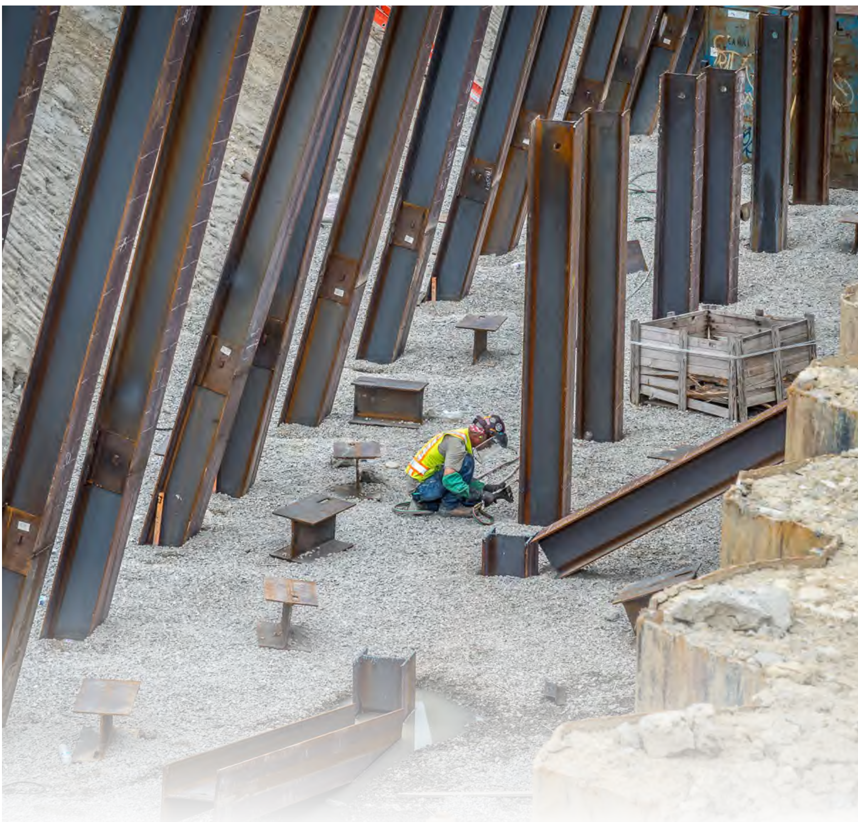
Michigan Department of Transportation

Field Manual for Pile Welding



Michigan Department of Transportation

BUREAU of BRIDGES and STRUCTURES

SPANNING CONNECTING SAFELY EFFICIENTLY

2nd Edition – January 2022

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Glossary

arc strike – Arc strikes are areas where the welding electrode comes into contact with the base metal outside of the final weld. Arc strikes result in heating and very rapid cooling. Arc strikes may result in hardening or fatigue cracking and serve as potential sites for fracture initiation.

back gouging – The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and full joint penetration upon subsequent welding from that side.

backing – A material or device placed against the back side of a joint to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal, as approved by the engineer.

base metal – The metal or alloy that is welded, brazed, soldered, or cut.

bending stress – The stress created in a member subjected to a bending moment. Bending stress results in part of the member cross section being subjected to tension and part of the member cross section being subjected to compression, separated by the neutral axis, at which location there is no stress.

CJP – Complete joint penetration.

concavity – The underfill (or suck back) of metal in the weld causing the weld surface to be below flush with the parent metal surfaces. This condition may exist on either root or face surfaces.

convexity – The solidified, overfilled weld metal causing the weld surface to be above flush with the parent metal surfaces. This condition may exist on root or face surfaces and, when measured, both should be added for an accumulated effect.

crater – A depression in the weld face at the termination of a weld bