See Note 6
- 5/8" 20°
Charpy V-Notch impact specimens
5 required at each location

SECTION A-A

SECTION B-B
Weld reinforcement machined flush with base metal.

SECTION C-C

NOTE: 1. For machined dimensions of test specimens, see Section 8A
2. Weld backing to be removed during specimen preparation

FIGURE 907 (continued)
NOTES:
1. See Articles 907.3 and 907.4 for required thickness “T” of test plates.
2. All test plate material shall have proper heat identity. The certified mill test reports shall demonstrate that test material meets the chemical and physical requirements of the material specified for the fabrication of FCM’s.
3. The minimum preheat and interpass temperatures shall be in accordance with Table 905.2.
4. Welding and machining shall be witnessed by the Inspector.
5. Machined test specimens and the Welding Procedure Qualification Record listing all welding parameters used to make the test weld shall be submitted to the DCES as provided in Section 8A.
6. This dimension may be increased as required for testing the reduced section tension specimens, depending on the plate thickness and the requirements of the testing equipment.
7. This dimension must be increased to provide for 2 AWMT specimens when the test plate thickness is 1-1/2 inches or less.
8. The reduced section tension specimen shall be in accordance with Section 8A except that the thickness shall be equal to the test plate thickness.
9. Toughness testing shall be performed as described in Article 806. Only full size (10 mm × 10 mm) specimens shall be used.
10. Specimens shall be removed for macroetch testing. Specimens shall be 3/8 inch in width. At least one cut face of each specimen shall be polished and etched for macroscopic examination by the DCES.

FIGURE 907 (continued)
908. QUALIFICATION OF WELDERS, WELDING OPERATORS, AND TACKERS

All welders, welding operators and tackers to be employed in the fabrication of fracture critical members shall be qualified by tests performed within six months prior to the start of fabrication, or shall be regularly requalified by testing on an annual basis provided there are no gaps in the welder's work experience that exceed six months as provided on Section 8B.

909. REPAIR WELDING

909.1 General. Repair welding is defined as any welding, including removal of weld or base metal in preparation for welding, necessary to correct defects in materials or workmanship.

Repair welding may be performed using any of the welding procedures qualified for use in the fabrication of FCM's. All repair welding shall be subject to nondestructive tests as provided herein.

Weld repair of base metal at the producing mill shall not be permitted.

909.2 Types of Repairs. All repairs to base and weld metal shall be classified as one of the following three categories as determined by the DCES.

Category I repairs may be performed without documentation or prior approval of the DCES. These repairs shall include the following:

a) Deposition of additional weld metal to compensate for insufficient weld throat.
b) Deposition of additional weld metal to fill shallow excavations produced by grinding to remove small discontinuities.
c) Repair of overlap.
d) Repair of undercut.

Category II repairs shall be documented as described in Article 909.3. The Contractor may prepare repair procedures for Category II repairs and submit them to the DCES for preapproval. Preapproved procedures may be employed after the QA Inspector has verified that the discontinuity to be repaired is as described in the approved procedure. These repairs shall include the following:

a) Repair of gouges in cut edges that are 7/16 inch deep or less.
b) Repair of laminar discontinuities less than one inch deep, or with a depth of less than one-half the thickness of the plate cut edge, whichever is less, provided that the laminar discontinuity is not within 12 inches of a tension groove weld. There shall be no visible lamellar discontinuities at the boundaries of tension groove welds.
c) Repair of base metal surfaces when ASTM A6 provides for repair welding.
d) First time excavation and repair from one surface of groove and fillet welds which contain porosity, slag, or incomplete fusion, provided the excavations do not exceed the following limits:

<table>
<thead>
<tr>
<th>Length of Weld “L”</th>
<th>Total Length of Excavations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1'-6&quot;</td>
<td>“L” or 10”, whichever is less</td>
</tr>
<tr>
<td>Over 1'-6&quot; to 3'-0&quot;</td>
<td>1'-0&quot;</td>
</tr>
<tr>
<td>Over 3'-0&quot; to 6'</td>
<td>1'-6&quot;</td>
</tr>
<tr>
<td>Over 6'-0&quot; to 12'-0&quot;</td>
<td>2'-0&quot;</td>
</tr>
<tr>
<td>Over 12'-0&quot; to 24'-0&quot;</td>
<td>3'-0&quot;</td>
</tr>
<tr>
<td>Over 24'-0&quot;</td>
<td>3'-0&quot; or 10 percent, whichever is greater</td>
</tr>
</tbody>
</table>

The depth of groove weld excavations shall not exceed 65 percent of the effective throat of the weld detailed on the shop drawings. Excavations beyond this depth shall be treated as Category III repairs.
e) Repair of "hot" or "restraint" cracks which are confined to root passes.
f) Repair of cracks in the "dead end" of a member which initiated from residual stress and could not propagate due to the absence of applied stress.
g) Deposition of weld metal up to 3/8 inch or one quarter the material thickness, whichever is less, to correct for length or joint geometry.

Category III repairs shall be documented as described in Article 909.3. The Contractor shall prepare repair procedures on an individual basis and submit them to the DCES for approval before repair welding is begun. These repairs shall include the following:

- Repair of gouges in cut edges greater than 7/16 inch deep.
- Repair of all laminar discontinuities other than Category II repairs.
- Repair of surface or internal defects in rolled, forged or cast products, other than Category II repairs.
- Repair of weld defects other than Category I or II repairs.
- Repair of all cracks, including base metal separations such as lamellar tears, other than Category II repairs.
- Dimensional corrections requiring weld removal and rewelding.
- Any weld correction to compensate for a fabrication error such as improper cutting, punching, drilling, machining, fitting, assembly, etc.

909.3 Repair Procedures. Repair procedures shall include full-size drawings in accordance with Article 205 to adequately describe the deficiency and proposed method of repair. Category III repair procedures shall detail the location of the discontinuity in the member. Repair procedures shall be in accordance with Article 726 except as modified below:

- The discontinuity shall be detailed as it appears from visual inspection and NDT.
- Preheat prior to air carbon arc gouging shall be shown. The minimum preheat shall be 150°F when the weld or base metal is subject to significant residual stress. Applied stresses shall be removed prior to initiating the repair.
- Preheat and interpass temperature shall be shown. ASTM A36, A441, A572 and A588 steels with thicknesses up to 1-1/2 inches shall be heated to 250°F minimum. Thicknesses above 1-1/2 inches shall be heated to 350°F minimum. Preheat and interpass temperatures shall be maintained without interruption until the repair is completed unless otherwise approved by the DCES.
- Postheat shall be employed and shall continue without interruption from the completion of repair welding to the end of the minimum specified postheat period. Postheat of the repair area shall be between 400°F and 500°F for one hour minimum for each inch of weld thickness or for two hours, whichever is less.
- Preheat, interpass temperature maintenance during repair, and post heat shall be contiguous operations.
- If stress relief heat treatment is required, it shall be completely described. Tests shall be performed to determine the effect of the heat treatment on both weld and base metal properties before the procedure is approved. Final acceptance NDT shall be performed after stress relief is complete.
- Repairs to tension butt welds shall be examined by ultrasonic and radiographic testing. Repairs to all other groove welds shall be examined by ultrasonic and/or radiographic testing as approved by the DCES. Fillet weld repairs shall be examined by magnetic particle testing. Radiographic testing may be performed as specified in Article 910 as soon as the weldment has cooled to ambient temperature. Final testing by ultrasonic or magnetic particle testing
shall not be performed until the weldments have been cooled to ambient temperature for at least the elapsed time indicated as follows:

ASTM A36, A441
A572 and A588

\[
\begin{align*}
&\leq 2'' \quad 24 \text{ hrs.} \\
&> 2'' \quad 48 \text{ hrs.}
\end{align*}
\]

Approved repair procedures shall be retained as part of the Contract records. The Contractor shall provide one copy of each approved repair procedure to the QA Inspector for submission to the DCES with his final inspection report.

910. RADIOGRAPHIC TESTING

Radiographic Inspection of FCM's or components of FCM's shall be performed in accordance with the provisions of Section 16 of this Manual, except that the thickness of the penetrant and the essential hole shall be as specified in Table 910. A smaller essential hole and/or a thinner penetrant than specified may be used.

In addition to the film identification required by Section 16, the letters "FCM" shall appear on each radiograph. The FCM images shall appear adjacent to the weld number and shall be obtained by placing lead letters on the steel on the source side prior to exposure. The minimum height of the lead letters shall be 5/16 inch.

Radiographs shall be identified in the Radiographic Inspection Report by the designation "FCM" adjacent to the weld identification.

| TABLE 910 — PENETRANT REQUIREMENTS FOR FRACTURE CRITICAL MEMBERS* |
|-----------------|-----------------|-----------------|-----------------|
| **Nominal material thickness range (inches)** | **Penetrant identification** | **Penetrant thickness (inches)** | **Essential hole** |
| up to 0.375     | 7               | .007            | 4T              |
| over 0.375 to 0.50 | 10              | .010            | 4T              |
| over 0.50 to 0.625 | 12              | .012            | 4T              |
| over 0.625 to 0.75 | 15              | .015            | 4T              |
| over 0.75 to 0.875 | 17              | .017            | 2T              |
| over 0.875 to 1.00 | 20              | .020            | 2T              |
| over 1.00 to 1.25 | 25              | .025            | 2T              |
| over 1.25 to 1.50 | 30              | .030            | 2T              |
| over 1.50 to 2.00 | 35              | .035            | 2T              |
| over 2.00 to 2.50 | 40              | .040            | 2T              |
| over 2.50 to 3.00 | 45              | .045            | 2T              |
| over 3.00 to 4.00 | 50              | .050            | 2T              |
| over 4.00 to 6.00 | 60              | .060            | 2T              |

*Fracture Critical Member or Component
911. ULTRASONIC TESTING

All joints required to be radiographed by Section 16 shall also be ultrasonic tested when the weld throat exceeds 1/2 inch in thickness. All testing shall be performed in accordance with Section 17. The cost of these tests shall be included in the price bid for the structural steel.

The DCES reserves the right to ultrasonic test other welded joints at his discretion. Such testing, when performed, shall be done by State representatives.

Discontinuities found in fracture critical members shall be recorded on the ultrasonic test report when their Indication Rating is + 14db or less.

912. MAGNETIC PARTICLE INSPECTION

When magnetic particle inspection of FCM’s or components of FCM’s is required, magnetization of the part to be inspected shall be accomplished using a yoke unless otherwise ordered by the DCES. All other provisions of Section 18, Magnetic Particle Inspection, shall apply.

913. DYE PENETRANT INSPECTION

Dye penetrant inspection of FCM’s or components of FCM’s, when required, shall be performed in accordance with Section 19, Dye Penetrant Inspection.

914. VISUAL INSPECTION

A careful visual inspection of all completed work, including an inch by inch detailed visual inspection of all welds, shall be performed by Quality Control and Quality Assurance inspectors to insure conformance with the Contract documents. A portable light source and magnifying glass shall be used as necessary to insure the accuracy of visual inspection.
SECTION 10
BOLTING AND RIVETING

1001. HIGH STRENGTH BOLTS, NUTS & WASHERS

1001.1 General. Where high strength bolts are indicated in the Contract Documents the bolts, nuts, and washers shall conform to the provisions of the current Standard Specification for High-Strength Bolts for Structural Steel Joints, ASTM A325.

All bolts, nuts and washers shall be marked by the manufacturer as described in the applicable ASTM Standard Specification and in Figure 1001.1.

Bolts, nuts and washers to be used in weathering steel applications shall be corrosion resistant and shall display proper markings to indicate they are manufactured from weathering steel. Type 1 bolts, nuts, and washers are generally used in painted applications. However, Type 2 and Type 3 bolts, nuts, or washers may also be used. When galvanized fasteners are specified, bolts shall be ASTM A325, Types 1 or 2; nuts shall be ASTM A563, Grade DH or A194, Grade 2H, and washers shall be F436 plain.

1001.2 Cleaning of Bolted Connections. Contact (faying) surfaces of all stringer and girder splices, stringer and girder direct support connections (attachment of stringers to cross girders, beams, etc.), and all main member connections in trusses, arches, towers, bents, and rigid frames shall be commercial blast cleaned in accordance with SSPC-SP6-No.6 to remove all dirt, rust, grease, paint, mill scale and other foreign material prior to assembly.

1001.3 Installation. All bolted connections are designed as friction type connections unless otherwise designated on the Plans. The length of the bolts shall be such that the point of the bolt will be flush with or outside of the face of the nut when completely installed. Sufficient thread must be provided to prevent the nut from encountering the thread run-out. Bolted connections shall be assembled with a hardened washer under the turned element. When oversize holes are permitted in accordance with the provisions of Section 2, Drawings, or Section 6, Preparation of Base Metals a hardened washer shall be installed over each oversize hole in an outer ply. Washers shall be used under both the head and the nut when bolts are used in connections in any of the following conditions:

a) replacement of existing bolts or rivets.
b) connections which are prepared by drilling in the field.
c) connections between new steel and existing steel.

Where an outer face of the bolted parts has a slope of more than 1:20 with respect to a plane normal to the bolt axis, a smooth beveled washer shall be used to compensate for the lack of parallelism.

Bolts shall be installed with the nuts protected from the weather or other corrosive elements unless clearance restrictions dictate otherwise. In general, bolts installed with the stem vertical shall have the heads up. Bolts installed with the stem horizontal shall have the heads out toward the weather.

Bolts shall be tightened to the minimum required tension described in Table 1001.3a by the turn-of-the-nut method. Enough bolts shall be installed and brought to a “snug tight” condition to ensure that the parts of the joint are brought into full contact with each other. Snug tight is defined as the tightness attained by a few impacts of a impact wrench or the full effort of a man using an ordinary spud wrench. This represents approximately 150 foot pounds for bolts 7/8 inch in diameter and larger. Following this initial operation, bolts shall be placed in any remaining holes in the connection and brought to snug tightness. All bolts in the joint shall then be tightened additionally by the
PAINTED STRUCTURES

3 Radial Lines at 60°

TYPE 1
- 3 Radial lines at 120° (optional)

TYPE 2

3 Circumferential lines at 120°

UNPAINTED STRUCTURES

WEATHERING

GRADE C

OTHER GRADES

Grade symbol must appear on one face of the nut.

GRADE C3

GRADE DH3

X-Manufacturers Identification Symbol.

Additional markings may be added at the manufacturers option.

FIGURE 1001.1 — REQUIRED MARKINGS FOR HIGH STRENGTH FASTENERS
applicable amount of nut or head rotation specified in Table 1001.3b. During this operation, there shall be no rotation of the part not turned by the wrench.

Impact wrenches, if used, shall be of adequate capacity and with a sufficient supply of air to perform the required tightening of each bolt in approximately ten seconds.

<table>
<thead>
<tr>
<th>TABLE 1001.3a — BOLT TENSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt Diameter (inches)</td>
</tr>
<tr>
<td>A325 Bolts</td>
</tr>
<tr>
<td>1/2</td>
</tr>
<tr>
<td>5/8</td>
</tr>
<tr>
<td>3/4</td>
</tr>
<tr>
<td>7/8</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1-1/8</td>
</tr>
<tr>
<td>1-1/4</td>
</tr>
<tr>
<td>1-3/8</td>
</tr>
<tr>
<td>1-1/2</td>
</tr>
</tbody>
</table>

\(^a\)Equal to 70 percent of specified minimum tensile strengths of bolts, rounded off to the nearest kip.

<table>
<thead>
<tr>
<th>TABLE 1001.3b — NUT ROTATION FROM SNUG TIGHT CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt Length (as measured from underside of head to extreme end of point)</td>
</tr>
<tr>
<td>Both faces normal to bolt axis</td>
</tr>
<tr>
<td>Up to and including 4 diameters</td>
</tr>
<tr>
<td>Over 4 diameters but not exceeding 8 diameters</td>
</tr>
<tr>
<td>Over 8 diameters but not exceeding 12 diameters</td>
</tr>
</tbody>
</table>

Nut rotation is relative to bolt, regardless of the element (nut or bolt) being turned. For bolts installed by 1/2 turn and less, the tolerance should be plus or minus 30°. For bolts installed by 2/3 turn and more, the tolerance should be plus or minus 45°.

For bolts lengths exceeding 12 diameters the required rotation must be determined by actual test in a suitable tension device simulating the actual conditions.
1001.4 Inspection. Bolt tension shall be verified by the use of an inspection torque wrench provided and operated by the Contractor. The inspection torque shall be determined at least once each day by tightening not less than three bolts of each length and diameter in a calibration device capable of indicating bolt tension. A washer shall be placed under the part being turned. Each of the three bolts shall be tightened in the calibration device to the minimum required tension for its diameter as listed in Table 1001.3a. The inspecting wrench shall then be applied to the element on the washer side of the fastener, and the torque necessary to turn the nut or head 5 degrees (approximately 1 inch at 12 inch radius) in the tightening direction shall be determined. The nut or head shall be in motion when the torque is measured. The average torque measured for a minimum of three bolts shall be taken as the “minimum job inspecting torque” to be used in the manner specified herein. The “maximum job inspecting torque” shall be determined by multiplying the “minimum job inspecting torque” by 1.5.

Fasteners shall be inspected after installation by applying the inspecting wrench to a minimum of 10% of the bolts, but not less than two bolts, selected at random, in each connection. The actual torque value of each inspected bolt shall be determined as the head or nut is rotated in the tightening direction. This value shall be within the minimum and maximum limits determined as described above. If any bolt in a connection is found to have a torque value below the minimum or above the maximum job inspecting torque, all bolts in that connection shall be inspected. All undertightened bolts shall be tightened, and reinspected. All overtightened bolts shall be loosened and the bolt and nut removed for visual inspection of the bolt and nut threads. If there is visible thread damage or the nut does not spin freely on the bolt when turned by hand without the aid of a wrench, a new bolt and nut shall be installed. Undamaged fasteners may be re-installed. All new fasteners shall be tightened and inspected as described above.

All labor and equipment necessary for the inspection of bolt tightness shall be provided by the Contractor. The State shall witness the bolt testing.

1001.5 Sampling & Testing. Fasteners shall be sampled and submitted to the Department Laboratory for testing, to ensure that they meet the physical, mechanical and chemical requirements of the specifications. Only fasteners to be used in the following critical connections shall be submitted for testing:

a) Stringer and girder splices
b) Stringer and girder direct support connections, i.e., attachment of stringers to cross girders, beams, etc.
c) All main member connections in trusses, arches, towers, bents and rigid frames.

All high strength fasteners in each control lot shall be inspected for proper markings prior to sampling and during the course of the work. Any lot containing improperly marked bolts, nuts and/or washers shall be rejected. Two sample bolts and nuts shall be selected at random from each manufacturer’s control lot. When Type 3 fasteners are required, two washers shall also be selected. Samples shall be submitted to the Department Laboratory for testing with a completed copy of Form BR 240. One BR 240 form shall be submitted for each manufacturer’s control lot. A manufacturer’s control lot is defined as all fasteners of the same grade and size which are produced under the same production controls. Before sampling the fasteners, the Inspector shall examine the certified copies of test reports provided by the manufacturer, to ensure that the bolts, nuts, and washers were manufactured to specification requirements and are of domestic origin, if applicable. The manufacturer’s control lot numbers on the test reports must match the lot numbers marked on the shipping containers. If this criteria is not met, the lot in question shall be rejected.

Any lot containing less than 20 bolts need not be sampled. Fasteners shall be inspected prior to or during installation to determine that they have no unacceptable workmanship defects such as head bursts (open breaks in the flats or corners of the heads), seams, cracks, burned heads etc. and that they do not have incomplete or improper markings. Fasteners having visible defects in material and workmanship or which are improperly marked shall not be submitted for testing and shall not be used in the work.
1002. TURNED BOLTS

Turned bolts shall be used only when approved by the DCES.

1003. UNFINISHED BOLTS

Bolts shall conform to the provisions of the current ASTM Specification A307 - Grade B, unless otherwise specified in the Contract Documents.

Bolts shall be of sufficient length to extend entirely through the nut but not more than 1/2 inch beyond.

Nuts shall conform to the current requirements of ASTM A563.

1004. RIVETS

Riveting may only be performed when shown on the Plans or otherwise approved by the DCES.

Rivets shall conform to ASTM A502, Steel Structural Rivets, Grades 1, 2 or 3 as shown on the Plans or otherwise approved. Grade 1 rivets are used for general purposes under average stress conditions. Grade 2 rivets shall be used with high strength steels requiring higher stress application. Grade 3 rivets are very similar to Grade 2, and shall be used where atmospheric corrosion resistance is required.

Rivets shall be heated uniformly to a light cherry red color and shall be driven while hot. The heating of the points of rivets more than the remainder will not be permitted. When ready for driving they shall be free from slag, scale and other adhering matter and when driven, they shall completely fill the holes.

Burned, burred or otherwise defective rivets, or rivets which throw off sparks when taken from the furnace, forge, or electric heater shall not be driven.

Loose, burned, badly formed or otherwise defective rivets shall be cut out. Caulking and re-cupping of rivet heads will not be allowed. When cutting out defective rivets, care shall be taken not to damage the adjacent metal. If necessary, rivet shanks shall be removed by drilling. Countersinking, when required, shall be neatly done and countersunk rivets shall completely fill the holes.

Rivets shall be driven by direct-acting riveters where practical. The riveting machine shall retain the pressure for a short time after upsetting is complete.

The diameters of rivets indicated on the plans shall be understood to mean their diameters before heating. Heads of driven rivets shall be of approved shape, concentric with the shanks, true to size, full, neatly formed, free from fins and in full contact with the surface of the member. Rivet heads may have a collar around their complete circumference. The collar shall not have a width greater than 1/8 inch or height greater than 1/16 inch. "Jockey caps", a partial collar, shall not exceed 1/16 inch in width.

Whenever the Contract documents call for field riveting, ASTM A325 bolts of the same nominal diameter shall be installed, unless otherwise ordered by the DCES.
1101. ASSEMBLY OF SHOP WELDED CONNECTIONS

1101.1 Welded Joint Fit-up. Parts to be joined by fillet welds shall be brought into as close contact as practical. Except for the provisions of Section 12, the maximum gap between parts being joined shall be 3/16 inch unless a modified welding procedure is approved by the DCES. If the separation is greater than 1/16 inch, the weld size shall be increased by the amount of the separation or the Contractor shall demonstrate that the required throat thickness has been obtained.

The separation between faying surfaces of lap joints and of butt welds landing on a backing shall not exceed 1/16 inch. The use of fillers is prohibited. Backing for skewed joints may require shaping, bending, or beveling to maintain this requirement.

Abutting parts to be joined by groove welds shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10 percent of the thickness of the thinner part joined, but in no case more than 1/8 inch, may be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 1/2 inch in 12 inches. Measurement of offset shall be based upon the center line of parts unless otherwise shown on the approved drawings.

Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, other suitable devices or by tack welds until welding has been completed. Tack welding, when permitted shall conform to the requirements of this manual. The use of jigs and fixtures is recommended where practical. Suitable allowances shall be made for warpage and shrinkage.

Dimensions of the cross section of groove welded joints which vary from those shown on the detail drawings by more than the tolerances shown in Section 7A shall be referred to the DCES for approval or correction.

1101.2 Assembly of Stiffeners. Intermediate stiffeners and connection plates shall be sniped at the corners and welded to the web and compression flange as specified in Article 203.8 unless otherwise detailed on the Plans. The fillet welds connecting the stiffener or connection plate to the web shall be started at the end of the stiffener that is adjacent to the tension flange and progress toward the compression flange. At least 90 percent of the fillet welds shall extend to within 1/4 inch of all sniped corners. The remaining percentage must start or stop within 1/2 inch of the snipe. Care shall be taken to prevent the stiffener welds from intersecting the continuous flange to web welds. The maximum possible clearance between intersecting welds is desired. All fillet welds must have full throat and no unfilled craters at the beginning and end of the weld. Localized undercut of the stiffener at the point where the welding machine is started or stopped shall not require repair unless severe in the opinion of the Inspector.

Before welding, there shall be no gap between the web and the intermediate stiffeners, bearing stiffeners, or connection plates in excess of 3/32 inch.

Intermediate stiffeners and connection plates may be cut 1/8 inch short and then assembled with the stiffener paint tight against the tension flange and the opposite end welded to the compression flange. The weld size at the compression flange shall be increased to include the gap as required by Article 1101.1. Stiffeners shall not be driven in place with sufficient force to distort the flange, web or stiffener.
Tack welds used during stiffener assembly shall begin at least 3 inches from the snipe of the stiffener and shall have a minimum length of 1-1/2 inch. This provision is made to prevent the starting and stopping of weld passes on tack welds. All tack welds shall be completely remelted and incorporated into the final weld.

1101.3 Attachment of Bearing Assemblies. Sole plates or bearing assemblies may be tack welded to the structural steel in the shop to facilitate shipment.

1102. SHOP ASSEMBLY OF FIELD WELDED CONNECTIONS

The Contractor shall be responsible for the proper preparation of groove joints to be welded in the field. The joints shall be prepared and assembled in the shop to insure that proper joint alignment and fit up is present at each joint when the correct camber is in the assembled pieces. The Contractor may, at his option, eliminate all shop assembly and joint preparation for field welding provided there is sufficient extra material at each joint to provide for machine oxygen cutting or air carbon arc gouging of the joint preparation after assembly on the ground prior to erection at the site or assembly in the erected position under the proper conditions of support to provide for camber. All provisions of this manual concerning joint preparation, welding and inspection, shall apply. The members shall be free from twists, bends or other deformations.

1103. SHOP ASSEMBLY OF BOLTED CONNECTIONS

1103.1 Bolted Parts. Bolted parts shall fit solidly together when assembled and shall not be separated by gaskets or any other compressible material. Joint contact surfaces of primary stress carrying members shall be cleaned as described in Article 1303. Other joint contact surfaces and the areas adjacent to the bolt holes shall be free of all scale except tight mill scale, burrs, dirt, paint, and other foreign material that may prevent solid seating of the parts.

Prior to assembly, contact surfaces of galvanized members shall be scored by wire brushing or blast cleaning.

Surfaces of metal to be in contact when assembled shall not be painted. Temporary protective coatings will be approved if completely removed before final assembly.

The component parts shall be assembled, drift pinned to prevent lateral movement, and firmly bolted to draw the parts into close contact before reaming or drilling is begun. Assembled parts shall be taken apart if necessary for the removal of burrs and shavings produced by the reaming or drilling operation.

Members shall be free from twists, bends or other deformations. Careful measurements shall be taken while the pieces are in assembly and before any reaming or drilling is performed to insure that the assembly conforms to the dimensions shown on the approved shop drawings within the dimensional tolerances described in Section 12.

Pieces to be connected by rivets or bolts shall not be subject to any welding unless such welding is shown on the plans or approved by the DCES.

1103.2 Support of Members During Assembly. All girders and beams are to be assembled in their cambered (no load) condition. When members are assembled with their webs vertical, they shall be supported at intervals of 20 feet, or two tenths of the span length, whichever is less. When the webs are horizontal, the above intervals of support may be extended provided there is no noticeable deflection between points of support. Trusses are to be assembled in their full dead load position unless the design of the structure provides for the secondary stresses created by assembling the truss in the fully cambered (no load) position. Trusses shall be supported during assembly at each panel point.
1103.3 Splices in Simply Supported Stringers and Girders. All holes in main material splices shall be reamed or drilled from the solid with all connecting parts assembled. This work shall be done with the full length of member assembled unless otherwise approved by the DCES.

1103.4 Main Member Connections to, or Splices in Trusses, Arches, Continuous Stringers and Girders, Towers, Bents and Rigid Frames. Assembly shall be full truss or girder assembly unless progressive truss or girder assembly, full chord assembly, progressive chord assembly or special complete structure assembly is listed as an alternate in the Contract Documents, or approved by the DCES. All structural components shall be assembled in the shop with milled ends of compression members in full bearing unless otherwise specified, and then shall have their holes reamed or drilled from the solid with all connecting parts assembled.

a) Full Truss or Girder Assembly. Full truss or girder assembly shall consist of assembling all members of each truss, arch rib, bent, tower face, continuous beam line, plate girder or rigid frame at one time. All main member connections shall be reamed or drilled from the solid with all connecting parts assembled. When stringers and girders are continuous because of their attachment to intermediate transverse structural steel supporting beams or girders regardless of cross section, these intermediate transverse beams or girders shall be part of the assembly.

b) Progressive Truss or Girder Assembly. When permitted, the fabricator may elect to use a system of progressive truss or girder assembly that is essentially the same as that described in Article 1103.4a except that the structure shall be assembled for 150 feet minimum, beginning at one end. Previously assembled portions may be removed from the assembly in such a manner that there is 150 feet of assembly, or at least three panel, chord or girder lengths in assembly at all times.

c) Full Chord Assembly. Full chord assembly shall consist of assembling the full length of each chord of each truss or each leg of each bent or tower with geometric angles at the joints and then reaming or drilling from the solid the field connection holes while the members are assembled. When this method of assembly is permitted, the Contractor shall have the option of reaming or drilling web members while assembled to the chords at proper geometric angles or reaming or drilling web members with properly located steel templates.

d) Progressive Chord Assembly. Progressive chord assembly may be employed at the Contractor's option when permitted. This method of assembly shall be the same as the described for full chord assembly except that the number of pieces and minimum assembled length specified for progressive truss and girder assembly shall apply.

e) Special Complete Structure Assembly. Special complete structure assembly shall consist of assembling the entire structure including the floor system. This method of assembly will not be required unless specifically called for in the Contract Documents.

1103.5 Reaming to a Template. When reaming to a template is permitted, the templates shall be steel, 1/4 inch minimum thickness, with hardened steel bushings. The template shall be accurately positioned from the working lines marked on the piece and inscribed on the template.

The finished holes shall meet the requirements of the Contract Documents and be aligned to insure proper camber in the completed assembly.

1103.6 Numerically Controlled Drilling. Numerically controlled drills may be used in lieu of reaming assembled or drilling from the solid as described in Articles 1103.3 and 1103.4, provided the Contractor's control and verification procedures are approved by the DCES. Approval of the procedure will not relieve the Contractor of his responsibility to provide accurately matching holes in properly aligned pieces when assembled.
A minimum of 40 percent of the first one-fourth of the connections fabricated shall be shop assembled as determined by the DCES to verify the quality of the holes, the accuracy of alignment and fit of mating pieces. Numerically controlled drilling shall not create a need for fills to produce accurate fit. If satisfactory work is verified by accurately checking the first quarter of the work drilled, shop assembly for verification may be reduced to a minimum of 10 percent, selected at random, to represent all connections that were required to be reamed assembled, or drilled from the solid.

All other connections which are drilled with numerically controlled equipment and are not shop assembled shall be checked for entering and fit of pieces by careful shop measurements made by the Contractor. The Contractor shall be responsible for the dimensions and fit of all pieces, whether shop assembled or not.

1103.7 **Abutting Joints.** Bolted joints and splices in main stress carrying members shall have their abutting parts carefully aligned. Whenever joints are designed with an opening of less than 3/8 inch between pieces to be joined, parts over 1/2 inch in thickness shall have their surfaces parallel and shall have an offset no greater than 1/16 inch from theoretical alignment prior to bolting up. For parts less than 1/2 inch in thickness, the above offset may be increased to 1/8 inch maximum. After all bolts are tightened to the specified tension, the parts shall be in contact so that the joint will develop the design friction capability and will prevent exposure of the bolt stem to the atmosphere.

If the design is based on transmitting all stress through the fasteners, the joints may be detailed open 1/4 inch maximum unless otherwise provided in the Contract Documents. Joints designed with a nominal 1/4 inch opening may be assembled with an accuracy of ± 1/8 inch, i.e., 1/8 inch minimum and 3/8 inch maximum.

1103.8 **End Connection Angles.** End connection angles of floor beams and stringers shall be flush with each other and accurately set as to position and length of member. In general, end connection angles shall not be finished unless required by the Contract Documents. However, faulty assembling and connecting may be cause for requiring them to be milled, in which case their thickness shall not be reduced by more than 1/16 inch, nor shall their fastener bearing value be reduced below design requirements.

1103.9 **Drifting of Holes.** Any drift pinning done during assembly shall be only the minimum necessary to bring the parts into position, and not sufficient to enlarge the holes or distort the metal.

1103.10 **Match-Marking.** Connecting parts assembled in the shop for the purpose of reaming or drilling holes in field connections shall be match-marked. A diagram showing the match marks shall be furnished to the Engineer, unless the connecting parts are shipped attached to the piece.

1103.11 **Field Assembly in Lieu of Shop Assembly.** The State will approve the elimination of shop assembly of continuous stringers and girders together with their attachments to transverse supporting beams provided the Contractor will perform exactly the same operation during field erection, i.e., ream assembled or drill from the solid, and assume all additional costs incurred by doing this work in the field.

### 1104. ASSEMBLY OF RIVETED MEMBERS

1104.1 **General.** The several pieces forming one riveted member shall be straight or properly cambered before assembly. Pieces shall be close fitting before riveting is begun. Riveted members shall be free from twists, bends, open or misaligned joints and other defects resulting from faulty workmanship.

1104.2 **Riveted Plate Girders.** Web plates of girders having no cover plates shall be detailed with the top edge of the web flush with the backs of the flange angles. Any portion of the plate projecting beyond
the angles shall be chipped flush with the backs of the angles. Web plates of girders having cover plates may be 1/2 inch less in width than the distance back to back of flange angles. At web splices, the clearance between the ends of the web plates shall not exceed 3/8 inch.

End stiffener angles and stiffener angles intended as supports for concentrated loads shall be milled or ground to secure a uniform even bearing against the flange angles. Intermediate stiffener angles shall fit sufficiently tight to exclude water after being painted.

Web splice plates and fillers under stiffeners shall fit within 1/4 inch at each end.

1105. ALIGNMENT OF MEMBERS DURING SHOP ASSEMBLY.

All steel required to be shop assembled for reaming, drilling from the solid, or weld joint preparation shall be aligned so that the control points (bearing locations or support points) are within ± 1/8 inch from the locations shown on the approved shop drawings. This tolerance shall apply to the X, Y, and Z coordinates, i.e., in all three dimensions.
SECTION 12
DIMENSIONAL TOLERANCES FOR FABRICATED MEMBERS

1201. GENERAL

The provisions of this section shall apply to all members, independent of cross section, whether straight or curved. Members heat-curved under the provisions of Section 15, Heat-Curving, Cambering and Straightening shall meet the dimensional tolerances of this section. Before welding, dimensions of shapes and plates shall conform to the tolerances described in ASTM Designation A6. After welding, all members shall conform to the dimensional tolerances of these specifications.

All measurements shall be compared to the dimensions shown on the approved shop drawings.

1202. DEVIATION FROM DETAILED LENGTH

Members with ends milled for bearing and members with faced-end connection angles may deviate from the detailed length by $\pm 1/32$ inch maximum. All other members may vary from the detailed length by $\pm 1/4$ inch maximum, unless otherwise approved by the DCES.

1203. DEVIATION FROM SPECIFIED DEPTH

The maximum deviation from the specified depth of welded beams and girders, measured at the web centerline, shall not exceed the following:

- For depths up to 36 inches, inclusive: $\pm 1/8$ inch
- For depths over 36 inches to 72 inches, inclusive: $\pm 3/16$ inch
- For depths over 72 inches: $\pm 5/16$ inch, $-3/16$ inch

1204. LOCATION OF WELDED BUTT JOINTS

Welded butt joints shall not be placed more than 1/2 inch from the detailed location.

1205. INTERMEDIATE STIFFENERS

1205.1 Location. Intermediate stiffeners may vary $\pm 1/2$ inch from the detailed location.

1205.2 Deviation from Straightness and Fit of Intermediate Stiffeners. The deviation from straightness of intermediate stiffeners shall not exceed 1/2 inch in the length of the stiffener. The edge of the stiffener that is welded to the web of the girder shall be straight and, when fit to the web, shall have no gaps in excess of 3/32 inch between the web and the stiffener. Where tight fit of intermediate stiffeners is specified, a gap of up to 1/16 inch between stiffener and flange is allowed.

1206. BEARING STIFFENERS

1206.1 Deviation from Straightness of Bearing Stiffeners. The out-of-straightness of bearing stiffeners shall not exceed 1/4 inch for stiffeners up to 6 feet in length and 1/2 inch for lengths over 6 feet. The centerline of the attached stiffener shall lie within the dimensional boundaries of a perfectly straight stiffener of the same thickness. They shall fit to the web as described in Article 1205.2.

1206.2 Ends in Bearing. The bearing ends of bearing stiffeners shall be flush and square with the web and at least 10 percent of the area at the bearing end shall be in intimate contact with the flange. The remaining portion may have a gap not exceeding 0.040 inch.
1207. BEARING AT POINTS OF LOADING

The maximum gap between abutting parts at any bearing point shall be 0.040 inch. When milling is specified at a point of bearing, the surfaces shall be plane and true within 0.010 inch.

1208. WARPAGE AND TILT OF FLANGES

The combined warpage and tilt of flanges of welded beams or girders shall be determined by measuring the offset at the toe of the flange from a line normal to the plane of the web, through the intersection of the centerline of web, with the outside surface of the flange plate. This offset shall not exceed 1/100 of the total width of the flange or 1/4 inch, whichever is greater. This deviation does not apply to bearing areas at points of loading. At bearing points the flange shall be perpendicular to the web and shall be flat so that bearing will be achieved between abutting parts as required in Article 1207.

1209. WEB TO FLANGE OFFSET

The lateral deviation between centerline of web and centerline of flange of fabricated girders shall not exceed 1/4 inch.

1210. DEVIATION FROM FLATNESS OF GIRDER WEBS

1210.1 Girders with Intermediate Stiffeners and/or Connection Plates. The maximum deviation from flatness of girder webs shall be determined by measuring offsets from a straight edge whose length is not less than the least dimension of any panel. The straight edge shall be placed in any position within the panel necessary to measure the maximum deviation of the web. A panel is defined as the web area bounded by flange plates or horizontal stiffeners and any two adjacent vertical stiffeners or connection plates, regardless of side to which attached.

The maximum deviation from web flatness shall be determined by applying the following formula to each panel:

\[ \text{maximum deviation} = \frac{d}{100} \]

where d is at least panel dimension in inches.

Table 1210.1 lists values obtained using the above formula.

| Least Panel Dimension (in.) | 12 | 18 | 25 | 37 | 44 | 50 | 56 | 62 | 69 | 75 | 81 | 87 | 94 | 100 |
|-----------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|     |

1210.2 Girders With No Full-Depth Web Attachments. The maximum deviation from web flatness of shafts (girders with no full-depth web attachments which may stiffen the web) shall be determined by applying the following formula:

\[ \text{maximum deviation} = \frac{d}{150} \]

where d is the depth of the web in inches.

Table 1210.2 lists values obtained using the above formula.

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### TABLE 1210.2 — MAXIMUM DEVIATION FROM WEB FLATNESS FOR GIRDER WITH-OUT INTERMEDIATE STIFFENERS, CONNECTION PLATES OR OTHER FULL DEPTH ATTACHMENTS THAT MAY STIFFEN THE WEB.

<table>
<thead>
<tr>
<th>Depth of Web (in.)</th>
<th>19</th>
<th>28</th>
<th>37</th>
<th>47</th>
<th>56</th>
<th>66</th>
<th>75</th>
<th>84</th>
<th>94</th>
<th>103</th>
<th>113</th>
<th>122</th>
<th>131</th>
<th>141</th>
<th>100</th>
</tr>
</thead>
</table>

1210.3 **Web Flatness at Bolted Ends.** Webs of plate girders that are shop assembled and have shrinkage distortion at the bolted end in excess of the flatness requirements specified may be shipped to the project site for erection provided shop assembly has demonstrated that the splice material will straighten the web to acceptable tolerances when less than 25 percent of the required splice bolts were installed.

1211. **DEVIA'TION FROM STRAIGHTNESS OF WELDED COLUMNS**

a) Length of 45 feet and under:

\[
\frac{1/8 \text{ inch} \times \text{No. of feet of test length}}{10}, \text{ but not over } 3/8 \text{ inch}
\]

b) Lengths over 45 feet:

\[
3/8 \text{ inch} + \frac{1/8 \text{ inch} \times \text{No. of feet of total length} - 45}{10}
\]

The above deviations do not apply to guide columns in vertical lift bridges. Guide columns shall be straight within the limits specified on the Plans or ordered by the DCES.

1212. **DEVIA'TION FROM HORIZONTAL ALIGNMENT**

Deviation from specified horizontal alignment (sweep) in curved beams and girders and deviation from straightness in beams and girders with no specified sweep shall not exceed the following:

a) \[ \pm \frac{1/8 \text{ inch} \times \text{Total no. of feet between supports}}{10} \]

or

b) \[ \pm \frac{1/8 \text{ inch} \times \text{No. of feet of test length}}{10} \]

If the top and bottom flange deviations are on opposite sides of the theoretical centerline, the total deviation (top flange plus bottom flange) shall not exceed the value computed by a) or b) above.

This maximum deviation may only be used when the member has sufficient lateral flexibility to permit the attachment of diaphragms, cross frames, lateral bracing, etc., without damaging the structural member or its attachments.

1213. **DEVIA'TION FROM SPECIFIED CAMBER**

1213.1 **General.** Camber measurements shall be made in the shop prior to shipment and in the field after erection to insure conformance with this Section.
Measurements in the shop shall be made by the Fabricator on each single erection piece after fabrication. When shop assembly is required, camber measurements shall also be made on the assembled members. Measurements shall be taken to check all of the camber control points shown on the approved shop drawings and assembly drawings. The camber measurement shall be made by the fabricator in the presence of the inspector and will be the basis for approval of camber prior to shipment.

Final camber measurements shall be made by the Contractor after erection. The Contractor shall notify the Engineer in advance so that camber measurements may be witnessed. After erection, each member shall have all of the specified camber, less the dead load deflection of the steel, within the tolerance specified in Article 1213.3. When members do not conform to this requirements the DCES may approve moderately excessive camber or order camber reduction by the heat-shrink process.

Camber deficiencies which place the member on the same side of theoretical lines as superstructure dead load deflections are unacceptable and may only be corrected by heat-shrink procedures approved by the DCES.

Camber deviations that cannot be corrected by the heat-shrink technique without adversely effecting the structural steel, in the opinion of the DCES, shall be cause for rejection and replacement of the steel at no cost to the State.

1213.2 Deviation from Specified Camber of Single Erection Pieces Prior to Shipment from the Shop.

a) Stringers, girders and floorbeams prior to assembly:

1) $-0, +1/4$ inch, or

2) $-0, +1/4$ inch $\times \frac{\text{No. of feet of test length}}{10}$, but not to exceed 3/4 inch, or

3) $-0, +1/8$ inch $\times \frac{\text{No. of feet from nearest end}}{10}$

b) Truss chord and web members prior to assembly:

$\pm 1/8$ inch $\times \frac{\text{No. of feet of total length}}{10}$, but not exceed 3/8 inch

c) Arch members and rigid frames prior to assembly:

$\pm 1/8$ inch $\times \frac{\text{No. of feet of total length}}{10}$, but not to exceed 3/4 inch

Measurements to verify conformance with the above requirements shall be made with the member lying on its side in the no-load condition or, when blocked in the no-load position, as approved by the DCES.

1213.3 Deviation from Specified Camber of Erected Steel Bridge Superstructures.

$-0 +1/4$ $\times \frac{\text{No. of feet of length from nearest support (bearing or pin)}}{10}$, but not to exceed 3/4 inch in cantilever sections or 1-1/2 inch between substructure supports.

Unless otherwise specified, all measurements shall be taken when the steel erection is complete and the superstructure is subject to steel dead load stresses only.
1214. DEVIATION FROM VERTICAL ALIGNMENT OF GIRDER WEBS
The maximum deviation of girder webs from vertical at points of support shall be:
   a) 1/4 inch, or
   b) 3/22 inch x Depth of web in feet, but not to exceed 3/4 inch.

The deviation of girder webs from vertical at mid span points may exceed the above requirements subject to the approval of the DCES.

1215. TOLERANCES FOR JOINT FIT-UP IN WELDED CONNECTIONS
See Figures 703.3 and 703.4.
SECTION 13
CLEANING AND PROTECTIVE COATINGS

1301. STRUCTURAL STEEL TO BE PAINTED

When structural steel is required to be painted, cleaning and painting shall be in accordance with the appropriate bid item in the Contract Documents. Unless otherwise noted, the final surface preparation, prior to painting, shall be done by blast cleaning to meet the requirements of "Commercial Blast Cleaning", as described in the Standard Specifications.

If, because of prolonged storage, delays in final field painting schedules, or for any other reason, the shop-applied protective coating deteriorates to the point where it is unacceptable, the Contractor shall restore the original protective coating to an acceptable condition at no additional cost to the state before continuing with field painting or other field coatings.

1302. WEATHERING STEEL

When structural steel is not required to be painted, the steel shall be cleaned prior to shipment from the fabrication shop. All weld fume deposits, slag, weld spatter, loose scale, oil, grease, dirt, paint, chalk or crayon marks and other foreign substances which may be unsightly or interfere with the formation of the oxidized protective coating shall be removed to the satisfaction of the DCES. The Contract Documents may require additional cleaning to remove all mill scale from specified surfaces.

1303. BOLTED SPLICES

Contact (faying) surfaces of all stringer and girder splices, stringer and girder direct support connections (attachment of stringers to cross girders, beams, etc.), and all main member connections in trusses, arches, towers, bents, and rigid frames shall be Commercial Blast Cleaned in accordance with SSPC-SP6-No. 6 to remove all dirt, rust, grease, paint, mill scale, and other foreign material prior to assembly.

1304. MACHINED SURFACES

Machine finished surfaces in sliding contact, including pins, pin holes, surfaces in sockets at the top of rocker bearings, etc., shall receive one coat of automotive grease as soon as machining is complete. Bronze plates in sliding contact shall also be coated with grease. The Contractor shall maintain all protective coatings to prevent corrosion. All protective coatings applied in the shop shall be removed immediately prior to erection of the superstructure. When the protective coating is removed, the parts shall be thoroughly cleaned and then coated with grease before erection of the superstructure. All other machine finished surfaces shall be painted as specified in the Contract documents.

1305. GALVANIZED COATINGS

When galvanizing is required, it shall conform to the requirements of "Galvanized Coatings and Repair Methods" described in the Standard Specifications. Welds that are to be galvanized shall be blast cleaned or otherwise treated to remove slag and any other material that will interfere with proper galvanizing.
SECTION 14
STORAGE, TRANSPORTATION, & ERECTION

1401. STORAGE OF MATERIALS

Structural material shall be stored above the surface of the ground on platforms, skids, or other supports, and shall be protected as far as practical from surface deterioration and kept free from accumulations of dirt, oil, or other foreign matter. No material shall, at any time, be dropped, thrown, or dragged on the ground. Girders and beams shall be handled and stored with their webs vertical and shall be adequately shored, braced, and/or clamped to resist any lateral forces which might occur. Long members such as columns and chords shall be supported at a sufficient number of intermediate locations to insure that there is no damage from deflection. Permanent distortion resulting from improper handling or storage will be cause for rejection.

Any damage incurred during storage at the shop shall be corrected by the Fabricator prior to acceptance for shipment by the Inspector. All fabricated material stored by the Contractor at the jobsite or other approved location will be subject to inspection by the Engineer and any corrective action required as the result of damage during storage shall be performed by the Contractor.

Repairs to damaged structural steel shall be done in accordance with procedures approved by the DCES.

1402. TRANSPORTATION

1402.1 Marking for Shipping. Erection pieces with computed weights exceeding three tons shall have the lifting weight to the nearest one-half ton marked thereon. Bolts and rivets of one length, nuts and washers shall be packaged separately by diameter. Pins, small parts, and small packages of bolts, rivets, washers, and nuts shall be shipped in boxes, crates, kegs, or barrels. The gross weight of any package shall not exceed 300 pounds. A list and description of the contained material shall be plainly marked on the outside of each shipping container. Shipping containers for high strength fasteners shall have the manufacturer's control lot numbers marked on the outside.

The weight of all tools and erection material shall be kept separate.

1402.2 Shipping. The loading, transportation, unloading and storage of structural material shall be conducted so that the metal will be kept clean and free from injury by rough handling.

Structural members shall be suitably supported and braced so that they will not be subjected to stresses in excess of those provided for in the design.

The method of shipment and requirements for transportation drawings shall conform to Article 206.

1403. ERECTION OF STRUCTURAL STEEL

1403.1 General. The Contractor's proposed structural steel erection procedure shall be described on erection drawings submitted to DCES for review. These drawings shall meet all provisions of Article 204, and when necessary, conform to the requirements of the Standard Specification section entitled "Work Affecting Railroads."

Pedestrians shall be protected at all times and no erection work shall be done over traffic on roadways, bikeways, waterways, and railroads. No erection work shall begin prior to the review of the erection procedure by the DCES and affected railroads and review of the traffic maintenance procedure by the Regional Director of Transportation. This review shall not be considered as relieving the Contractor of the responsibility for the safety of his method or equipment used, or for the responsibility of carrying out the work in accordance with the requirements of the Contract documents.

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**1403.2 Falsework.** Curved girders and long span straight girders shall be stabilized with falsework, temporary braces, or holding cranes until a sufficient number of adjacent girders are erected with all diaphragms and crossframes connected to provide the necessary lateral stability. All trusses shall be erected on falsework unless otherwise approved by the DCES. The falsework shall provide for proper camber and alignment and shall be properly designed, constructed, and maintained for the loads which will be imposed upon it. When erecting trusses, the falsework shall be left in place until all connections are bolted and accepted by the Engineer unless otherwise provided in the erection procedure. Care shall be taken in the use of falsework and other temporary supports to insure that the temporary elevation of structural steel provided by the falsework is consistent with the deflections that will occur as the structure is completed.

Bridge railings shall not be bolted or welded in their final position until the falsework has been removed.

**1403.3 Field Connections.** Bolting or welding procedures necessary to complete the erection of the structure shall be shown on the erection drawings. The procedures shall include the sequence and method for connecting main members and secondary members. For stringer and girder spans, the following minimum information shall be included in the notes, modified as necessary to conform to design and erection requirements for each structure:

Splices and field connections of main stress carrying members shall be made with a minimum of 50% of the holes filled with approved high strength bolts and full size erection pins before the external support systems are released. At least one-half of this percentage shall be bolts, tightened to specification requirements. The bolts and pins shall be installed uniformly throughout the connection except that erection pins shall be used in the extreme corners of all main connections.

Members to be assembled on the ground before erection shall be blocked to their proper no load profile and 100% of the approved high strength bolts shall be installed and tightened to specification requirements before erecting the member.

All diaphragms and crossframes shall be installed as the work progresses unless the Contractor shows by calculation and the DCES approves a lesser amount as sufficient to stabilize the member. All diaphragms between adjacent girders shall be connected before release of the crane or other lifting device unless modifications have been requested and approved consistent with Article 204. When applicable, the number and location of diaphragms and crossframes needed to insure lateral stability of the members during all phases of the erection procedure, including during the lifting and upon release of the member, shall be shown on the erection drawings.

Between the first two lines of straight girders, each diaphragm or cross frame to girder connection shall be made with at least 50% of the holes filled with approved high strength bolts. The bolts shall be tightened until there is no gap between the connected parts. After the first two lines are erected and stabilized, diaphragms or crossframes installed between subsequent lines of girders may have each of their connections made with a minimum of two approved high strength bolts installed in each connection unless a greater number of bolts is required for stability. The bolts shall be tightened until there is no gap between the connected parts.

Between all lines of curved girders, each diaphragm or crossframe to girder connection shall be made with at least 50% of the holes filled with approved high strength bolts. The bolts shall be tightened until there is no gap between the connected parts.

If surfaces which are to be connected by field bolting or field welding have been painted or become rusted or contaminated with any foreign material that would make these connecting procedures unacceptable, the Contractor shall clean the surfaces at no additional cost to the State. A tight coating of light rust will be permitted on faying surfaces of bolted joints. No rust will be permitted at the fusion boundaries of groove welds.

Bolting procedures shall be in conformance with Section 10.
Erection bolts shall be the same nominal diameter and shall conform to the same specification as the final bolts. Cylindrical erection pins shall be the same size as the hole.

1403.4 Repair of Damaged or Misaligned Steel. All damaged or misaligned structural steel shall be straightened or corrected by procedures approved by the DCES. The method of repair proposed by the Contractor shall be submitted on a standard shop drawing for approval of the DCES prior to beginning the work. Approval, when granted, shall not relieve the Contractor of his responsibility for the successful completion of the work.

1403.5 Field Reaming and Drifting of Holes. Members shall be subject to only light drifting to align holes. Any members subjected to drifting that results in distortion of the member or elongation of the holes will be rejected.

Main members and secondary members with oversize holes shall not be field reamed without approval of the DCES.

Secondary members which have holes punched full size may be subjected to limited field reaming when approved by the DCES. If approved, reaming shall not elongate holes by an amount greater than 1/16 inch for 75% of the holes in any erection sub-assembly and 1/8 inch for the remaining 25% of the holes in the erection sub-assembly, i.e., diaphragm, lateral brace, etc.

The DCES may approve additional reaming of secondary members provided adequate edge distances and fastener spacing are maintained and the next larger size fastener is used. The edge distances shall be considered the same for either a rolled or planed edge.

Field reaming producing results exceeding the limits previously described, will be cause for rejection of the member.

1403.6 Adjustment of Pin Nuts. All nuts on pins shall be properly tightened and locked as specified on the plans or approved by the DCES. The pins shall be aligned in the holes so that the members shall take full and even bearing upon them.

1404. REMOVAL OF RUST AND STAINS FROM CONCRETE
All rust and other stains shall be removed from concrete surfaces in accordance with the requirements of the Standard Specification entitled Structural Concrete. This requirement shall apply for cleaning all new concrete as well as for cleaning all existing concrete stained or damaged by the Contractor's operations. If the Contractor elects to reduce concrete staining and rusting of surfaces which must be cleaned, he may, at no additional cost to the State, spray unpainted portions of steel members with an approximately one mil thick coat of commercial lacquer that has been given a slight coloration that will denote its presence. This lacquer coating may remain on all surfaces which are to be imbedded in, or are to be in contact with, concrete. The lacquer must be removed from all contact surfaces of bolted connections, from within three inches of a welded joint, and from areas that will subsequently be covered by field painting.

1405. FIELD INSPECTION
All erection shall be subject to the inspection of the Engineer-in-Charge, who shall be given all facilities required for a thorough inspection of the work. Materials and workmanship subject to shop inspection are identified by the acceptance stamp of the Shop Inspector as described in Article 303.7. Materials and workmanship not required to be shop inspected shall be inspected by the Engineer. Certified copies of the results of tests conducted by the manufacturer shall be furnished to the Engineer in accordance with the requirements of the specification for that item.

1406. FIELD REPAIR
All repairs to structural steel shall be subject to approval by the DCES.

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SECTION 15
HEAT CURVING, CAMBERING, AND STRAIGHTENING

1501. HEAT CURVING ROLLED BEAMS AND WELDED PLATE GIRDER

1501.1 General. Rolled beams and welded plate girders designed to be built with a specified horizontal curvature may be fabricated using heat curving procedures which conform to the following requirements provided that the Plans or Specifications do not require other methods of producing the required curvature.

Steels that are manufactured to a specified minimum yield point greater than 50,000 psi shall not be heat-curved, cambered or straightened without the written approval of the DCES.

Members required to be fabricated to a radius shorter than the minimum radius of curvature as described in this Section shall be fabricated as welded plate girders with the flanges oxygen cut to the required radius prior to assembly to the web.

Generally, members shall be heat curved at the fabricator's plant. Stringers and girders may be heat curved at the job site provided the Contractor bears all additional costs for field heat curving, including field inspection by an approved inspection agency, cleaning, and painting.

1501.2 Minimum Radius of Curvature. Heat curving of beams and girders will be allowed when the horizontal radius of curvature measured to the centerline of the member web is greater than both values calculated by the followings two equations, and greater than 150 feet at any and all cross sections throughout the length of the member.

\[ R = \frac{14bD}{\sqrt{F_y \psi t}}, \quad R = 7500 \frac{b}{F_y \psi}, \]  

where:
- \( F_y \) = specified minimum yield point in ksi of the member web.
- \( \psi \) = ratio of the total cross section area to the cross sectional area of both flanges.
- \( b \) = width of the widest flange in inches.
- \( D \) = clear distance between flanges in inches.
- \( t \) = web thickness in inches.
- \( R \) = radius in inches.

In addition to the above, when the required radius of curvature is less than 1000 feet, and the flange thickness exceeds three inches, or the flange width exceeds thirty inches, heat curving will not be allowed.

1501.3 Camber Increase for Dead Load Deflection Caused by Residual Stresses. To compensate for possible loss of camber of heat curved girders (camber losses of this nature are also known to occur in straight beams and girders but to a lesser degree) in service as residual stresses dissipate, the amount of camber in inches at the point of maximum deflection may be increased by the amount shown in the following formula:

\[ \delta \text{ increase} = 0.02L'F_y, \]  

where:
- \( L' \) = span length or distance between points of dead load contraflexure in inches.
- \( E \) = modulus of elasticity in ksi.
- \( y_o \) = the distance from the neutral axis of the steel member to the extreme outer fiber in inches (maximum distance for non symmetrical sections).
Any camber increase indicated by the formula shall be approved by the DCES who may multiply the formula result by a factor of 0.5 to 0.95 based upon experience with long term deflections.

Distribute \( \Delta \) increase from the point of maximum deflection as a parabola. This distribution shall be between dead load points of contraflexure. Fifty percent of this camber increase may be included in the bridge profile because camber loss will not be complete until after several months of service. The remaining fifty percent of the camber increase may be included in the anticipated steel dead load deflection. This shall include all steel deflection prior to composite action between the steel superstructure members and any attached concrete designed to act as a composite section.

**1501.4 Preparation for Heat Curving.** Members shall be heat curved prior to completion of the following work unless otherwise approved by the DCES.

a) Attachment of end bearing stiffeners.

b) Attachment of lateral gusset plates.

c) Attachment of longitudinal stiffeners.

d) Welding of intermediate stiffeners and connection plates to the flanges.

e) Shop or field painting.

When longitudinal stiffeners are required, they shall be heat curved or oxygen cut to the required radius prior to being welded to the curved girder.

**1501.5 Support of Members for Heating.** Members may be heat curved with the web in either the vertical or horizontal position.

When the radius is less than 1000 feet, members must be heat curved with the web in the horizontal position, or preloaded to induce stress prior to heating.

When the member is heat curved with the web in the horizontal position, the member must be supported at its ends and at intermediate points as required to produce a uniform curvature in the member and compressive stresses in the upward projecting flange legs throughout the full length of the piece being curved. Intermediate safety catch blocks shall be maintained at mid-distance between supports of the member and not more than two inches below the flanges at all times during the heating process to catch the member in case of a sudden sag due to plastic flange buckling.

When the member is heat curved with the web in the vertical position, the member must be braced or supported in such a manner that the tendency of the member to deflect laterally during the heat curving process will not cause the member to overturn.

The method of supporting or loading shall be described on a sketch sheet and submitted to the DCES with copies of the design computations in accordance with Article 207. The method of support and computations for preloading shall be approved prior to beginning the work. Preload compressive stresses will be permitted up to a maximum of 20,000 psi. This stress limit shall apply for all steels covered by this specification. Preloading as specified herein will reduce the number of heating patterns required to produce the desired curvature.

Any method of handling, supporting, or loading that causes the member to distort permanently (yield without the application of heat) will result in rejection of the member. All nondestructive tests to evaluate damage and any corrective work ordered by the State to compensate for overstressing shall be performed by the Contractor at no cost to the State.

**1501.6 Heating Process and Equipment.** Heating shall be performed using large, approximately 1 inch diameter, multiorifice (rosebud) heating torches operating on approximately 25 psi propane and 125 psi oxygen. The torches and tips to be used will be subject to the approval of the DCES. Selection shall be made to promote heating efficiency and prevent unnecessary distortion.
Heating shall be confined to the patterns described herein and shall be conducted to bring the steel within the planned pattern to a temperature between $1,000^\circ$ F and $1,150^\circ$ F as rapidly as possible without overheating the steel.

Any heating procedure which causes a portion of the steel to be heated to a temperature greater than $1,250^\circ$ F shall be considered destructive heating. Destructive heating shall automatically cause the rejection of the steel. Steel rejected for destructive heating shall be investigated for reacceptance, repair, or replacement by tests ordered by the DCES. The cost of such tests and any necessary repair or replacement shall be borne by the Contractor.

1501.7 Location of Heating Patterns. Heating patterns shall be spaced uniformly along the full length of each flange to produce a circular (not parabolic) curvature. Sufficient heating patterns shall be used in each piece to eliminate unsightly chording effects. Heating patterns shall be adjusted to produce the necessary curvature, compensating for differences in flange thickness and width as necessary. Thicker and wider plates, in general, require wider heating patterns to produce the same amount of curvature. Care shall be taken when heating relatively thin, wide plates to guard against flange buckling.

1501.8 Heating Patterns and Method of Heating. Only truncated triangular heating patterns shall be used. The base of the triangle shall be the flange edge that will be concave after curving. The apex of the heating triangle shall be truncated to provide a 1 inch width. The truncated end of the heating triangle shall be located as follows:

a) When the required radius is $1,000$ feet or less, the truncated end of the heating triangle shall be located $1/8$ of the flange width but not more than 2 inches beyond the intersection of the web and flange.

b) When the required radius is greater than $1,000$ feet, the heating pattern may be as described above or may, at the fabricator's option, be modified to locate the truncated end of the heating triangle at the junction of web and flange.

Heating patterns shall be marked on the flange surfaces prior to heating. Heat shall be applied to the top and bottom flange at essentially the same location in the member. Beginning at the truncated end of the heating pattern, heating shall progress slowly toward the base of the pattern spreading with an included angle of 15 to 30 degrees. The base of the heating triangle shall not exceed 10 inches regardless of flange width and thickness. The heating torches shall not begin to progress toward the base of the heating pattern until the truncated end of the pattern is brought up to the specified temperature. Once heating begins to progress towards the base at the pattern, the heating torch(es) shall not be returned to the apex of the heating triangle. When the flange thickness exceeds 1-1/4 inches, both surfaces of the flange shall be heated simultaneously. Heat shall not be applied to the inside flange surface until the heat being applied to the outside surface has progressed beyond the web and flange junction. When heating the inside flange surface, the truncated end of the heating triangle shall be just inside the junction of web and flange and the triangle shall share a common base with the heating pattern on the outside of the flange at that point.

The heating torches shall be manipulated to guard against general and surface overheating. When heating thick plates, it may be necessary to occasionally interrupt heating for periods of less than one minute to allow the heat to soak into the flange and avoid surface overheating.

1501.9 Heat Measurement. The Contractor shall provide the Inspector with temperature indicating crayons manufactured for $600^\circ$ F, $1,000^\circ$ F, $1,100^\circ$ F and $1,250^\circ$ F. Heat measurements shall be made after the heating flame has been removed from the steel.

1501.10 Artificial Cooling. Quenching with water or water and air will not be permitted. Cooling with dry compressed air will be permitted after the steel has cooled to $600^\circ$ F.
1501.11 Control of Web and Flange Distortion. Web distortion is the first indication that the heating process is not being conducted properly. Web or flange distortion in excess of that allowed by this manual will not be permitted. When intermediate stiffeners are placed on only one side of a girder web, temporary intermediate braces, i.e., wood blocks or posts, must be placed on the opposite side during heating to prevent rotation of the flange during the heating process. One quarter inch thick asbestos sheet material shall be placed against the web before applying heat to the inside flange surface. When heating the inside flange surface, the torches shall be directed to prevent applying heat directly to the web. The asbestos sheet material may be a two feet square piece that the workmen move from pattern to pattern as the work progresses.

1501.12 Web Cutting for Heat Curved Welded Plate Girders. The fabricator shall cut sufficient extra camber into the webs of plate girders to provide for all camber losses during fabrication and heat curving. The heat curving process will in general not cause as much camber loss during fabrication as welding of the web to flanges and welding of stiffeners and connection plates to the compression flange.

1501.13 Rolled Beams with Cover Plates. When rolled beams are fabricated with cover plates, the cover plates may be attached before heat curving if the total thickness of one flange plus cover plate is less than 2 inches and the radius of curvature is greater than 1,000 feet. When rolled beams with cover plates attached are heat curved, two torches shall be used regardless of flange and cover plate thickness, and the Contractor shall magnetic particle inspect the flange to cover plate fillet welds. This work shall be performed after all heating is complete and shall conform to the requirements of Section 18.

All other rolled beams with cover plates must be heat curved before the cover plates are attached. The cover plates shall be either heat curved or oxygen cut to the required radius before being welded to the curved beam.

1502. HEAT CAMBERING OF ROLLED BEAMS AND WELDED PLATE GIRDERs

1502.1 General. All provisions of Article 1501 shall apply except as modified by this Article. Heat cambering procedures shall be approved by the DCES prior to beginning the work. When heat cambering is approved, only deep vee heating patterns will be permitted.

1502.2 Heat Cambering of Rolled Beams. Rolled beams shall be heat cambered to provide the required curvature. Triangular heating patterns shall be spaced throughout the length of the member. The apex of the heating triangle shall be located in the web at a point not less than 75 percent of the depth of the member from the flange that will be concave after cambering. Heating shall begin at the apex of the heating pattern and progress slowly with a total included angle not exceeding 20 degrees towards the base of the pattern and across the full width of the flange as described in Article 1501.8.

The heating torch shall not be returned to the apex of the heating triangle after heating has progressed towards the base. Preloading may be performed as described in Article 1501.5 provided the maximum stress does not exceed 20,000 psi. Heating patterns shall be centered on connection plates whenever possible.

When rolled beams are to be fabricated with cover plates, the rolled beams shall be heat cambered prior to the attachment of the cover plates.

All detail material such as connection plates, bearing stiffeners, and gusset plates shall be attached to the rolled beam after the beam has been heat cambered.

1502.3 Heat Cambering of Welded Plate Girders. Heat cambering of welded plate girders will only be approved as a necessary repair procedure for plate girders rejected for improper camber. The heating procedure and any proposed preloading shall be approved by the DCES prior to beginning the work.
When it is necessary to correct camber deficiencies in welded plate girders, heating will only be permitted in deep vee heating patterns centered on intermediate stiffeners and connection plates. In some cases, additional stiffeners may be required to provide sufficient heating sites. This provision is designed to prevent or reduce web distortion. The apex of the heating pattern shall be located in the web not less than 75 percent of the depth of the member from the flange that will be concave after cambering. The maximum included angle of the heating pattern shall be 10 degrees. The maximum width of the base of the heating pattern shall be 10 inches. Where shallow members or thin webs require heating patterns with a width substantially less than 10 inches at the junction of the web to flange, the heating pattern in the flange may extend beyond the limits of the heating pattern in the web by a maximum of one inch on each side provided the total width of pattern in the flange does not exceed 10 inches.

1502.4 Support of Members for Heat Cambering. Members to be heat cambered shall be supported with the web vertical and with the flange which will be concave after cambering placed upwards. Supports shall be spaced to take the maximum advantage of dead load in the member before heat is applied. Members may be supported with the web horizontal if an approved preloading procedure is used.

1503. HEAT STRAIGHTENING DAMAGED STRUCTURAL STEEL

All heat straightening procedures shall be subject to prior approval by the DCES. Straightening procedures shall describe in detail the distortion to be corrected and all procedures for preloading, heating cooling, verifying final dimensions, and nondestructive tests. The provisions of Articles 1501 and 1502 shall apply.
SECTION 16
RADIOGRAPHIC TESTING

1601. GENERAL

The procedures and standards set forth herein are to govern radiographic testing of groove welds in butt joints in plates, shapes, and bars by X ray or gamma ray sources. The methodology shall conform to ASTM E94, "Standard Recommended Practice for Radiographic Testing", and ASTM E142, "Standard Method for Controlling Quality of Radiographic Testing", except as provided herein.

Any variation from the provisions of these specifications must have prior approval of the DCES, and shall be confirmed in writing. Such variations include, but are not limited to:

- radiographic testing of fillet, tee, and corner welds,
- changes in source-to-film distance,
- unusual application of film,
- unusual penetrrometer applications including film side penetrometers and wire penetrometers,
- radiographic testing of thicknesses greater than six inches and
- film types, densities, and variations in exposure, development, and viewing techniques.

All radiographic inspection performed by State personnel, inspection agencies under contract to the State, Contractors or their agents working on State contracts shall conform to the requirements of this specification.

1602. EXTENT OF TESTING

1602.1 Butt Joints in Primary Tension Members. All butt joints in primary tension members shall be radiographed. This shall include all tension flange butt welds and the tension portion of web butt welds in stringers and girders. Joints to be radiographed shall also include tension butt welds in columns, bents, towers, rigid frames, arches, truss chords, truss web members, and longitudinal stiffener splice welds when attached to the tension areas of members.

Radiographic inspection will be used to determine the soundness of tension butt welds throughout their entire length unless otherwise specified.

1602.2 Web Splices. Tension areas of web splices in stringers and girders shall be interpreted to represent one third of the web butt joint, with a minimum length of 16 inches, beginning at the tension flange unless otherwise specified. When a web joint is subject to reversal of stress, the entire web (100%) and both flange joints shall be radiographed.

1602.3 Field Splices. Butt welded field splices in structural members shall be subject to 100 percent examination by radiographic inspection unless otherwise specified.

1602.4 Repairs. "Spot" inspection and "spot" radiography shall not be used except for the examination of localized repairs in welds previously rejected by radiographic tests. Repair radiographs shall represent a minimum length of weld equal to the repair excavation plus 3 inches each side.

1602.5 Radiographic Inspection of Welds Subject to Shear or Compression. Any groove weld in a butt joint may be subject to radiographic inspection regardless of the direction of stress if required by the Contract Documents or ordered by the Inspector.
All compression and shear joints in a member shall be radiographed when any radiograph in a tension joint in the member has an accumulative discontinuity length which exceeds 10 percent of the length of the joint.

**1602.6 Extension of Test Area.** If defects are found in any area which is subject to partial examination, the area examined shall be extended to insure that the limits of the rejectable discontinuities have been discovered and repaired. If the extended area examined contains rejectable discontinuities, the complete weld shall be radiographed.

**1603. FRAUDULENT RADIOGRAPHS**

The State may order new and separate radiographic inspection of all butt welds in all structural steel fabricated for the State in a given shop when there is evidence, in the opinion of the DCES, that the Fabricator has submitted fraudulent radiographs or reports.

**1604. RADIOGRAPHIC PROCEDURE**

**1604.1 General.** Radiographs shall be made using a single source of X- or gamma radiation. The radiographic sensitivity shall be judged based on penetrameter image. Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required penetrameters and the essential holes as described in Table 1604.1. Identifying letters and numbers shall show clearly in the radiograph. Radiography shall be performed in accordance with all applicable safety requirements.

All joints shall be prepared for radiography by grinding as described in Article 723. Weld profiles shall be as described in Article 723. Extension bars and run off plates shall be removed prior to radiographic inspection.

When joints are ground in accordance with the provisions of Article 723, steel shims will not be required under the penetrameter.

**TABLE 1604.1 — PENETRAMETER REQUIREMENTS**

<table>
<thead>
<tr>
<th>Nominal material thickness range (inches)</th>
<th>Penetrameter identification</th>
<th>Penetrameter thickness</th>
<th>Essential hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 0.375</td>
<td>12</td>
<td>0.012</td>
<td>4T</td>
</tr>
<tr>
<td>over 0.375 to 0.625</td>
<td>15</td>
<td>0.015</td>
<td>4T</td>
</tr>
<tr>
<td>over 0.625 to 0.75</td>
<td>17</td>
<td>0.017</td>
<td>4T</td>
</tr>
<tr>
<td>over 0.75 to 1.00</td>
<td>20</td>
<td>0.020</td>
<td>4T</td>
</tr>
<tr>
<td>over 1.00 to 1.25</td>
<td>25</td>
<td>0.025</td>
<td>4T</td>
</tr>
<tr>
<td>over 1.25 to 1.50</td>
<td>30</td>
<td>0.030</td>
<td>2T</td>
</tr>
<tr>
<td>over 1.50 to 2.00</td>
<td>35</td>
<td>0.035</td>
<td>2T</td>
</tr>
<tr>
<td>over 2.00 to 2.50</td>
<td>40</td>
<td>0.040</td>
<td>2T</td>
</tr>
<tr>
<td>over 2.50 to 3.00</td>
<td>45</td>
<td>0.045</td>
<td>2T</td>
</tr>
<tr>
<td>over 3.00 to 4.00</td>
<td>50</td>
<td>0.050</td>
<td>2T</td>
</tr>
<tr>
<td>over 4.00 to 6.00</td>
<td>60</td>
<td>0.060</td>
<td>2T</td>
</tr>
</tbody>
</table>
1604.2 Preparation for Exposure.

1604.2.1 General. All film cassettes shall be loaded with two films of the same specification. Appropriate lead screens shall be used. A center screen is recommended when the steel thickness exceeds 1 1/4 inches. The loaded cassette shall be held in intimate contact with the steel by a process that will avoid film pressure marks. The back side of the cassette shall be protected from scatter radiation for its full length and width by a lead sheet.

1604.2.2 Film Type. Radiographic film shall be Type 1 or Type 2 as described in ASTM E94. Lead foil screens shall be used as described in ASTM E94. Fluorescent screens shall not be permitted.

1604.2.3 Film Size. When the joint thickness is less than 3 inches, radiographs may be 4 1/2 inches by 17 inches in size. When the length of the joint is such that more than one radiograph is required, one of the films may be shortened to 4 1/2 inches by 10 inches if the Contractor elects to do so. When joint thicknesses are 3 inches or greater, the minimum film size shall be 7 inches by 17 inches. Larger radiographs may be required in areas where there have been excessive repairs or to radiograph joints with unusual dimensions. All repair radiographs shall be made using 4 1/2 inches by 17 inches or larger film.

1604.2.4 Radiographic Sources. Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness requirement of ASME Section V, Article 2. X-ray units, 600 kvp maximum and Iridium 192 may be used as a source for all radiographic inspection provided they have adequate penetrating ability. Cobalt 60 may be used as a radiographic source only when the steel being radiographed is 3 inches or greater in thickness.

1604.2.5 Penetrameters. Penetrameters shall be manufactured from steel, preferably stainless steel, and shall conform to the dimensions shown in Figure 1604.2a. Each penetrameter shall be manufactured with three holes, one of which shall be of a diameter equal to twice the penetrameter thickness (2T). The diameter of the two remaining holes shall be selected by the manufacturer. They will ordinarily be equal to one times (1T) and four times (4T) the penetrameter thickness. Penetrameter designations 7 through 25 shall contain a 4T hole. For more detailed information, see ASTM E142.

The thickness of the penetrameter and the essential hole shall be as specified in Table 1604.1. A smaller essential hole and/or a thinner penetrameter may be used provided all other provisions for radiography are met.

Thickness shall be measured as T, and/or T, at the locations shown in Figures 1604.2b and 1604.2c. Penetrameters shall be placed on the source side, parallel to the weld joint, with the holes at the outer end as detailed in Figures 1604.2b and 1604.2c. The use of film side penetrameters shall be cause for rejection of the radiographs.

At least two penetrameters, one at each end of the joint or film, shall show clearly on each radiograph as shown in Figure 1604.2b. When a transition in thickness occurs at a welded joint, each film shall clearly show two penetrameters on the thinner plate and one penetrameter on the thicker plate as shown in Figure 1604.2c. Steel backing, when allowed, shall not be considered part of the weld thickness in penetrameter selection.

1604.2.6 Technique. Radiographs shall be made with a single source of radiation centered as near as practical with respect to the length and width of that portion of the weld being examined.
The source to subject distance shall not be less than the total length of film being exposed. In addition, the source to subject distance shall not be less than the amount shown in the following table:

<table>
<thead>
<tr>
<th>Maximum thickness of weld under examination (T)</th>
<th>Minimum source to subject distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1/4” to 2”, inclusive</td>
<td>24”</td>
</tr>
<tr>
<td>&gt; 2” to 2 1/2”, inclusive</td>
<td>18”</td>
</tr>
<tr>
<td>&gt; 2 1/2”</td>
<td>7T</td>
</tr>
</tbody>
</table>

Welded joints shall be radiographed and the film indexed by methods that will provide complete and continuous inspection of the joint within the limits specified to be examined. Joint limits shall show clearly in the radiographs. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable. Films shall have sufficient length and shall be placed to produce at least 1/2 inch of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

Welds longer than 14 inches but less than 30 inches in length may be radiographed by overlapping film cassettes and making a single exposure, or by using single film cassettes and making separate exposures.

The method used shall provide complete and continuous inspection, produce radiographs of acceptable quality and meet the requirements of this Section.

To check for backscattered radiation, a lead symbol “B”, 1/2 inch high and 1/16 inch thick, shall be attached to the back of each film cassette. If the “B” image appears on the radiograph, the radiograph shall be considered unacceptable.

In general, webs and flanges shall be radiographed before the member is assembled. When, because of some unusual situation, it is necessary to radiograph a member which has already been assembled (a tee conformation), the source shall be placed between the flanges and the film shall be placed against the outside flange surface such that both the flange edge and the web to flange welds are clearly delineated on the film. A similar technique shall be used for radiographing webs of members already assembled.
Minimum penetrator thickness 0.005 inch
Minimum diameter for 1T hole 0.010 inch
Minimum diameter for 2T hole 0.020 inch
Minimum diameter for 4T hole 0.040 inch

Place identification numbers here

Holes shall be true and normal to the surface of the penetrator. Do not chamfer.

Design for penetrator thickness from 0.005 inch and including 0.050 inch:

- From 0.005 inch through 0.012 inch, see ASTM E142, Table 1.
- From 0.012 inch through 0.030 inch, made in 0.0035 inch increments.
- From 0.020 inch through 0.050 inch, made in 0.005 inch increments.

Penetrameter thicknesses between the increments indicated are permitted, provided they do not exceed the maximum thickness required.

Place identification numbers here

Design for penetrator thickness from 0.060 inch to 0.160 inclusive made in 0.010 inch increments.

Note:
Tolerances on penetrator thickness and hole diameter shall be ±10% or one half of the thickness increment between penetrator sizes, whichever is smaller.

**FIGURE 1604.2a—PENETRATOR DESIGN**
Lead film identification numbers shall be placed directly over the numbers die-stamped in the steel for the purpose of matching film to weld after processing.

FIGURE 1604.2b – RADIOPHGRAPHER IDENTIFICATION AND PENETRAMETER LOCATIONS –EQUAL THICKNESS

Measure T2 at point of maximum thickness under penetrameter placed on slope.

FIGURE 1604.2c – RADIOPHGRAPHER IDENTIFICATION AND PENETRAMETER LOCATIONS –UNEQUAL THICKNESS
1604.3 Quality of Radiographs. In general, the quality of the radiographs will be determined by the quality of the penetrant images and freedom from film defects. All radiographs shall be free from mechanical, chemical, or other blemishes that may mask or be confused with the image of any discontinuity in the radiograph. Such blemishes include, but are not limited to:

a) Fogging and cassette light leaks.
b) Processing defects such as streaks, water marks, or chemical stains.
c) Scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears.
d) Loss of detail due to poor screen to film contact.
e) False indications due to defective screens or internal faults.

1604.4 Density Limitations. Radiographs shall have an H&D density of 1.8 minimum for radiographs made with an X ray source and 2.0 minimum for radiographs made with a gamma ray source. The maximum density shall be 4.0. Densities within the range of 2.5 to 3.5 are preferred for single film viewing.

H&D (radiographic) density is a measure of film blackening, expressed as:

\[ D = \log \frac{I_o}{I} \]

where

\[ D = \text{H&D (radiographic) density}, \]
\[ I_o = \text{light intensity incident on the film}, \] and
\[ I = \text{light intensity transmitted through the film} \]

When transitions in thickness are radiographed where the ratio of the thickness of the thicker section to the thinner section is 3 or greater, radiographs should be exposed to produce a density of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements shall be waived in the thicker section. Except for this condition, densities outside the maximum and minimum limits listed above will be cause for rejection of the radiograph. Radiographic density shall not vary by more than 0.50 in any section of equal thickness shown in the radiograph.

1604.5 Film Identification. In order that films may be properly identified for examination, filing and actual physical matching with the steel when required, the following information shall appear on each film:

a) New York State contract number.
b) Initials of radiographic inspection company.
c) Initials of fabricator and the fabricator’s shop order number.
d) Date.
e) Erection mark.
f) Weld number and an individual piece mark, in the event that there is a duplication of erection marks on the contract.
g) Location letters.
h) Penetrameters.

See Figure 1604.2b & c for details of film identification. All the information described in this subsection shall appear on each film. The images appearing on the film shall be obtained by placing lead numbers and letters on the steel on the source side prior to exposure. The minimum height of numbers and letters shall be 5/16 inch. The Contractor will be permitted to preprint the New York State contract number, the initials of the radiographic company, and the fabricator’s initials on the radiographs by a direct light process provided that this information is not placed within 3/4 inch of the edge of the weld. When the direct light preprinting technique is used, the remaining items of film identification listed above shall be produced on the radiograph by the use of lead numbers as described. The fabricator’s shop order number shall be placed on the radiograph by the use of lead numbers.
NOTE: Grease pencils and similar materials shall not be used to mark on radiographs. No identifying mark or notation shall be placed on a radiograph by any procedure that might interfere with the interpretation of the radiograph without prior approval of the DCES.

1604.6 Weld Identification. Individual welds are identified on the film and in the radiographic inspection report based upon weld numbers assigned prior to radiography by numbering the web and flange welds from left to right beginning from the marked end of the erection piece as shown on the shop drawing.

Each weld joint shall be permanently die stamped with the identifying erection mark, weld number, piece mark when required, and location letters required by this specification as shown in Figure 1604.6.

The die stamped numbers and letters shall be 3/8 inch to 1/2 inch high. Dies shall be lightly struck to produce the minimum impression that can be clearly seen in the absence of paint and mill scale. Low stress dies, i.e., dies manufactured to produce impressions that are rounded at the bottom of the impression rather than sharp edged, shall be used.

Lead location letters and weld numbers used to permanently identify the radiographs shall be placed directly over the impressions die stamped in the steel prior to radiography. Spacing shall be somewhat random. Templates shall not be used. In general, when radiographs are viewed in register, only those films representing the same joint should have the location letters perfectly superimposed.

Care should be taken to insure that the die stamped impressions are not lost during any repair welding or surface preparation that follows radiography. To help insure that the exact center of weld is not lost during the work, at least two center punch marks should be placed 1.00 foot from the center of the weld. These marks may be placed on one or both sides of the weld with one impression 2 inches to 3 inches from each end of the joint.

FIGURE 1604.6 – PERMANENT IDENTIFICATION OF BUTT JOINTS
1605. EXAMINATION, REPORT, AND DISPOSITION OF RADIOGRAPHS

1605.1 General. The contractor shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H&D density of 4.0. Film review shall be done in an area of subdued light.

1605.2 Standards of Acceptance. Welds subject to radiographic inspection shall have no cracks regardless of the direction of stress or type of structure. Porosity or fusion type discontinuities shall be evaluated by the following criteria.

1605.2.1 Tension Welds in Bridges. The greatest dimension of any porosity or fusion type discontinuity that is 1/16 inch or larger in greatest dimension shall not exceed the size, “B-Dimension of Discontinuity” indicated in Figure 1605a for the effective throat thickness or weld size inspected. The distance from any porosity or fusion type discontinuity described above to another such discontinuity, to an edge, or to any intersecting weld shall not be less than “C-Minimum Clearance”, for the size of discontinuity under examination. When two discontinuities can be measured as a single discontinuity from the extreme limits of the two discontinuities, including the space between them, and the combined length of discontinuity does not exceed the size, “B-Dimension of Discontinuity”, for the effective throat thickness or weld size inspected, no repair shall be required.

The limitations given by Figure 1605a for a 1 1/2 inch joint or weld throat thickness shall apply to all joints or weld throats of greater thickness. Unless otherwise restricted, the sum of the greatest dimension of porosity and fusion type discontinuities less than 1/16 inch in greatest dimension shall not exceed 3/8 inch in any linear inch of weld.

1605.2.2 Compression and Shear Welds in Bridges. The greatest dimension of any porosity or fusion type discontinuity that is 1/8 inch or larger in greatest dimension shall not exceed the size, “B-Dimension of Discontinuity”, indicated in Figure 1605b for the effective throat thickness or weld size inspected. The distance from any porosity or fusion type discontinuity described above to another such discontinuity, to an edge, or to any intersecting weld shall not be less than “C-Minimum Clearance”, for the size of discontinuity under examination. When two such discontinuities can be measured as a single discontinuity from the extreme limits of the two discontinuities, including the space between them, and the combined length of discontinuity does not exceed the size, “B-Dimension of Discontinuity”, for the effective throat thickness or weld size inspected, no repairs shall be required.

The limitations given by Figure 1605b for 1-1/2 inch joint or weld throat thickness shall apply to all joints or weld throats of greater thickness.

Unless otherwise restricted, the sum of the greatest dimension of porosity and fusion type discontinuities less than 1/16 inch in greatest dimension shall not exceed 3/8 inch in any linear inch of weld.

1605.2.3 Welds in Buildings. Porosity or fusion type discontinuities having a greatest dimension of 3/32 inch or greater shall be unacceptable if they exceed the following limits:

a) The greatest dimension of the discontinuity is larger than 2/3 of the effective throat thickness or 2/3 the weld size or 3/4 inch.

b) The discontinuity is closer than three times its greatest dimension to the end of a groove weld subject to tension.

c) A group of such discontinuities in line when:

1) The sum of the greatest dimensions of all such discontinuities is larger than the effective joint thickness or weld size in any length of six times the effective joint thickness.
or weld size. When the length of the weld being examined is less than six times the effective thickness or weld size, the permissible sum of the greatest dimensions shall be proportionally less than the effective throat thickness or weld size.

2) The space between two such discontinuities which are adjacent is less than three times the greatest dimension of the larger of the discontinuities in the pair being considered. When two such discontinuities can be measured as a single discontinuity from the extreme limits of the two discontinuities, including the space between them, and the combined discontinuity is still accepted under the provisions specified above, no repair shall be required.

d) Independent of the requirements of the above paragraphs, discontinuities having a greatest dimension of less than 3/32 inch are considered unacceptable if the sum of their greatest dimensions exceeds 3/8 inch in any linear inch of weld.

1605.2.4 Repair of Discontinuities. Welds shown by radiographic testing to have discontinuities prohibited by Articles 1605.2.1 thru 1605.2.3 shall be corrected in accordance with Article 726.

1605.3 Radiographic Reports and Submission of Radiographs. A separate radiographic report will be required for each erection piece. The radiographic report shall be prepared by the company providing radiographic inspection services and will be subject to the review and approval of the Inspector before transmittal to the DCES. Radiographic reports shall conform in general to the example shown in Figure 1605.3. The Radiographic Inspection Report described in Figure 1605.3 has been completed to show the testing and repair of a fairly complex weldment.

A schematic drawing of the complete erection piece shall appear at the top of the sheet and shall show all points of support for the member. The thickness and width or length of all joints shall be shown on the drawings. The required penetrrometer designation shall be shown adjacent to the joint. The direction of lettering of web welds shall be shown. Each individual radiograph shall be listed as accepted or rejected. All visible discontinuities shall be explained. No films shall be forwarded to the State as accepted that contain any indication that could be interpreted as a rejectible discontinuity. The explanation that this is a surface indication is only acceptable under unusual conditions. Surface marks, except the die stamp indications required by the specifications, shall be removed before the joint is radiographed.

All repair welds shall be identified in the report and in the radiograph by the letter "R" following the radiograph identification. The first repair shall be designated "R1", the second "R2", etc.

The radiographs for each erection piece and the radiographic inspection report describing the piece shall remain in the shop or at the site until the last joint to be radiographed in that member is accepted. The repair and acceptance of each joint shall be placed in logical order in the report. When the last joint in the piece is interpreted to be acceptable by the radiographer representing the fabricator, the film and report for that joint shall be submitted to the Inspector for review as required for each day's radiography.

When the Inspector accepts this final joint, one radiograph for each joint represented in the erection piece shall be presented to the Inspector with two copies of the completed radiographic inspection report for submission to the DCES. If the fabricator prefers to mail the radiographs and reports directly to the State after approval by the Inspector, this procedure is acceptable. Films and reports are to be forwarded to the DCES not later than two business days following the acceptance of the last joint in the piece.

The radiographic inspection report for the last erection piece requiring radiography on each shop order shall be clearly identified as the final report for that shop order.

The State will endeavor to review radiographs promptly as they are received. The State's review and disposition of radiographs and radiographic inspection reports is final. The DCES may reject
radiographs and/or reports that have previously been accepted by a radiographic inspection company and approved by an Inspector representing the State. The State assumes no responsibility for the improper interpretation of radiographs or reports by others. Prompt review by the State is designed to prevent the discovery of defects after the steel has been shipped from the plant. However, should the steel be shipped and erected prior to the discovery of rejectable defects, all costs associated with the repair of such defects shall be the responsibility of the Contractor.

The final review provided by the State is designed to monitor the effectiveness of the work performed by the Contractor, radiographer and the shop inspector. The State does not issue letters of acceptance. Radiographs may be considered acceptable unless otherwise notified by the State.

The Contractor (Fabricator) and the Inspector will be notified by mail of all radiographs found unacceptable by the State. Unacceptable radiographs will be retained by the State, together with all subsequent repair radiographs. Radiographs required as a result of films or welds rejected by the DCES shall be submitted separate from other radiographs, and shall be accompanied by a letter that answers all questions raised in the State rejection notice.
I. To determine the maximum size of discontinuity permitted in any one joint or weld throat thickness:
   Project (A) horizontally to (B)

II. To determine the minimum clearance allowed between edges of discontinuities of any size:
   Project (B) vertically to (C)

*Maximum discontinuity size shall be less than 1/16 inch in this area. Sum of discontinuities shall not exceed 3/16 inch within this distance from the edge or to any intersecting weld.

**FIGURE 1605a – LIMITATIONS OF POROSITY AND FUSION TYPE DISCONTINUITIES IN TENSION WELDS—BRIDGES**
I. To determine the maximum size of discontinuity permitted in any joint or weld throat thickness:
   Project (A) horizontally to (B)

II. To determine the minimum clearance allowed between edges of discontinuities of any size:
    Project (B) vertically to (C)

---

C - Minimum Clearance Measured Along the Longitudinal Axis of the Weld Between Edges of Porosity or Fusion-Type Discontinuities (inches)
   (Larger or Adjacent Discontinuities Governs)

*The maximum size of discontinuities located within this distance from an edge or intersection of a weld shall be 1/8 inch, but a 1/8 inch discontinuity must be 1/4 inch or more away from the edge or intersection. The sum of discontinuities equal to or less than 1/8 inch in size and located within this distance from the edge or intersection shall not exceed 3/16 inch. Discontinuities 1/16 inch to less than 1/8 inch will not be restricted in other locations, unless they are separated by less than 2L (L being the length of the larger discontinuity) in which case the defects shall be measured as one length equal to the total length of the discontinuities and spaces and evaluated by this Figure.

FIGURE 1605b - LIMITATION OF POROSITY AND FUSION TYPE DISCONTINUITIES IN COMPRESSION WELDS–BRIDGES
WELD LOCATION AND IDENTIFICATION SKETCH

<table>
<thead>
<tr>
<th>DATE</th>
<th>WELD IDENTIFICATION</th>
<th>AREA</th>
<th>INTERP. ACC.</th>
<th>REPAIRS ACC.</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
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<td>TF1</td>
<td>A-B</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>&quot;</td>
<td>B-C</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-2-81</td>
<td>TF2</td>
<td>A-B</td>
<td>X</td>
<td></td>
<td>Slag - 1&quot; from &quot;A&quot; edge</td>
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<tr>
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<td>&quot;</td>
<td>B-C</td>
<td>X</td>
<td></td>
<td></td>
</tr>
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<td>A-B</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>&quot;</td>
<td>B-C</td>
<td>X</td>
<td></td>
<td>Porosity - Edge of plate</td>
</tr>
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<td>A-B</td>
<td>X</td>
<td></td>
<td>Slag - 1&quot; from &quot;A&quot; within code</td>
</tr>
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<td>TF2-R1</td>
<td>A-B</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-4-81</td>
<td>TF3-R1</td>
<td>B-C</td>
<td>X</td>
<td></td>
<td>Porosity - Edge of plate</td>
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<td>TF3-R2</td>
<td>B-C</td>
<td>X</td>
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<td>A-B</td>
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</tbody>
</table>

Radiographer: ____________________________ Interpreter: ____________________________
QA Inspector: ____________________________ Date of Final Approval: ____________________________

FIGURE 1605.3 - SAMPLE RADIOGRAPHIC INSPECTION REPORT.
SECTION 17
ULTRASONIC TESTING

1701. GENERAL

The procedures and standards set forth in this Section shall govern the ultrasonic testing of groove welds between the thicknesses of 5/16 and 8* inches, inclusive, when such testing is required by the Contract Documents. Provision is also made for base metal soundness tests using straight beam search units.

Variations in testing procedures, equipment and acceptances standards not included in this Section may only be used with the approval of the DCES. Such variations include other thicknesses, weld geometries, search unit (transducer) sizes, frequencies, couplant, etc.

Electrogas and Electroslag welds shall be subject to radiographic inspection in addition to the ultrasonic tests required by the Contract Documents.

1702. EXTENT OF TESTING

Testing shall be performed where and as required by the Contract Documents.

1703. PERSONNEL QUALIFICATION

Personnel performing ultrasonic testing shall be qualified by written and performance tests administered by the State unless otherwise approved by the DCES.

1704. ULTRASONIC EQUIPMENT

1704.1 General. The ultrasonic test instrument shall be the pulse echo type. It shall generate, receive, and present on a cathode ray tube (CRT) screen pulses in the frequency range from one to six megahertz (MHz). The presentation on the CRT screen shall be the “video” type, characterized by a clean, crisp trace.

Test instruments shall include internal stabilization so that after warm-up, no variation in response greater than ± 1 dB occurs with a supply voltage change of 15 percent nominal or, in the case of battery charge, operating life. There shall be an alarm or meter to signal a drop in battery voltage prior to instrument shutoff due to battery exhaustion.

The test instrument shall have a calibrated gain control (attenuator) adjustable in discrete 1 or 2 db steps over a range of at least 60 db. The accuracy of the gain control settings shall be within plus or minus 1 db.

The dynamic range of the instrument’s CRT display shall be such that a difference of 1 db of amplitude can be easily detected on the CRT.

1704.2 Straight Beam Search Units. Straight beam (longitudinal wave) search unit transducers shall have an active area of not less than 1/2 square inch nor more than 1 square inch. The transducer shall be round or square. Transducer frequency shall be between 2 to 2.5 MHz. Transducers shall be capable of resolving the three reflections as described in Article 1711.1.

*In bridge construction, this specification only provides for testing in thicknesses of 5/16 to 6 inches inclusive. Ultrasonic testing of welds in bridges, where the thickness exceeds 6 inches, will be subject to the provisions of a separate individual job specification.
1704.3 Angle Beam Search Units. Angle beam (shear wave) search units shall consist of a transducer and an angle wedge. The unit may be comprised of two separate elements or may be an integral unit. The transducer frequency shall be between 2 and 2.5 MHz. The transducer crystal shall be square or rectangular in shape and may vary from 5/8 to 1 inch in width and from 5/8 to 13/16 inch in height as described in Figure 1704.3a. The ratio of width to height shall be between 1.2 : 1.0 and 1.0 : 1.0, except that 1 inch wide by 1/2 inch high transducers shall be permitted.

The search unit shall produce a sound beam in the material being tested within plus or minus 2 degrees of the following proper angles: 70 degrees, 60 degrees, or 45 degrees, as described in Article 1711.2b.

Each search unit shall be marked to clearly indicate the frequency of the transducer, nominal angle of refraction, and index point. The index point location procedure is described in Article 1711.2a.

Maximum allowable internal reflections from the search unit shall be as described in Article 1712.3.

The dimensions of the search unit shall be such that the distance from the leading edge of the search unit to the index line shall not exceed 1 inch. The qualification procedure using the IIW reference block shall be in accordance with Article 1711.2f and as shown in Figure 1704.3b.

The combination of search unit and instrument shall resolve three holes in the resolution test block shown in Figure 1705a. The search unit position is described in Article 1711.2e.

![Diagram of Transducer Crystal](image_url)
1705. **REFERENCE STANDARDS**

The International Institute of Welding (IIW) ultrasonic reference block, shown in Figure 1705a, shall be the standard used for both distance and sensitivity calibration. More portable reference blocks of other designs may be used provided they meet the requirements of this specification and are referenced back to the IIW block. Approved designs are shown in Figure 1705b. See Figure 1711 for applications.

Differences between alternate calibration blocks and the IIW block shall be accounted for in determining the Reference Level and Defect Rating.

The use of a "corner" reflector for calibration purposes is prohibited.
U.S. Customary dimensions (inches)

SI Dimensions (mm)

Notes:
1. All dimensions shown shall be accurate to within ±0.005 inches.
2. Surfaces that transmit or reflect sound shall be machined to produce a surface roughness not greater than 125 microinches.
3. All material shall be ASTM A36 or acoustically equivalent.
4. All holes shall have a smooth internal finish and shall be drilled at 90 degrees to the material surface.
5. Degree lines and identification markings shall be indented into the material surface so that permanent orientation can be maintained.
6. Other IIW approved reference blocks with slightly different dimensions or distance calibration slot features are permissible.

FIGURE 1705a – INTERNATIONAL INSTITUTE OF WELDING (IIW) ULTRASONIC REFERENCE BLOCKS
Type DSC – Distance and sensitivity reference block

Type DS - Distance and sensitivity reference block

Type DC – Distance reference block

FIGURE 1705b – OTHER REFERENCE BLOCKS
ALL DIMENSIONS SHOWN SHALL BE ACCURATE TO WITHIN ±0.005 INCHES.
1. Surfaces that transmit or reflect sound shall be machined to produce a surface roughness not greater than 125 microinches.
2. All material shall be ASTM A36 or acoustically equivalent.
3. All holes shall have a smooth internal finish and shall be drilled at 90 degrees to the material surface.
4. Degree lines and identification markings shall be indented in the material surface so that permanent orientation can be maintained.
5. Other IIW approved reference blocks with slightly different dimensions or distance calibration slot features are permissible.

FIGURE 1705b (continued) – OTHER REFERENCE BLOCKS
1706. EQUIPMENT QUALIFICATION

1706.1 Horizontal Linearity. The horizontal linearity of the test instrument shall be requalified after each 40 hours of instrument use in each of the distance ranges that the instrument will be used. The qualification procedure shall be in accordance with Article 1712.1.

1706.2 Calibrated Gain Control. The instrument’s gain control (attenuator) shall meet the requirements of Article 1704.1 and shall be checked for correct calibration at two month intervals in accordance with AWS D1.1.

1706.3 Certification. Each ultrasonic unit shall be certified for general operational performance at a minimum time interval of 12 months with a method approved by the instrument manufacturer.

1706.4 Internal Reflections. Maximum internal reflections from each search unit shall be verified at a maximum time interval of 40 hours of instrument use in accordance with Article 1712.3.

1706.5 Search Units. With the use of an approved calibration block, each angle beam search unit shall be checked after each eight hours of use to determine that the contact face is flat, that the sound entry point is correct, and that the beam angle is within the permitted plus or minus 2 degrees tolerance in accordance with Article 1711.2a. Search units which do not meet these requirements shall be corrected or replaced.

1707. CALIBRATION FOR TESTING

1707.1 General. Calibration for sensitivity and horizontal sweep (distance) shall be made by the ultrasonic operator just prior to and at the location of testing of each weld. All calibrations and tests shall be made with the reject (clipping or suppression) control turned off. Recalibration shall be made after a change of operators, each 30 minute maximum time interval, or when the electrical circuitry is disturbed in any way which includes the following:

- a) Transducer change
- b) Battery change
- c) Electrical outlet change
- d) Coaxial cable change

Ultrasonic test instruments equipped to produce more than one signal intensity (pulse energy) shall be calibrated and operated at the lowest setting (Pulse Energy 1) unless otherwise stated in the Ultrasonic Test Report and approved by the DCES.

The sound path distance shall be measured as the distance to the point where the left side of the trace deflection breaks the base line.

1707.2 Calibration for Straight Beam Testing. Calibration for straight beam testing shall be performed as follows:

- a) Horizontal Sweep. The horizontal sweep shall be adjusted on an approved calibration block to represent the equivalent of at least two plate thicknesses on the CRT screen. The search unit position is described in Article 1711.1
- b) Sensitivity. The sensitivity shall be adjusted on the base metal at a location free of indications so that the first back reflection from the far side of the plate will be 50 to 75% of the full screen height.
1707.3 Calibration for Angle Beam Testing. Calibration for angle beam testing shall be performed as follows:

a) Horizontal Sweep. The horizontal sweep shall be adjusted on an approved calibration block to represent the actual sound path distance by using acceptable distance calibration blocks shown in figures 1705a and 1705b. The distance calibration shall be made using either the 5 inch scale or 10 inch scale on the CRT screen, whichever is appropriate, unless joint configuration or thickness prevents full examination of the weld at either of these settings, in which case the distance calibration shall be made using the 15 or 20 inch scale, as required. The search unit position is described in Article 1711.2c.

b) Sensitivity. The sensitivity shall be adjusted by the use of the gain control (attenuator) so that a horizontal reference level trace deflection results on the CRT screen from the maximum indication of the 0.06 inch diameter hole in the IFW block or from the equivalent reference reflector in other acceptable calibration blocks. The search unit position is described in Article 1711.2d. This basic sensitivity then becomes the zero reference level for discontinuity evaluation, and shall be recorded on the ultrasonic test reports under “Reference Level”, “b”, Figure 1709.

1708. TESTING PROCEDURES

1708.1 General. A line shall be marked on Face A of the weldment representing the X axis of the weld joint. The X axis shall be located as described in Table 1700A.

A “Y” accompanied with a weld identification number shall be clearly marked on Face A of the base metal adjacent to the weld at the left end or top of each weld that is ultrasonically tested.

This marking is used for the following purposes:

a) Weld identification.
b) Identification of Face A.
c) Distance measurements and direction (+ or -) from the X axis.
d) Location measurement from weld ends or edges.

1708.2 Cleaning. All surfaces to which a search unit is applied shall be free of weld spatter, dirt, grease, oil (other than that used as a couplant), paint, and loose scale and shall have a contour permitting intimate coupling.

1708.3 Couplant. A couplant shall be used between the search unit and the test material. The couplant shall be either glycerin or cellulose gum and water mixture of suitable consistency. A wetting agent may be added if needed. Light machine oil may be used for couplant on calibration blocks. Tests shall verify that the couplant used during calibration produces the same sensitivity as the couplant used during testing. Any variation shall be compensated for as approved by the DCEs.

1708.4 Testing with Straight Beam Search Units.

a) Methods of Tests.

1) Amplitude Method. The instrument shall be adjusted as described in Article 1707.2. The amplitude of the first back reflection shall be recorded as the reference level. No further adjustments of the instrument will be made. All discontinuities which produce an indication on the screen which equals or exceeds the reference level indication shall be rejected.

2) Total Loss of Back Reflection Method. The instrument shall be adjusted as described in Article 1707.2. With no further adjustment to the instrument, the specified area of the base metal shall be searched for laminations. Any area found to exhibit total loss of back
reflection shall be rejected. When the defect is located at the mid-thickness of the plate, total loss of back reflection shall be indicated on the screen when the multiple echoes from the defect are found to have a normal decay pattern.

b) Lamination Test Prior to Weld Test. The entire base metal through which ultrasound must travel to test the weld shall be tested for laminar reflectors with a straight beam search unit conforming to the requirements of Article 1704.2 using the Amplitude Method. If any area of base metal is considered rejectable by this test and is located in a position that would interfere with the normal weld scanning procedure, the following alternate weld scanning procedure shall be used:

1) Determine the area of the laminar reflector, its depth from the surface, and record the data in the ultrasonic test report.
2) Grind both faces of the weld flush if necessary to attain full ultrasonic coverage.
3) Using the applicable scanning pattern shown in Figure 1714, examine the inaccessible part of the weld by testing from both faces in order to attain full weld evaluation.

c) Laminations Adjacent to Tension Groove Welds. If laminar defects are found by visual or nondestructive tests adjacent to tension groove welds, the base metal shall be tested for soundness in accordance with the following procedure:

1) The end 6 inches of the plate or shape adjacent to the tension groove weld shall be divided into two equal areas for testing. Each area shall be 3 inches wide in the direction of the length of the plate or shape, and shall extend for the full width of the section.
2) The instrument shall be calibrated in accordance with Article 1707.2 using a straight beam search unit conforming to the requirements of Article 1704.2. The scanning patterns shall overlap to insure 100% inspection. The end 6 inches of the plate or shape shall be tested by the Total Loss of Back Reflection Method. Any lamination found to be rejectable by this test shall cause the rejection of the steel for use adjacent to a tension groove weld.
3) If rejectable defects are not discovered by the Total Loss of Back Reflection Method, the end 3 inch wide strip adjacent to the tension groove weld shall be retested using the Amplitude Method. Any lamination found rejectable by this test shall cause rejection of the steel for use adjacent to a tension groove weld.
4) The steel shall be rejected for use adjacent to tension groove welds if the results of the magnetic particle inspection reveals defects in excess of the limits described in Article 505.2.

1708.5 Testing With Angle Beam Search Units.

a) General. Welds shall be tested using an angle beam search unit conforming to the requirements of Article 1704.3 with the instrument calibrated in accordance with Article 1707.3 using the angle as shown in Table 1700A. Following calibration and during testing, the only instrument adjustment permitted is the sensitivity level adjustment with the calibrated gain control or attenuator. Sensitivity shall be increased from the reference level for weld scanning in accordance with Table 1700B for Bridges and Table 1700C for Buildings.

b) Testing Angle and Scanning Procedure. The testing angle and scanning procedure shall be in accordance with the requirements of Table 1700A. Note that Table 1700A requires testing from Faces A and B under certain conditions. All butt welds shall be tested from each side of the weld axis. Corner and "T" welds shall be primarily tested from one side of the weld axis only. All welds shall be tested using the applicable scanning pattern or patterns shown in Figure 1714 as necessary to detect both longitudinal and transverse flaws.

c) Indication Level. When a discontinuity indication appears on the screen, the maximum attainable indication from the discontinuity shall be adjusted to produce a horizontal reference level trace deflection on the CRT screen. This adjustment shall be made with the calibrated
gain control or attenuator, and the instrument reading in decibels shall be used as the Indication Level, “a,” for calculating the Indication Rating, “d,” as shown on the test report.

d) Attenuation Factor. The Attenuation Factor, “c,” on the test report is attained by subtracting 1 inch from the sound path distance and multiplying the remainder by two. This factor shall be rounded out to the nearest db value. Fractional values less than 1/2 db shall be reduced to the lower db level and those of 1/2 or greater increased to the higher level.

e) Indication Rating. The Indication Rating “d” in the UT Report represents the algebraic difference in decibels between the Indication Level and the Reference Level with correction for attenuation as indicated in the following expressions:

\[
\begin{align*}
\text{Instruments with gain in db:} & \quad a - b - c = d \\
\text{Instruments with attenuation in db:} & \quad b - a - c = d
\end{align*}
\]

f) Defect Length. The length of flaws shall be determined in accordance with the procedure described in Article 1713.2.

\[
\begin{align*}
\text{Defect Location.} & \quad \text{Each rejectable discontinuity shall be indicated on the weld by a mark directly over the discontinuity for its entire length. The depth from the surface and type of discontinuity shall be noted on nearby base metal.}
\end{align*}
\]

h) Acceptance Criteria. Each weld discontinuity shall be accepted or rejected on the basis of its indication rating and its length, in accordance with Table 1700B for bridges, or Table 1700C for buildings, whichever is applicable.

i) Repairs. Welds found unacceptable by ultrasonic testing shall be repaired by methods permitted by Article 726. Repaired areas shall be retested ultrasonically.

1709. PREPARATION AND DISPOSITION OF REPORTS

A report form which clearly identifies the work and the area of inspection shall be completed by the ultrasonic technician at the time of inspection. The report form for welds shall contain sufficient information to identify the weld, the inspector (signature), and the disposition of the weld. An example of such a form is shown in Figure 1709.

All rejectable discontinuities shall be recorded in the test report. Other discontinuities shall be recorded if the Indication Rating is +10db or less for bridges, or +6db or less for buildings. Repaired and retested welds shall be recorded on the original or continuation of the original report form.

A full set of completed report forms of welds subject to ultrasonic testing by the Contractor, including any that show unacceptable quality prior to repair, shall be delivered to the State upon completion of the work. The contractor’s obligation to retain ultrasonic reports shall cease upon delivery of this full set of reports to the State.

1710. WITNESSING OF ULTRASONIC TESTS

All ultrasonic tests required by the Contract Documents that are not performed by State forces or by an inspection agency under contract to the State shall be witnessed by a representative of the State.
ULTRASONIC INSPECTION REPORT

Report __________________
Sheet ____________________

Contract ________________ Project Identification No. ________________
Structure __________________________ County __________________________
Fabricating Shop __________________________ Cont. No. __________________________
Shop __________________________ Dwg. No. __________________________

Reported to: New York State Department of Transportation

WELD LOCATION AND IDENTIFICATION SKETCH

Piece Mark

<table>
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<tr>
<th>Date</th>
<th>Indication Number</th>
<th>Weld Identification</th>
<th>Transducer Angle</th>
<th>Reflected From Face</th>
<th>Log</th>
<th>Decibels</th>
<th>Discontinuity</th>
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<td>a</td>
<td>b</td>
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</tbody>
</table>

Technician: __________________________________________ Inspection Agency: __________________________________________

NYSDOT Certificate No. __________________________ Witnessed by: __________________________________________

FIGURE 1709 - SAMPLE ULTRASONIC INSPECTION REPORT
CALIBRATION OF THE ULTRASONIC UNIT WITH THE IIW OR OTHER APPROVED REFERENCE BLOCKS (See Figure 1711)

1711.1 Longitudinal Mode.

a) Distance Calibration.
   1) Set the transducer in position G on the IIW block, position H on the DC block, or position M on the DSC block.
   2) Adjust instrument to produce indications at 1 inch (25.4 mm), 2 inches (50.8 mm), 3 inches (76.2 mm), 4 inches (101.4 mm), etc., on the CRT.

b) Amplitude.
   1) Set the transducer in position G on the IIW block, position H on the DC block, or position M on the DSC block, or as described in Article 1707.2.
   2) Adjust the gain until the maximized indication from the first back reflection attains 50 to 75 percent screen height.

c) Resolution. Set the transducer in position F on the IIW block. Transducer and instrument should resolve all three distances.

d) Horizontal Linearity Qualification. The procedure shall be in accordance with Articles 1706.1 and 1712.1.

e) Gain Control or Attenuation Qualification. The procedure shall be in accordance with AWS D1.1.

1711.2 Shear Wave Mode (Transverse)

a) Sound Entry Point. Locate or check the transducer sound entry point (index point) by the following procedure:
   1) Set the transducer in position D on the IIW block, position J or L on the DSC block, or I on the DC block.
   2) Move the transducer until the signal from the radius is maximized. The point on the transducer which is in line with the line on the calibration block is indicative of the point of sound entry.

b) Sound Path Angle. Check or determine the transducer sound path angle by the following procedure:
   1) Set the transducer in position B on the IIW block for angles 40 degrees through 60 degrees.
   2) Set the transducer in position C on the IIW block for angles 60 degrees through 70 degrees.
   3) Set the transducer in position K on the DSC block for angles 45 degrees through 70 degrees.
   4) Set the transducer in position N on the SC block for 70 degree angle.
   5) Set the transducer in position O on the SC block for 45 degree angle.
   6) Set the transducer in position P on the SC block for 60 degree angle.
   7) Move the transducer back and forth over the line indicative of the transducer angle until the signal from the radius is maximized. Compare the sound entry point on the transducer with the angle mark on the calibration block (tolerance ±2 degrees).
c) Distance Calibration Procedure.

1) Set the transducer in position D on the IIW block for any angle.
2) Adjust the instrument to attain indications on the CRT at 4 inches (101.4 mm) and 8 inches (203.2 mm) on the Type 2 block or 9 inches (228.6 mm) on the Type 1 block.
3) Set the transducer in position J or L on the DSC block for any angle.
4) Adjust the instrument to attain indications at 1 inch (25.4 mm), 5 inches (127 mm) and 9 inches (230 mm) on the CRT in the L position.
5) Adjust the instrument to attain indications at 3 inches (76.2 mm), and 7 inches (177.8) on the CRT in the L position.
6) Set the transducer in position I on the DC block for any angle.
7) Adjust the instrument to attain indications at 1 inch (25.4 mm), 2 inches (50.8 mm), 3 inches (76.2 mm), 4 inches (101.4 mm), etc. on the CRT.

d) Amplitude or Sensitivity Calibration Procedure.

1) Set the transducer in position A on the IIW block for any angle.
2) Adjust the maximized signal from the 0.06 inch hole to attain a horizontal reference line height indication.
3) Set the transducer in position L on the DSC block for any angle.
4) Adjust the maximized signal from the 1/32 inch slot to attain a horizontal reference line height indication.
5) Set the transducer on the SC block in position N for 70 degree angle, position O for 45 degree angle, or position P for 60 degree angle.
6) Adjust the maximized signal from the 1/16 inch hole to attain a horizontal reference line height indication.
7) The decibel reading obtained in 2) shall be used as the “Reference Level” “b” reading on the Test Report sheet.

e) Resolution.

1) Set the transducer on the resolution block, position Q for 70 degree angle, position R for 60 degree angle, or position S for 45 degree angle.
2) Transducer and instrument shall resolve the three test holes, at least to the extent of distinguishing the peaks of the indications from the three holes when the instrument controls are set at normal test settings.

f) Approach Distance of Search Unit. The minimum allowable distance, X, between the toe of the search unit and the edge of IIW block shall be as follows and as described in Figure 1704.3b.

1) for 70 degrees transducer, X = 2 inches.
2) for 60 degree transducer, X = 1 7/16 inches.
3) for 45 degree transducer, X = 1 inch.
FIGURE 1711 – TRANSDUCER POSITIONS
1712. EQUIPMENT QUALIFICATION PROCEDURES

1712.1 Horizontal Linearity Procedure. Since this qualification procedure is performed with a straight beam search unit which produces a longitudinal wave with a sound velocity of almost double that of a shear wave, it is necessary to double the shear wave distance ranges to be used in applying this procedure. Example: The use of a 10 inch screen calibration in shear wave would require a 20 inch screen calibration for this qualification procedure. The following procedure shall be used for instrument certification:

1) Couple a straight beam search unit meeting the requirements of Article 1704.2 to the IIW, DSC, DC or DS block in Position G, H, M, T, or U, Figure 1711, as necessary to attain 5 back reflections in the range being certified.
2) Adjust the first and fifth back reflections to their proper locations with the use of the distance calibration and zero delay adjustments.
3) Each indication shall be adjusted to reference level with the gain or attenuation control.

Each intermediate trace deflection location shall be correct within ±2% of the screen width.

1712.2 Vertical Linearity Procedure. The vertical linearity of the test instrument shall be calibrated by a procedure approved by the DCES.

1712.3 Internal Reflections Procedure.

1) Calibrate the equipment in accordance with Article 1707.
2) Remove the search unit from the calibration block without changing any other equipment adjustments.
3) Increase the calibrated gain or attenuation 20 db more sensitive than reference level.
4) The CRT screen area beyond 1/2 inch sound path and above the reference level height shall be free of any indication.

1713. FLAW SIZE EVALUATION PROCEDURES

1713.1 Straight Beam Testing. When the discontinuity is larger than the transducer, full loss of back reflections may be produced when probing directly over the flaw. The boundaries of the discontinuity shall be determined by locating the points on the steel at the center line of the search unit where the indication amplitude drops 6 db.

The approximate size of discontinuities which are smaller than the transducer shall be determined by beginning outside the discontinuity and moving the transducer toward the area of the discontinuity until an indication on the CRT begins to form. The leading edge of the search unit at this point is indicative of the edge of the discontinuity.

The ultrasonic equipment shall be calibrated in accordance with Article 1707.2 during the above tests.

1713.2 Angle Beam Testing. The length of a discontinuity shall be determined by locating the points on the steel, projected from the centerline of the search unit, where the indication amplitude drops or raises 6 db, and measuring between these points. Contiguous discontinuities with defect ratings that vary by more than six decibels shall be recorded as separate discontinuities. The measured length of each discontinuity shall be entered under "Indication Length" on the test report, Figure 1709.

When evaluating certain large cracks or other planar discontinuities, the test instrument may respond to individual facets of the flaw rather than accurately responding to all of the reflective area within the sound beam. Flaws that are found to be acceptable in accordance with Tables 1700B and 1700C, but produce a signal response of measurable amplitude when the search unit is moved forward and backward in accordance with scanning movement B, Figure 1714, shall be rejected by the ultrasonic technician and reported to the DCES for final determination.
1714. SCANNING PATTERNS

Scanning patterns shall be as described in Figure 1714.

Notes:
1. Testing patterns are all symmetrical around the weld axis with the exception of pattern D which is conducted directly over the weld axis.
2. Testing from both sides of the weld axis is to be made wherever mechanically possible.

Plan View of Welded Plate

Scanning for Longitudinal Discontinuities.

a) Scanning Pattern A. Rotation angle \( \alpha = 10 \) degrees.
b) Scanning Pattern B. Scanning distance \( b \) shall be such that the full section of weld being tested is covered.
c) Scanning Pattern C. Progression distance \( c \) shall be approximately one-half the transducer width.

Note: Patterns A, B and C are combined into one scanning pattern.

Scanning for Transverse Discontinuities.

a) Use scanning pattern D when weld reinforcement is ground flush.
b) Use scanning pattern E when weld reinforcement is not ground flush. Scanning angle \( e = 15 \) degrees maximum.

Note: The scanning pattern is to be such that the full weld section is covered.

Electroslag or Electrogas Welds.

a) The search unit rotation angle \( e \) shall be between 45 degrees and 60 degrees.

Note: The scanning pattern shall be such that the full weld section is covered.

FIGURE 1714 – SCANNING PATTERNS
## TABLE 1700A

### PROCEDURE CHART

<table>
<thead>
<tr>
<th>Weld Type</th>
<th>Weld or Material Thickness</th>
<th>5/16 to 1/2</th>
<th>&gt;1/2 to 1</th>
<th>&gt;1 to 1 1/2</th>
<th>&gt;1 1/2 to 1 3/4</th>
<th>&gt;1 3/4 to 2 1/2</th>
<th>&gt;2 1/2 to 3 1/2</th>
<th>&gt;3 1/2 to 4 1/2</th>
<th>&gt;4 1/2 to 5</th>
<th>&gt;5 to 6 1/2</th>
<th>&gt;6 1/2 to 7</th>
<th>&gt;7</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Butt</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<td>*</td>
</tr>
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<td>Tee</td>
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<td>1a 0</td>
<td>1b 0</td>
<td>1c F</td>
<td>2 F</td>
<td>2 F</td>
<td>2 F</td>
<td>3 F</td>
<td>4 F</td>
<td>5 F</td>
<td>6 F</td>
<td>7 F</td>
<td>8 F</td>
</tr>
<tr>
<td>Corner</td>
<td></td>
<td>1d or le 0</td>
<td>1d or le 0</td>
<td>1c F or XF</td>
<td>2 F or XF</td>
<td>2 F or XF</td>
<td>2 F or XF</td>
<td>3 F or XF</td>
<td>4 F or XF</td>
<td>5 F or XF</td>
<td>6 F or XF</td>
<td>7 F</td>
<td>8 F</td>
</tr>
<tr>
<td>Electrogas &amp; Electroslag</td>
<td></td>
<td>1a and RT 0</td>
<td>1b and RT 0</td>
<td>1c and RT 0</td>
<td>2 and RT 0</td>
<td>2 and RT 0</td>
<td>2 and RT 0</td>
<td>8 and RT 0</td>
<td>8 and RT 0</td>
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<td>9 and RT 0</td>
<td>9</td>
<td>9</td>
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</tbody>
</table>

### PROCEDURE LEGEND

<table>
<thead>
<tr>
<th>Area of Weld Thickness</th>
<th>TOP QUARTER</th>
<th>MIDDLE QUARTER</th>
<th>BOTTOM QUARTER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>70° I and II</td>
<td>70° I and II</td>
<td>70° I and II</td>
</tr>
<tr>
<td>1b</td>
<td>70° I and II</td>
<td>70° I and II</td>
<td>70° I and II</td>
</tr>
<tr>
<td>1c</td>
<td>70° I and II</td>
<td>70° I</td>
<td>70° I</td>
</tr>
<tr>
<td>1d</td>
<td>70° I and II AB</td>
<td>70° I and II AB</td>
<td>70° I and II AB</td>
</tr>
<tr>
<td>1e</td>
<td>70° I, II and III</td>
<td>70° I, II and III</td>
<td>70° I, II and III</td>
</tr>
<tr>
<td>2</td>
<td>70° + 60° II</td>
<td>70° + 60° II</td>
<td>70° + 60° II</td>
</tr>
<tr>
<td>3</td>
<td>70° + 45° II</td>
<td>70° + 45° II</td>
<td>70° + 45° II</td>
</tr>
<tr>
<td>4</td>
<td>60° B</td>
<td>70°</td>
<td>60°</td>
</tr>
<tr>
<td>5</td>
<td>60° B</td>
<td>60°</td>
<td>60°</td>
</tr>
<tr>
<td>6</td>
<td>45° B</td>
<td>70°</td>
<td>45°</td>
</tr>
<tr>
<td>7</td>
<td>45° B</td>
<td>45°</td>
<td>45°</td>
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<tr>
<td>8</td>
<td>70° B</td>
<td>70° A</td>
<td>70° A</td>
</tr>
<tr>
<td>9</td>
<td>70° GA+60° B</td>
<td>70° A B</td>
<td>60° A+70° GB</td>
</tr>
</tbody>
</table>

[@] Butt
[@@] Butt
TABLE 1700A (continued)

LEGEND

X Check from Face "C"
G Grind Weld Face Flush
O Not Required
RT Radiographic Inspection
I Examine weld in Leg I
II Examine weld in Leg II
III Examine weld in Leg III
F Further evaluate fusion boundary indications with either 70°, 60° or 45° transducer, whichever sound path is nearest to being perpendicular to the suspected fusion surface.
* Required only where reference level indication of defect is noted in fusion zone while searching at scanning level with primary procedure selected from first column.
** Use 15 or 20 inch screen distance calibration (the smaller value) as necessary to permit testing of the complete weld and adjacent heat-affected zones using the search unit required by the Procedure Legend.
† Applies to single vee, double vee, single "U", double "U" and square groove welds.
‡† Applies to single bevel, double bevel, single "J" and double "J" groove welds.
"A" Face The face of the material from which the initial scanning is done.
"B" Face Opposite the "A" Face.
"C" Face The face opposite the weld on the connecting member on Tee or Corner joints.

NOTES:

1. All examinations are to be made from Face "A" except as noted in the Procedure Legend and scanned from both sides of the weld on Face "A" or Face "A" and Face "B" as indicated, where physically possible.

2. Unless otherwise indicated by the Procedure Legend, all tests are to be performed in Leg I. Leg II is specified in some cases to avoid testing in the first inch of the sound path. Leg III may only be used when required by the Procedure Legend or approved by the DCES.

3. Face "A" on both connecting members at a butt weld must lie in a single plane. Should neither Face "A" nor Face "B" of a Butt Weld lie in a single plane, the testing procedure will be subject to the approval of the DCES.

EXAMPLE: Butt Weld in 4" Material Procedure No. 4
TABLE 1700B — HIGHWAY & RAILWAY BRIDGES

Ultrasonic acceptance-rejection criteria

<table>
<thead>
<tr>
<th>Flaw severity class</th>
<th>Weld thickness and search unit angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5/16 to 3/4</td>
</tr>
<tr>
<td></td>
<td>70° 70° 70° 60° 45°</td>
</tr>
<tr>
<td>Class A</td>
<td>+10 &amp; lower</td>
</tr>
<tr>
<td>Class B</td>
<td>+11</td>
</tr>
<tr>
<td>Class C</td>
<td>+12</td>
</tr>
<tr>
<td>Class D</td>
<td>+13 &amp; up</td>
</tr>
</tbody>
</table>

NOTES:

1. Class B and C flaws shall be separated by at least 2L, L being the length of the longer flaw, except that when two or more such flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the flaw shall be considered a single acceptable flaw.
2. Class B and C flaws shall not begin at a distance less than 2L from the end of the weld or from any intersection weld, L being the flaw length.
3. Flaws detected at "scanning level" in the root face area of complete penetration double vee, double "J", double "U", and double bevel groove weld joints shall be evaluated using an indication rating 4 db more sensitive than that described in this table, i.e., add +4 db to the values in this table.

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

Class B (medium flaws)
Any indication in this category having a length greater than 3/4 inch shall be rejected.

Class C (small flaws)
Any indication in this category having a length greater than 2 inches in the middle half or 3/4 inch length in the top or bottom quarter of weld thickness shall be rejected.

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

*Flaws evaluated with 60° or 45° search units and rejected at the acceptance levels listed in the table, but which are acceptable at the minimum acceptance level listed for a 70° transducer shall also be evaluated with a 70°, 70°, & 45° or 70° & 60° search units, as necessary to evaluate the flaw with all three angles transducers. If this detailed testing reveals that the sound beam of the 60° or 45° search unit is striking the flaw at 90° ± 15° the acceptance level listed for a 70° transducer shall be used as the basis for acceptance, regardless of the angle of the search unit used to evaluate the flaw.

Scanning levels

<table>
<thead>
<tr>
<th>Sound path, inches</th>
<th>Above zero reference, db</th>
</tr>
</thead>
<tbody>
<tr>
<td>to 2 1/2</td>
<td>+20</td>
</tr>
<tr>
<td>&gt; 2 1/2 to 5</td>
<td>+25</td>
</tr>
<tr>
<td>&gt; 5 to 10</td>
<td>+35</td>
</tr>
<tr>
<td>&gt; 10 to 15</td>
<td>+45</td>
</tr>
<tr>
<td>&gt; 15 to 20</td>
<td>+55</td>
</tr>
</tbody>
</table>

201
# Ultrasonic acceptance-rejection criteria

<table>
<thead>
<tr>
<th>Flaw severity class</th>
<th>5/16 in. to 3/4 in.</th>
<th>&gt; 3/4 in. to 1 1/2</th>
<th>&gt; 1 1/2 to 2 1/2</th>
<th>&gt; 2 1/2 to 4</th>
<th>&gt; 4 to 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>+5 &amp; lower</td>
<td>+2 &amp; lower</td>
<td>-1 &amp; lower</td>
<td>+2 &amp; lower</td>
<td>-3 &amp; lower</td>
</tr>
<tr>
<td>Class B</td>
<td>+6</td>
<td>0</td>
<td>+3</td>
<td>+5</td>
<td>-2</td>
</tr>
<tr>
<td>Class C</td>
<td>+7</td>
<td>+4</td>
<td>+2</td>
<td>+5</td>
<td>0</td>
</tr>
<tr>
<td>Class D</td>
<td>+8</td>
<td>+5</td>
<td>+4</td>
<td>+7</td>
<td>+2</td>
</tr>
</tbody>
</table>

## NOTES:

1. Class B and C flaws shall be separated by at least 2L, L being the length of the longer flaw, except that when two or more such flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or C, the flaw shall be considered a single acceptable flaw.
2. Class B and C flaws shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the flaw length.
3. Flaws detected at "scanning level" in the root face area of complete penetration double Vee, double "J", double "U", and double bevel groove weld joints shall be evaluated using an indication rating 4 db more sensitive than that described in this table, i.e., add +4 db to the values in this table.
4. Electroslag or electrogas welds — Flaws detected at "scanning level" which exceed 2 inches in length shall be suspected as being piping porosity and shall be further evaluated with radiography.

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

### Class B (medium flaws)
Any indication in this category having a length greater than 3/4 inch shall be rejected.

### Class C (small flaws)
Any indication in this category having a length greater than 2 inches in the middle half or 3/4 inch length in the top or bottom quarter of weld thickness shall be rejected.

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

*Flaws evaluated with 60° or 45° search units and rejected at the acceptance levels listed in the table, but which are acceptable at the minimum acceptance level listed for a 70° transducer shall also be evaluated with a 70°, 70° & 45° or 70° & 60° search units, as necessary to evaluate the flaw with all three angles transducers. If this detailed testing reveals that the sound beam of the 60° or 45° search unit is striking the flaw at 90° ± 15° the acceptance level listed for a 70° transducer shall be used as the basis for acceptance, regardless of the angle of the search unit used to evaluate the flaw.*

## Scanning levels

<table>
<thead>
<tr>
<th>Sound path, inches</th>
<th>Above zero reference, db</th>
</tr>
</thead>
<tbody>
<tr>
<td>to 2 1/2</td>
<td>+14</td>
</tr>
<tr>
<td>&gt;2 1/2 to 5</td>
<td>+19</td>
</tr>
<tr>
<td>&gt;5 to 10</td>
<td>+29</td>
</tr>
<tr>
<td>&gt;10 to 15</td>
<td>+39</td>
</tr>
<tr>
<td>&gt;15 to 20</td>
<td>+49</td>
</tr>
</tbody>
</table>
SECTION 18
MAGNETIC PARTICLE INSPECTION

1801. GENERAL

The procedures and standards set forth in this section shall be followed whenever magnetic particle inspection is required by the Contract Documents or ordered by the DCES. All magnetic particle inspection performed by State forces, inspection agencies under contract to the State, contractors or their agents shall conform to the requirements of this Specification. Variations in testing procedures or equipment shall require approval by the DCES.

1802. TESTING PROCEDURES AND EQUIPMENT

All testing shall be performed in accordance with the provisions of ASTM Designation E709, Standard Method for Dry Powder Magnetic Particle Inspection, except as modified herein. Magnetization of the part to be inspected shall be accomplished using either the prod or yoke technique, as determined by the DCES.

In the prod technique, a localized circular magnetic field is established in the part as a result of passing an electric current between the prods. In the yoke technique, a longitudinal magnetic field is established in the part as a result of placing the poles in contact with the part and energizing the coil of the electromagnet. Only ferromagnetic materials can be tested by these techniques.

1802.1 Prod Technique. When the prod technique is required by the DCES, the following provisions shall apply.

The magnetizing source shall produce direct current or rectified half wave direct current. Alternating current shall not be permitted as a magnetizing source. The minimum magnetizing current shall be 400 amperes and there shall be not less than 100 amperes per inch of prod spacing. Higher testing currents approaching a current density of 150 amperes per inch of prod spacing are preferred. Arcing must be controlled by proper testing techniques.

When the prod technique is used to perform magnetic particle inspection on ASTM A588 steel or any steel with a minimum specified yield stress of 50 ksi or greater, aluminum prods shall be used on the test equipment. Copper prods shall not be used on such steels.

1802.2 Yoke Technique. When the yoke technique is required, the electromagnet shall operate on a 110VAC, 60 cycle power supply, and shall produce a pulsed DC magnetic field. The magnetic field strength shall be such that a minimum 40 pound lifting force is produced at the maximum pole spacing to be used. An alternating current magnetic field will not be permitted.

1802.3 Prod or Pole Positioning. The prods or poles shall be oriented in two directions approximately 90 degrees apart at each inspection point, to detect both longitudinal and transverse discontinuities. The prod or pole positions shall overlap as the testing progresses to insure 100% inspection of the areas to be tested. Discontinuities are detected best when their major axis is normal to the magnetic lines of force. Therefore, the prod technique is most sensitive to discontinuities whose major axis is parallel to a line drawn between the two prods, whereas the yoke technique is most sensitive to discontinuities whose major axis is normal to a line drawn between the two poles.

1802.4 Surface Condition. The surface being inspected shall be clean and dry and free of oil, rust, loose mill scale, paint, and other coatings. Grinding may be required to provide proper electrical contact for the prod technique and to remove surface irregularities that interfere with interpretation of test indications regardless of the technique used.
1803. WITNESSING OF MAGNETIC PARTICLE TESTS

All magnetic particle inspection that is not performed by State forces or an inspection agency under contract to the State shall be witnessed by a representative of the State.

1804. PREPARATION AND DISPOSITION OF REPORTS

The test technician shall prepare and sign a test report for each erection piece subject to inspection. The report shall contain sufficient information to identify the extent of the weld or base metal inspected, the name of the technician, and the name of the State representative witnessing the work, if required by Article 1803. All indications of discontinuities shall be recorded in the test report. The method of test, contract number, project identification number (PIN), county, date of test, fabricator's shop order number, and the erection mark shall be listed on each report.

A complete set of test reports shall be delivered to the DCES upon completion of the work.

1805. STANDARDS OF ACCEPTANCE

Welds subject to magnetic particle inspection shall have no cracks. Porosity and fusion type defects shall be evaluated in accordance with the provisions of Articles 724 or 725 as applicable.
SECTION 19
DYE PENETRANT INSPECTION

1901. GENERAL

The procedures and standards set forth in this Section shall be used whenever dye penetrant inspection is required by the Contract Documents or ordered by the Engineer under the provisions of these Specifications. This inspection method is limited to the detection of discontinuities that are open to the surface. Penetrant tests shall only be performed when the steel is between the temperatures of 40°F to 110°F.

1902. TESTING PROCEDURES

All testing shall be performed in accordance with the provisions of ASTM Designation E165, Method B, Visible Solvent, Removable Penetrant.

The surface being inspected shall be cleaned in accordance with ASTM Designation E165. Surface irregularities that interfere with the interpretation of test results shall be removed by grinding. All welds shall be smoothed by grinding prior to testing.

1903. WITNESSING OF DYE PENETRANT TESTS

All dye penetrant inspection that is not performed by State employees or an inspection agency under contract to the State shall be witnessed by a representative of the State.

1904. PREPARATION AND DISPOSITION OF REPORTS

A test report shall be prepared for each erection piece subject to inspection. The report shall be prepared by the technician performing the test. The report shall contain sufficient information to identify the extent of the weld or base metal inspected, the name of the technician (signature), and the name of the State representative witnessing the work, if required by Article 1903. All indications of discontinuities shall be recorded in the test report. The contract number, project identification number (PIN), county, and date of test shall be listed on each report together with the fabricator's shop order number and the erection mark on the piece.

A complete set of test reports shall be delivered to the DCES upon completion of the work.

1905. STANDARDS OF ACCEPTANCE

Welds subject to dye penetrant inspection shall have no cracks. Porosity and fusion type defects shall be evaluated in accordance with the provisions of Articles 724 or 725 as applicable.
APPENDIX A

REPAIR OF UNACCEPTABLE FASTENER HOLES

A1. GENERAL

When mislocated or unacceptable holes are made in base metal, the DCES shall be notified and shall
determine if repair will be permitted or replacement of the piece is required.

When the DCES determines that repair of the piece is permitted, the Contractor (Fabricator) shall submit
a written repair proposal with drawings in accordance with the provisions of Article 205. The DCES shall
review and approve the repair procedure before any work is done.

A2. PREPARATION OF HOLES FOR REPAIR

When a welded repair is approved by the DCES, the holes shall be prepared for welding in the following
manner:

1 ) Insert a tightly fitted steel "slug" into the hole, to one-half the hole depth. The slug shall be of
the same material as the base metal.

2 ) Beginning on the unfilled side of the hole, prepare an elongated, boat-shaped cavity down to and
slightly into the slug. When repair welding is to be performed in the flat position, the sides of the
cavity should slope back 10° minimum and the ends should slope back 45° minimum. The cavity
may be made by grinding or air carbon arc gouging followed by grinding.

3 ) Completely fill the cavity with weld metal using an approved weld process and employing a str-
inger bead welding technique. Weaving or plug welding will not be permitted.

4 ) Backgouge to sound weld metal and prepare a similar cavity on the other side by the same
method. Backgouging shall completely remove all remnants of the slug and extend into sound
weld and base metal.

5 ) Fill this cavity with weld metal using the procedure described in 3).

When two or more adjacent holes are to be repair welded, the repair cavity shall combine holes or repair
holes singly as determined by the DCES.

When a piece with unacceptable holes is fixed in the vertical position, the repair shall be made so that the
long axis of the cavity is horizontal and the top of the cavity shall slope upwards at 45° minimum.

A3. WELDING

Repair welding shall be done by processes and procedures which are approved by the DCES. Only the
stringer bead technique will be approved. All welding shall be performed by welders or welding operators
qualified in accordance with Section 8, Qualification. All welding shall utilize a minimum preheat and in-
terpass temperature of 250°F. The DCES may specify higher preheat and interpass temperature and post
heat as necessary.

Repair welding of unacceptable holes in Fracture Critical Members shall be considered Category III
repairs and all provisions of the Fracture Control Plan shall apply.
A4. NONDESTRUCTIVE TESTING

All repair welds shall be ground flush and smooth as described in Article 723 prior to nondestructive testing.

Holes which are repair welded in main stress carrying material shall be radiographed and evaluated in accordance with Section 16 and Figure 1605a of this Manual.

Holes which are repair welded in secondary members shall be either radiographed or ultrasonic tested by a State certified technician. The choice of testing method and weld quality standard shall be as ordered by the DCES.

Repair welds in fracture critical members shall be radiographed and ultrasonic tested as required for FCM's.

If a new hole is to be made in close proximity to a repaired hole, the nondestructive testing shall be performed and the repair approved before the new hole is drilled.
NOTE: The crack was discovered during radiographic inspection. The extent and shape of the crack as shown in Detail A was determined by magnetic particle and ultrasonic testing in accordance with the provisions of the New York State Steel Construction Manual (SCM).

CATEGORY III REPAIR PROCEDURE

1) Preheat the work area of the flange plate to 150°F minimum. After preheating, air carbon arc gouge as shown in Detail B to remove the crack.

2) Grind the surface of the excavation to remove carbon arc pick-up and irregularities.

3) Perform magnetic particle inspection of the excavated area to inspect for removal of the crack.

4) Preheat the flange repair area to 150°F minimum and maintain. Preheat, interpass temperature maintenance, and postheat shall be continuous operations.

5) Weld the excavation using the submerged arc process in accordance with the provisions of the approved welding procedure specification.

6) Remove the run-off tab and grind the repaired area flush and smooth.

7) Increase the heating temperature to between 400°F and 500°F. Maintain the preheat temperature for 15 hours minimum. After this time period, reduce and then remove the heat source and cool the weldment so that the repair weld will cool slowly to ambient temperature.

8) Radiograph the repaired area.

9) Perform ultrasonic inspection after the repaired area has cooled to ambient temperature for at least 24 hours.

10) All NDT shall be done in accordance with the provisions of the SCM.

Defect has been examined prior to repair and appears to be as described.

QA Inspector Date

Repair has been completed, inspected and is acceptable.

QA Inspector Date

APPENDIX B
SAMPLE REPAIR DRAWING

<table>
<thead>
<tr>
<th>W33 CONTRACT NO.</th>
<th>SHOP ORDER NO.</th>
<th>WDL REFERENCE NO.</th>
<th>IDENTIFICATION FORM NO.</th>
<th>BASE METAL SPEC.</th>
<th>ASSG. NO.</th>
</tr>
</thead>
<tbody>
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</table>
APPENDIX C
GUIDE FOR INDEPENDENT QUALITY ASSURANCE INSPECTORS

C1. GENERAL

Quality Control (QC) and Quality Assurance (QA) are the responsibility of the Contractor. Independent quality assurance (State) inspection will be provided when and as directed by the Department.

Independent QA inspection is not intended to supplement or replace any inspection that is the responsibility of the Contractor, but rather to verify that the Contractor's QC-QA programs produce acceptable results. Independent QA inspection will generally not be provided on a full time basis. The QA inspector should schedule his work to effectively determine by random inspections and measurements, the ability of the Contractor's inspection and required tests to insure that all materials and workmanship meet the requirements of the Contract Documents. Acceptance of structural steel at the shop is based upon observations of the Contractor's QC & QA inspection and tests, plus random inspection of materials and workmanship by the State QA Inspector. Defects in materials or workmanship, even when discovered subsequent to acceptance by a State representative, are the responsibility of the Contractor.

C2. PREPARATION FOR INSPECTION

The Inspector should prepare himself for the work by reviewing the approved shop drawings, pertinent correspondence, the Steel Construction Manual, applicable provisions of the Standard Specifications, and special specifications. Shop drawings and copies of correspondence pertaining to materials or workmanship should be provided by the Contractor. Specifications and any necessary instructions will be provided by the State.

C3. EQUIPMENT

The inspector should have access to the following equipment to facilitate his inspection. Items marked with an asterisk may be provided by the Contractor.

a) Flashlight
b) Magnifying glass
c) Steel measuring tape (100 ft)*
d) Steel wire*
e) Straight edge*
f) Rule(s)
g) Calipers*
h) Weld gage(s)
i) Pit depth gage*
j) Feeler gages
k) Roughness comparator
l) Portable Rockwell C hardness tester
m) Welding shield*
n) Temperature indicating crayons*
o) Wet film thickness gage
p) Dry film thickness gage*
q) Approved acceptance stamp
C4. INSPECTION

a) Before Welding.

1) Check mill test reports to verify that the mechanical properties, chemical analysis, and BUY AMERICA provisions when required, conform to the requirements of the Contract Documents.

2) Verify the heat identity of random plates and shapes. Verify the heat identity of all fracture critical material.

3) Visually inspect surfaces and machined ends.

4) Observe the layout to see if the Contractor is taking steps to achieve the required accuracy. Check that pieces, when assembled, will be stressed parallel to the rolling direction.

5) Visually inspect flame cut surfaces and measure hardness when required.

6) Examine welder, welding operator and tacker qualifications. Witness qualification tests when required.

7) Review welding procedure specifications and verify State approval.

8) Inspect welding equipment for conformance to Article 704.

9) Check for proper weld joint fit-up and groove weld preparation.

10) Verify proper use of run-off plates and backing bars when approved.

11) Examine joint for cleanliness and removal of mill scale. Materials that may be sources of hydrogen and other gasses are particularly to be avoided.

12) Observe tack welding and examine tack welds.

13) Determine by temperature measurement that a soaking (thru-thickness) preheat has been established before welding is initiated.

14) Verify proper storage and condition of electrodes and fluxes. Determine that welding consumables are those approved in the welding procedure specification.

b) During Welding.

1) Observe the size, shape and appearance of weld beads.

2) Verify that operating parameters (amps, volts, travel speed, etc.) conform to the approved welding procedure specification.

3) Verify proper weld cleaning between passes.

4) Verify that weld joint is backgouged sound weld metal.

5) Verify that no welding is done over visible base metal or weld defects.

6) Visually inspect welds as they are completed for conformance with Contract Document requirements.

7) Verify that all weld repairs are done in accordance with approved welding procedures.
c) After Welding.

1) Verify that post heat, when required, is maintained at the required temperature for the specified minimum time. Determine that post heat is initiated immediately upon completion of welding.

2) Observe removal of run-off plates and weld backing to insure that destructive procedures are not employed.

3) Determine that grinding of surfaces and edges conforms to specification requirements and does not reduce weld and base metal thicknesses below acceptable limits.

4) Observe (spot check) preparation for radiography and radiographic technique. Review radiographs and reports.

5) Observe (spot check) ultrasonic tests, magnetic particle tests and dye penetrant tests when these tests are required by the Contract Documents or ordered by the DCES. Review reports.

6) Inspect preparation for repair welding, welding, and post heat when required.

7) Observe heat curving, cambering, or straightening when allowed. Verify conformance with specification requirements.

8) Examine fastener holes in components before assembly.

9) Check the shop assembly and examine fastener holes in assembled or template reamed pieces.

10) Observe camber and curvature measurements.

11) Check cleaning of weathering steel and cleaning and painting of painted steel.

12) Check storage conditions of finished members.

13) Verify that loading for shipment conforms to specification and/or transportation drawing requirements.

14) When it appears that all requirements for fabrication and loading have been acceptably completed, place the final acceptance stamp near the erection mark. Acceptance tag small pieces and bundles.

C5. RECORDS

a) The Inspector shall keep a permanent, bound diary as required by the DCES.

b) The Inspector shall submit a weekly Status of Fabrication Report to the DCES.

c) The Inspector shall promptly complete the acceptance report form entitled "Report of Shipment of Structural Material (Form B & GC-4b)" for transmittal to the Regional Director.

d) The Inspector shall sign the following reports or drawings prepared by the Contractor.

1) Repair Sketches or Drawings. He shall sign to indicate verification of the defect type, size and location and to indicate acceptance of the repair.
2) Radiographic Reports. The Inspector shall sign when all welds described in the report are considered acceptable.

3) Magnetic Particle Test Reports. The Inspector shall only sign when all the work described in the report is required to be witnessed by him.

4) Dye Penetrant Test Reports. The inspector shall only sign when all the work described in the report is required to be witnessed by him.
APPENDIX D
TERMS AND DEFINITIONS

A

acceptable weld: A weld that meets all the requirements and the acceptance criteria prescribed by the welding specifications.

air carbon arc gouging: A process for metal removal where the metal is melted by an electric arc and blown clear of the removal area by compressed air. Inert gas may be approved by the DCES for special applications where compressed air is not readily available.

all weld metal tension specimen: A test specimen with the reduced section composed wholly of weld metal.

amplitude (UT): The vertical height of the trace deflection on the cathode ray tube of the ultrasonic flaw detector.

amplitude length rejection level (UT): The maximum length of discontinuity permitted by various indication ratings associated with effective throat, as indicated in Tables 1700B and 1700C.

angle of bevel: See preferred term bevel angle.

arc blow: The deflection of an electric arc from its normal path because of magnetic forces.

arc strike: A discontinuity consisting of any localized remelted metal, heat-affected metal, or a change in the surface profile of any part of a weld or base metal resulting from an arc.

arc voltage: The voltage across the welding arc.

as-welded: The condition of weld metal, welded joints, and weldments after welding prior to any subsequent thermal, mechanical, or chemical treatments.

attenuation (UT): The loss in acoustic energy which occurs between any two points of travel. This loss may be due to absorption, reflection, etc. The attenuation factor for steel, using the shear wave pulse echo method of testing is 2 db per inch of sound path distance after the first inch.

attenuation (RT): The absorption of photons by the test material. This absorption is dependent upon the material thickness, density, and atomic nature.

automatic welding: Welding with equipment which performs the welding operation without constant observation and adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work.

axis of a weld: A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

B

back gouging: The removal of weld metal and base metal from the other side of a partially welded joint to assure complete penetration upon subsequent welding from that side.

backing: Material (steel or weld metal) placed at the root of a weld joint for the purpose of supporting molten weld metal.
backing pass: A pass made to deposit a backing weld.

backing ring: Backing in the form of a ring, generally used in the welding of piping.

backing strip: Backing in the form of a strip.

backing weld: Backing in the form of a weld.

bare electrode: A filler metal electrode consisting of a single metal or alloy that has been produced into a wire, strip, or bar from and that has had no coating or covering applied to it other than that which was incidental to its manufacture or preservation.

base metal: The metal to be welded or cut.

bevel: An angular type of edge preparation.

bevel angle: The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.

blasting: A method of cleaning or surface roughening by a forcibly projected stream of sharp angular abrasive.

boxing: The continuation of a fillet weld around a corner of a member as an extension of the principal weld.

butt joint: A joint between two members aligned approximately in the same plane.

butt weld: An erroneous term for a weld in a butt joint. See butt joint.

caulking: Plastic deformation of weld and base metal surfaces by mechanical means to seal or obscure discontinuities.

chamfer: See preferred term bevel.

complete fusion: Fusion that has occurred over the entire base material surfaces intended for welding and between all layers and weld beads.

complete joint penetration: Joint penetration in which the weld metal completely fills the groove and is fused to the base metal throughout its total thickness.

complete joint penetration groove weld: A groove weld which has been made from both sides or from one side on a backing having complete penetration and fusion of weld and base metal throughout the depth of the joint.

complete penetration: See preferred term complete joint penetration.

consumable guide electroslag welding: See electroslag welding.

continuous weld: A weld which extends continuously from one end of a joint to the other. Where the joint is essentially circular, it extends completely around the joint.

corner joint: A joint between two members located approximately at right angles to each other.
couplant (UT): A material (see Article 1708.3 for allowable couplants) used between the face of the ultrasonic search unit (transducer) and the test surface to permit or improve the transmission of the ultrasound between the search unit and the material under test.

covered electrode: A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld.

crack: See Appendix E.

crater: In arc welding, a depression at the termination of a weld bead or in the molten weld pool.

crater crack: See Appendix E.

DCES: Deputy Chief Engineer (Structures) or his authorized representative. For projects not under the jurisdiction of the Department of Transportation, DCES shall mean the Building Commissioner, owner or owner’s representative.

decibel (db) (UT): The logarithmic expression of a ratio of two amplitudes or intensities of acoustic energy.

decibel rating (UT): See preferred term indication rating.

defect: A discontinuity or discontinuities which by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability.

defect level (UT): See preferred term indication level.

defect rating (UT): See preferred term indication rating.

defective weld: A weld containing one or more defects.

deflection: See Appendix E.

deposited metal: Filler metal that has been added during a welding operation.

depth of fusion: The distance that fusion extends into the base metal or previous pass from the surface melted during welding.

dilution: The change in chemical composition of a welding filler metal caused by the admixture of the base metal or previously deposited weld metal in the deposited weld bead. It is normally measured by the percentage of base metal or previously deposited weld metal in the weld bead.

direct current electrode negative: The arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc. See also straight polarity.

direct current electrode positive: The arrangement of direct current arc welding leads in which the work is the negative pole and the electrode is the positive pole of the welding arc. See also reverse polarity.

direct current reverse polarity: See reverse polarity and direct current electrode positive.
direct current straight polarity: See straight polarity and direct current electrode negative.

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

downhand: See preferred term flat position.

E

electrode: A component of the welding circuit through which current is conducted to the arc, molten slag, or base metal.

electrogas welding (EGW): An arc welding process which produces coalescence of metals by heating with an arc between a continuous filler metal (consumable) electrode and the work. Molding shoe(s) are used to confine the molten weld metal for vertical position welding. The electrodes may be either flux cored or solid. Shielding may or may not be obtained from an externally supplied gas or mixture.

electroslag welding (ESW): A welding process producing coalescence of metals with molten slag which melts the filler metal and the surfaces of the work to be welded. The molten weld pool is shielded by this slag which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc which heats the slag. The arc is then extinguished and the conductive slag is maintained in a molten condition by its resistance to electric current passing between the electrode and the work. An alternate method uses a consumable guide, in which filler metal is supplied by an electrode and its guiding member.

F

faying surface: The mating surface of a member which is in contact or in close proximity with another member to which it is to be joined.

filler metal: The metal to be added in making a welded joint.

fillet weld: A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint.

fissures: See Appendix E.

flare-bevel-groove weld: A weld in a groove formed by a member with a curved surface in contact with a planar member.

flare-V-groove weld: A weld in a groove formed by two members with curved surfaces.

flash: The material which is expelled or squeezed out of a weld joint and which forms around the weld.

flat position: The welding position used to weld the upper side of the joint with the face of the weld approximately horizontal. See Articles 803 and 810.

flux: Material used to prevent, dissolve, or facilitate removal of oxides and other undesirable surface substances.

flux cored arc welding (FCAW): An arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is provided by a flux contained within the electrode. Additional shielding is obtained from an externally supplied gas or gas mixture.
flux cored electrode: A composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidation, arc stabilization, and slag formation. Alloying materials may be included in the core. External shielding is required under the provisions of this Manual.

fusion: The melting together of filler metal and base metal, or the melting of base metal only, which results in coalescence. See depth of fusion.

fusion-type discontinuity: Signifies slag inclusion, incomplete fusion, incomplete joint penetration, and similar discontinuities associated with fusion.

fusion boundary: The interface between the weld metal (consisting of filler metal and melted base metal) and the unmelted base metal as observed visually or by metallographic tests.

fusion zone: The area of base metal melted as determined on the cross section of a weld.

G

gas pocket: See preferred term porosity.

gouging: The forming of a bevel or groove by material removal. See air carbon arc gouging.

groove angle: The total included angle of the groove between parts to be joined by a groove weld.

groove face: That surface of a member included in the groove.

groove weld: A weld made in the groove between two members to be joined.

H

H&D density: (Hurter & Driffield density) A method for measuring the degree of exposure of radiographs. The density is equal to the logarithm of the ratio of the light intensity incident on the film to the light intensity transmitted.

heat-affected zone: That portion of the base metal which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding or cutting.

heat-affected zone crack: See Appendix E.

heat-shrink: A procedure for curving, straightening or cambering plates, beams, girders and other pieces or fabricated members by the controlled application of heat to specific locations in the piece. The dimensional change of the material results from the upset shortening of the steel in the heated areas.

horizontal position: fillet weld: The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface. See Articles 803 and 810.

groove weld: The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane. See Articles 803 and 810.

horizontal (zero) reference line (UT): A horizontal line near the center of the ultrasonic test instrument scope to which all echoes are adjusted for db reading.
inadequate joint penetration: See Appendix E.

incomplete fusion: See Appendix E.

indication (UT): The signal displayed on the oscilloscope signifying the presence of a sound wave reflector in the part being tested.

indication level (UT): The calibrated gain or attenuation control reading obtained for a reference line height indication from a discontinuity.

indication rating (UT): The decibel reading in relation to the zero reference level after having been corrected for sound attenuation.

intermittent weld: A weld in which the continuity is broken by recurring unwelded spaces.

interpass temperature: In a multiple pass weld, the temperature (minimum or maximum as specified) of the deposited weld before the next pass is started.

joint: The junction of members or the edges of members that are to be joined or have been joined.

joint penetration: The minimum depth of a groove weld which extends from its face into a joint, exclusive of reinforcement. Joint penetration may include root penetration.

joint welding procedure: The materials and detailed methods and practices employed in the welding of a particular joint.

lack of fusion: See preferred term incomplete fusion.

lamellar tearing: See Appendix E.

lamination: See Appendix E.

land: See preferred term root face.

lap joint: A joint between two overlapping members.

laps: See Appendix E.

layer: A stratum of weld metal or surfacing material. The layer may consist of one or more weld beads laid side by side.

leg (UT): The path the shear wave travels in a straight line before being reflected by the surface of material being tested. See sketch for leg identification. Note: Leg I plus leg II equals one vee path.

leg of a fillet weld: The distance from the root of the joint to the toe of the fillet weld.

longitudinal crack: See Appendix E.
machine welding: Welding with equipment which performs the welding operation under the constant observation and control of an operator. The equipment may or may not perform the loading and unloading of the work. See automatic welding.

manual welding: A welding operation performed and controlled completely by hand.

megahertz (MHz)(UT): Million cycles per second.

metallic inclusions: See Appendix E.

multiple electrodes: The combination of two or more single or parallel electrode systems. Each of the component systems has its own independent power source and its own electrode feeder.

node (UT): See preferred term leg.

non-metallic inclusions: See Appendix E.

overhead position: The position in which welding is performed from the underside of the joint. See Articles 803 and 810.

overlap: See Appendix E.

oxygen cutting: A group of cutting processes used to sever or remove metals by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In the case of oxidation resistant metals, the reaction is facilitated by the use of a chemical flux or metal powder.

parallel electrode: Two electrodes connected electrically in parallel and exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. Welding current, when specified, is the total for the two electrodes.

partial joint penetration: Joint penetration which is less than complete.

partial joint penetration groove weld: A groove weld welded from one or both sides and having joint penetration which is less than complete.

pass: See preferred term weld pass.

peening: The mechanical working of metals using impact blows.

penetrameter: A radiographic quality indicator. See Article 1604.2.5 for a description of the penetrameters required.

piping porosity: See Appendix E.
plug weld: A circular weld made through a hole in one member of a lap or tee joint fusing that member to the other. The walls of the hole may or may not be parallel and the hole may be partially or completely filled with weld metal. (A fillet welded hole or a spot weld should not be construed as conforming to this definition.)

porosity: See Appendix E.

positioned weld: A weld made in a joint which has been so placed as to facilitate making the weld.

postweld heat treatment: Any heat treatment subsequent to welding.

preheating: The application of heat to the base metal immediately before welding or cutting.

preheat temperature: A specified temperature that the base metal must attain in the welding or cutting area immediately before these operations are performed.

procedure qualification: The demonstration that welds made by a specific procedure can meet prescribed standards.

qualification: See preferred term procedure qualification.

reference level (UT): The decibel reading obtained for a horizontal reference line height indication from a reference reflector.

reference reflector (UT): The reflector of known geometry contained in the IIW Reference Block or other approved blocks.

reinforcement of weld: Weld metal in excess of the specified weld throat.

rejectable discontinuity: See preferred term defect.

residual stress: Stress remaining in a structure or member as a result of thermal or mechanical treatment or both. Stress arises in fusion welding primarily because the weld metal contracts on cooling from the solidus to room temperature.

resolution (UT): The ability of ultrasonic equipment to distinguish separate indications from closely spaced reflectors.

reverse polarity: The arrangement of direct current arc welding leads with the work as the negative pole and the electrode as the positive pole of the welding arc. A synonym for direct current electrode positive.

root crack: See Appendix E.

root face: That portion of the groove face adjacent to the root of the joint.

root of joint: That portion of a joint to be welded where the members approach closest to each other. In cross section, the root of the joint may be either a point, a line, or an area.

root of weld: The points, as shown in cross section, at which the back of the weld intersects the base metal surfaces.
root opening: The separation at the root of the joint between the members to be joined.

root pass: A weld deposit that extends into or includes part or all of the root of the joint.

scanning level (UT): The db setting used during scanning, as described in Tables 1700 B & C.

seal weld: Any weld designed primarily to provide a specific degree of tightness against leakage.

semiautomatic arc welding: Arc welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

shielded metal arc welding (SMAW): A manually controlled arc welding process which produces coalescence of metals by heating with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

shielding gas: Protective gas used to prevent atmospheric contamination.

single electrode: One electrode connected exclusively to one power source which may consist of one or more power units.

shrinkage stress: See preferred term residual stress.

size of weld:

groove weld: The joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are one and the same.

fillet weld: For equal leg fillet welds, the leg length of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the length of the largest right triangle that can be inscribed within the fillet weld cross section.

Note: When one member makes an angle with the other member greater than 105 degrees, the leg length (size) is of less significance than the effective throat which is the controlling factor for the strength of a weld.

slag inclusion: Oxides and other nonmetallic solids entrapped in weld metal or between weld metal and base metal. Slag inclusions generally result from the failure to remove the slag between beads and layers of multipass welds, from improper manipulation of the electrode or from failure to provide a proper contour on which each weld bead is deposited.

slot weld: A weld made in an elongated hole in one member of a lap or tee joint joining that member to that portion of the surface of the other member which is exposed through the hole. The hole may be open at one end and may be partially or completely filled with weld metal. (A fillet welded slot should not be construed as conforming to this definition.)

sound beam distance (UT): See preferred term sound path distance.

sound path distance (UT): The distance between the search unit, test material interface and the reflector as measured along the center line of the sound beam.

spatter: The metal particles expelled during welding which does not form a part of the weld.

straight polarity: The arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc. A synonym for direct current electrode negative.
stress corrosion cracking: Failure of metals by cracking under combined action of corrosion and stress, residual or applied.

stress relief heat treatment: Uniform heating of a structure or a portion thereof to a sufficient temperature to relieve the major portion of the residual stresses, followed by uniform cooling.

stringer bead: A type of weld bead made without appreciable weaving motion.

stud base: The stud tip at the welding end, including flux and container, and 1/8 inch of the body of the stud adjacent to the tip.

stud welding (SW): An arc welding process which produces coalescence of metals by heating with an arc between a metal stud or similar part and the other work part. When the surfaces to be joined are properly heated, they are brought together under pressure. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used.

submerged arc welding (SAW): An arc welding process which produces coalescence of metals by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The arc and molten metal is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary source (welding rod or flux).

tack weld: A weld made to hold parts of a weldment in proper alignment until the final welds are made.

tacker: A fitter, or someone under the direction of a fitter, who tack welds parts of a weldment to hold them in proper alignment until the final welds are made.

tandem: Refers to a geometrical arrangement of electrodes in which a line through the arcs is parallel to the direction of welding.

tee joint: A joint between two members located approximately at right angles to each other in the form of a T.

temporary weld: A weld made to attach a piece or pieces to a weldment for temporary use in handling, shipping, or working on the weldment.

throat crack: See Appendix E.

toe crack: See Appendix E.

toe of weld: The junction between the face of a weld and the base metal.

transverse crack: See Appendix E.

underbead crack: See Appendix E.

undercut: A groove melted into the base metal adjacent to the toe or root of a weld and left unfilled by weld metal.

underfill: See Appendix E.
vertical position: The position of welding in which the axis of the weld is approximately vertical. See Articles 803 and 810.

vee path (UT): The distance a shear wave sound beam travels from the search unit test material interface to the other face of the test material and back to the original surface.

weathering steel: Steel with a chemical composition such that its oxidation product (rust) acts as a protective coating and the steel is designated by the Contract Documents to remain unpainted.

weave bead: A type of weld bead made with transverse oscillation.

current: A localized coalescence of metals produced either by heating to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.

weldability: The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service.

weld bead: A weld deposit resulting from a pass.

welder: One who performs a manual or semiautomatic welding operation. (Sometimes erroneously used to denote a welding machine.)

welder certification: Certification in writing that a welder has produced welds meeting prescribed standards.

welder qualification: The demonstration of a welder's ability to produce welds meeting prescribed standards.

welding: A metal joining process used in making welds.

welding current: The current in the welding circuit during the making of a weld.

welding machine: Equipment used to perform the welding operation.

welding operator: One who operates machine or automatic welding equipment.

welding procedure: The detailed methods and practices including all joint welding procedures involved in the production of a weldment.

welding procedure qualification record: A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld for the purposes of qualifying a welding procedure specification.

welding procedure specification: A document providing in detail the required variables for a specific application to assure repeatability by properly trained welders and welding operators.

weld metal: That portion of a weld which has been melted during welding.
welding process: A materials joining process which produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.

welding sequence: The order of making the welds in a weldment.

weldment: An assembly whose component parts are joined by welding.
APPENDIX E

DESCRIPTION OF COMMON WELD AND BASE METAL DISCONTINUITIES

E1. GENERAL

This appendix describes discontinuities which may or may not be classified as defects under the provisions of this Manual. Except for cracks, discontinuities are rejectable only if they exceed the specification requirements for type, size, distribution or location. All cracks are rejectable discontinuities under the provisions of this Manual. Discontinuities may be found in the base metal, weld metal, or heat-affected zones in butt, tee, corner and lap joint configurations. The following articles present a fairly comprehensive list of discontinuities which may be encountered in fabrication.

E2. LIST OF DISCONTINUITIES

The most common types of discontinuities found in butt, tee, corner and lap joints are listed in Table E1 and shown in Figures E1 thru E6.

Weld and base metal discontinuities of specific types are more common when certain welding processes and joint details are used. High restraint and limited access to portions of a weld joint preparation may lead to a higher than normal incidence of weld and base metal discontinuities.

Each general type of discontinuity is discussed in detail in this appendix. The Steel Construction Manual and the AWS Structural Welding Code use the term “fusion type discontinuity” as an all encompassing term to describe slag inclusions, incomplete fusion, inadequate joint penetration and similar generally elongated discontinuities in weld fusion.

Since the Manual requires all complete joint penetration welds without backing to be back gouged to sound metal before welding from the second side, inadequate joint penetration is technically impossible if all provisions of the Manual are met. Many codes consider fusion discontinuities less critical than cracks. The Manual reflects our agreement with this provision. Some codes specifically prohibit not only cracks, but also any area of incomplete fusion or inadequate joint penetration. The Manual does not prohibit incomplete fusion or inadequate joint penetration, per se, even though these discontinuities are planar defects that, in a fracture analysis, will perform in a manner similar to cracks. Incomplete fusion and inadequate joint penetration defects are treated as fusion discontinuities since they generally do not have the flaw tip acuity of a crack and because routine nondestructive tests generally cannot distinguish between the various types of fusion defects.

Specific joint types and welding procedures may have an effect on the type, location and incidence of discontinuities. The conditions that may effect the formation of discontinuities are described in the following articles.

1) Porosity. Porosity is created when gas is entrapped in solidifying metal. The discontinuity formed is generally spherical but may be elongated. When there are gas discontinuities in ingots that are reduced to wrought products, gas voids in the ingot will appear as laminations in the finished product. This appendix will only discuss porosity as a weld discontinuity. Unless porosity is gross (large and/or extensive), it is not as critical a flaw as sharp, planar discontinuities that intensify stress. Porosity is a sign that the welding process is not being properly controlled or that the base metal is contaminated or of variable composition. Porosity is not caused exclusively by hydrogen, but the presence of porosity indicates that there is a possibility of hydrogen in the weld and heat affected zone that may lead to cracking.

  a) Uniformly Scattered Porosity. Uniformly scattered porosity is scattered pores distributed throughout a single weld pass or throughout several passes of a multiple pass weld. Whenever
uniformly scattered porosity is encountered, the cause is generally faulty welding technique or materials. Porosity will only be present in a weld if the technique used, materials, or the conditions of the weld joint preparation lead to gas formation and entrapment. If the weld cools slowly enough to allow gas to pass to the surface before solidification, there will be no porosity in the weld.

b) **Cluster Porosity.** Cluster porosity is a localized grouping of pores that usually results from improper initiation or termination of the welding arc.

c) **Linear Porosity.** Linear porosity is porosity (pores) aligned along a joint boundary, the root of the weld, or an interbead boundary. Linear porosity is caused by contamination that leads to gas evolution at particular locations within the weld.

d) **Piping Porosity.** Piping porosity is a term for elongated (cylindrical) gas discontinuities. Piping porosity in fillet welds extends from the root of the weld towards the surface of the weld. When one or two pores are seen in the surface of the weld, careful excavation will generally show that there are many subsurface piping porosity discontinuities interspersed among the exposed pores. Much of the piping porosity found in welds does not extend all the way to the surface. Piping porosity in electroslag and electrogas welds can become very extensive in number and length. Pores as long as twenty inches have been measured in some welds.

2) **Inclusions.**

a) **Nonmetallic Slag.** Slag inclusions result from nonmetallic, solid material being entrapped in weld metal, between weld passes, or between weld and base metal. Slag inclusions can be found in welds made by most arc welding procedures. In general, slag inclusions result from faulty welding technique, failure to clean properly between weld passes, and conditions that lead to limited access for welding within the joint. If allowed, molten slag will flow to the top of the weld. Sharp notches in joint boundaries or between weld passes often cause slag to be entrapped under the molten weld metal.

b) **Metallic Tungsten.** Tungsten inclusions are only found in welds made by the gas tungsten arc welding process. Since this process is not used under the provisions of this Manual, the discontinuity is listed for interest only. Tungsten inclusions may be found in aluminum welds made by the gas tungsten arc welding process. A nonconsumable tungsten electrode is used to establish a welding arc between the electrode and the base metal. If the tungsten electrode is dipped into the molten metal, or if the current is set too high, tungsten droplets may be transferred from the electrode to the molten metal. Tungsten inclusions appear as light marks or areas in radiographs because the inspecting radiation has a higher absorption rate in tungsten than it does in steel or aluminum.

3) **Incomplete Fusion.** Incomplete fusion may result from improper welding techniques, improper preparation of materials for welding, or improper joint design. Deficiencies causing incomplete fusion include insufficient welding heat, improper electrode manipulation, or lack of access to all boundaries of the weld joint that are to be fused during welding. On rare occasions, weld metal may fail to fuse to the base metal even though the prepared joint surface has been melted beyond the original interface. Tightly adhering oxides will interfere with complete fusion, even when there is access for welding and proper welding procedures are used.

4) **Inadequate Joint Penetration.** Inadequate joint penetration is penetration of the welding arc that is less than required. Technically, this discontinuity may only be present when the welding procedure specification requires penetration of the weld metal beyond the original joint boundaries and the weld deposit fails to penetrate the areas of weld joints that depend upon penetration for fusion. In-
adequate joint penetration may result from insufficient welding heat, improper electrode manipulation or guidance, or improper joint design which requires melting of more base metal than the arc can penetrate. Some welding procedures have much greater penetrating ability than others. This manual requires that all complete joint penetration groove welds without backing be back gouged to sound metal before welding from the second side so that there is no possibility of inadequate joint penetration at the root of the weld. In bridge construction, weld joint designs calling for specific root penetration to produce complete joint penetration groove welds are not used.

5) Undercut. Undercut considered to be a defect is generally the result of either an improper welding technique, excessive welding heat or both. It is generally located at the junction of the weld and base metal at the toe of fillet welds or at the fusion line of groove welds. Undercut may also be encountered at the root of groove welds made from one side only. Undercut creates a mechanical notch at the fusion boundary of the weld. All welds have some undercut if examined carefully. Undercut is not considered a weld defect until the degree of undercutting exceeds the amount allowed by the Contract Documents. Some undercut produces a sharp notch defect. Other undercuts may be more rounded. Some undercut may only be seen in metallographic tests where etched weld cross sections are examined under magnification. The sharper and deeper the notch created by undercutting, the more serious the defect.

6) Underfill. Underfill is the depression on the face of the weld extending below the surface of the adjacent base metal. Underfill results from the failure of the welder or welding operator to completely fill the weld joint as required by the welding procedure specification.

7) Overlap. Overlap is a sharp surface connected discontinuity that forms a severe mechanical notch when the weld metal protrudes or flows beyond the toe or face of the weld without fusion. It can occur as a result of failure to control the welding process, improper selection of welding materials, or improper preparation of the base metal prior to welding. Tightly adhering oxides on the base metal may interfere with fusion and overlap may result.

8) Laminations. Laminations are planar discontinuities elongated in the rolling direction. They are most commonly found near the mid thickness of wrought products. Laminations may be completely internal and detectable only by nondestructive tests, or they may extend to an edge or end where they are visible at the surface. Laminations may be discovered when cutting or machining exposes internal laminations. Laminations are formed when gas voids (porosity), nonmetallics, or the ingot shrinkage cavity are rolled flat. Laminations generally run parallel to the surface of rolled products and are most commonly found in shapes and plates. Some laminations are partially roll-forge welded along their interface by the high temperature and pressure of the rolling or forging operation. The soundness of the roll-forged weld depends upon the presence or absence of oxides or nonmetallics on the surfaces of the original voids. Laminations that are partially or completely roll-forged welded may conduct sound across the interface and therefore may not be accurately evaluated by ultrasonic tests. Metals containing laminations generally cannot be relied upon to transmit tensile stresses in the through-thickness direction. Laminations may be a source of gas voids and cracks in adjacent butt welds.

9) Delamination. Delamination is the separation of a partially or completely roll-forge welded lamination under stress. The stress may be residual stress from welding or applied stress. Delaminations may be found visually at the edges or ends of pieces or may be discovered by ultrasonic tests.

10) Seams and Laps. Seams and laps are longitudinal base metal discontinuities that may be found in rolled products. When seams and laps are located parallel to the principal stress, they are generally not considered critical defects. When seams or laps are perpendicular to the applied or residual stresses, they will often propagate as cracks. Seams and laps are surface connected discontinuities that result from cracks in the surface of the ingot or mechanical deformations resulting from the manufacturing process. These discontinuities are modified during rolling so that the bottom of a seam is generally not as sharp as the original ingot or slab crack. They may be masked by mill scale or the surface texture of the finished product. Welding over seams and laps can lead to cracking.
11) **Lamellar Tears.** Lamellar tears are generally terrace-like separations in the base metal adjacent to the heat affected zone, typically caused by thermally induced shrinkage stresses resulting from welding. Lamellar tearing is a form of fracture resulting from high stress in the short-transverse (thru-thickness) direction which may extend over long distances. The tears are roughly parallel to the surface of the rolled product and generally initiate in regions of the base metal having a high incidence of coplanar, stringer-like non-metallic inclusions and/or in areas of the base metal subject to high residual stress. The fracture usually propagates from one lamellar plane to another by shear along lines that are roughly normal to the rolled surface.

12) **Cracks.** Cracks occur in weld and base metal when localized stresses exceed the ultimate strength of the material. Cracking is generally associated with stress amplification near discontinuities in welds and base metal, or near mechanical notches associated with weldment design. High residual stresses are generally present and hydrogen embrittlement is often a contributor to crack formation. Welding related cracks are generally brittle in nature, exhibiting little plastic deformation at the crack boundaries.

Cracks can be classified as either hot cracks or cold cracks. Hot cracks develop at elevated temperatures. They commonly form upon solidification of the metal at temperatures near the melting point. Hot cracks propagate along grain boundaries. Cold cracks develop after solidification is complete. Cold cracks, sometimes called delayed cracks or hydrogen cracks, can form hours and even months after the completion of welding, and are commonly associated with hydrogen embrittlement. Cold cracks propagate both between and through the grains. Cracks may be termed longitudinal or transverse depending upon their orientation.

a) **Longitudinal Cracks.** When a crack is parallel to the axis of the weld, it is called a longitudinal crack regardless of whether it is along the centerline of the weld metal, or in the heat affected zone of the base metal. Longitudinal cracks in submerged arc welds, made by automatic welding procedures, are often associated with high welding speeds and sometimes aggravated by segregation of weld metal constituents and/or extensive porosity that does not show on the surface of the weld. Longitudinal cracks in small welds between heavy sections are often the result of high cooling rates and high restraint.

b) **Transverse Cracks.** Transverse cracks are perpendicular to the axis of the weld. They may be in weld metal, base metal, or both. Transverse cracks may be limited in size and contained completely within the weld, or may propagate from the weld metal into the adjacent heat affected zone and into the unaffected base metal. Transverse cracks initiating in weld metal are commonly the result of longitudinal shrinkage stresses acting upon excessively hard (brittle) weld metal. Transverse cracks initiating in the heat affected zone are generally hydrogen cracks.

c) **Crater Cracks.** Crater cracks are cracks that form in the crater or depression that is formed by improper termination of the welding arc. Crater cracks are shallow hot cracks that usually form a multi-pointed star-like cluster, although they may have other shapes.

d) **Throat Cracks.** Throat cracks are longitudinal cracks that are generally located in the center of the weld bead. They are generally, but not always, hot cracks.

e) **Toe Cracks.** Toe cracks are generally cold cracks. They initiate or propagate from the toe of the weld where restraint stresses are highest. Toe cracks initiate approximately normal to the base metal surface and propagate to various depths in the base metal depending upon the residual stress and toughness of the base metal.

f) **Root Cracks.** Root cracks are generally longitudinal cracks in the root of the weld. Root cracks are generally hot cracks.
g) **Underbead and Heat Affected Zone Cracks.** Underbead and heat affected zone cracks are almost always cold cracks that form in the heat affected zone. They are generally short cracks, but may join to form much larger continuous cracks. Underbead and heat affected zone cracks generally align themselves with weld boundaries that concentrate residual stresses. Underbead cracking and all other hydrogen cracks can become a serious problem when three elements are present; a susceptible microstructure, high residual stress and hydrogen.

h) **Fissures.** The term fissure is used to describe small to moderate size separations along prior austenite grain boundaries. This discontinuity is commonly found in electroslag and electrogas welds. Fissures occur in other welds, but they are easier to detect in electroslag welds because of the much larger prior austenite grain size. When electroslag welds are subject to high restraint, and hydrogen is present, fissuring may become a major problem. Fissuring in electroslag and electrogas welds is generally restricted to the center portion of the weld that is subject to high tensile residual stress resulting from solidification. Fissures can be either hot or cold cracks, although cold cracking is more common. The term microfissure is used for cracks that are so small that magnification must be used to detect the separation. The term macrofissure is used when the separation is large enough to be seen with the unaided eye.
<table>
<thead>
<tr>
<th>Type of discontinuity</th>
<th>Location</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Porosity</td>
<td></td>
<td></td>
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<tr>
<td>a) Uniformly scattered</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>b) Cluster</td>
<td></td>
<td></td>
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<tr>
<td>c) Linear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Piping</td>
<td></td>
<td></td>
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<tr>
<td>2) Inclusions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Non-metallic slag</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>b) Metallic tungsten</td>
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<td></td>
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<tr>
<td>3) Incomplete fusion</td>
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</tr>
<tr>
<td>(also called lack of</td>
<td>W</td>
<td>Found at joint boundaries or between passes.</td>
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<tr>
<td>fusion)</td>
<td></td>
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<tr>
<td>4) Inadequate joint penetration (also called lack of joint penetration)</td>
<td>W</td>
<td>Found at root of weld preparation.</td>
</tr>
<tr>
<td>5) Undercut</td>
<td>BM</td>
<td>Found at junction of weld and base metal at surface.</td>
</tr>
<tr>
<td>6) Underfill</td>
<td>W</td>
<td>Found at outer surface of joint preparation.</td>
</tr>
<tr>
<td>7) Overlap</td>
<td>W</td>
<td>Found at junction of weld and base metal at surface.</td>
</tr>
<tr>
<td>8) Laminations</td>
<td>BM</td>
<td>Found in base metal, generally near mid-thickness of section.</td>
</tr>
<tr>
<td>9) Delamination</td>
<td>BM</td>
<td>Found in base metal, generally near mid-thickness of section.</td>
</tr>
<tr>
<td>10) Seams and Laps</td>
<td>BM</td>
<td>Found at base metal surface. Almost always longitudinal.</td>
</tr>
<tr>
<td>11) Lamellar tears</td>
<td>BM</td>
<td>Found in base metal near weld HAZ.</td>
</tr>
<tr>
<td>12) Cracks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Longitudinal</td>
<td>W,HAZ,BM</td>
<td>Found in weld or base metal adjacent to weld fusion boundary.</td>
</tr>
<tr>
<td>b) Transverse</td>
<td>W,HAZ,BM</td>
<td>Found in weld (may propagate from weld into HAZ and base metal).</td>
</tr>
<tr>
<td>c) Crater</td>
<td>W</td>
<td>Found in weld at point where arc is terminated.</td>
</tr>
<tr>
<td>d) Throat</td>
<td>W</td>
<td>Found at weld axis.</td>
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<tr>
<td>e) Toe</td>
<td>HAZ</td>
<td>Found at junction between face of weld and base metal.</td>
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<tr>
<td>f) Root</td>
<td>W</td>
<td>Found in weld metal at root.</td>
</tr>
<tr>
<td>g) Underbead and Heat Affected Zone</td>
<td>HAZ</td>
<td>Found in base metal in HAZ (may propagate into unaffected base metal)</td>
</tr>
<tr>
<td>h) Fissures</td>
<td>W</td>
<td>Found in weld metal</td>
</tr>
</tbody>
</table>

W-weld
BM-base metal
HAZ-heat affected zone
FIGURE E 5 – SINGLE PASS FILLET WELD IN A TEE JOINT
APPENDIX F
SUGGESTED FORMS
RADIOGRAPHIC INSPECTION REPORT

Contract D
Structure
Fabricating Shop
Reported to: New York State Department of Transportation

WELD LOCATION AND IDENTIFICATION SKETCH

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<th>DATE</th>
<th>WELD IDENTIFICATION</th>
<th>AREA</th>
<th>INTERP.</th>
<th>REPAIRS</th>
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Radiographer _______________________  Interpreter _______________________

QA Inspector _______________________  Date of Final Approval _______________________

Report ______  Sheet ______ of ______

Structure County Shop Shop
ULTRASONIC INSPECTION REPORT

Report ____________________________
Sheet _______ of _________

Contract D Project Identification No. ____________
Structure County
Fabricating Shop Shop

Reported to: New York State Department of Transportation

WELD LOCATION AND IDENTIFICATION SKETCH

Piece Mark

<table>
<thead>
<tr>
<th>Date</th>
<th>Indication Number</th>
<th>Weld Identification</th>
<th>Transducer Angle</th>
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<th>Leg</th>
<th>Decibels</th>
<th>Discontinuity</th>
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Technician ____________________________ Inspection Agency ____________________________

NYSDOT Certificate No. ____________________________ Witnessed by ____________________________
**WELDING PROCEDURE SPECIFICATION**

- Material specification
- Welding process
- Manual, semiautomatic or automatic
- Position of welding
- Filler metal specification AWS
- Filler metal classification
- Electrode and manufacturer
- Flux and manufacturer
- Shielding gas
- Dew point
- Flow rate
- Single or multiple pass
- Single or multiple arc
- Welding current
- Polarity
- Welding progression
- Root treatment
- Preheat and interpass temperature
- Postheat treatment

**WELDING PROCEDURE**

<table>
<thead>
<tr>
<th>Pass no.</th>
<th>Electrode size</th>
<th>Welding parameters</th>
<th>Travel speed</th>
<th>Joint detail</th>
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<tr>
<td></td>
<td></td>
<td>Amperes</td>
<td>Volts</td>
<td></td>
</tr>
</tbody>
</table>

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in Section 8A.

- Procedure no. __________________________ Fabricator or Erector __________________________
- Revision no. __________________________ Authorized by __________________________
- Date __________________________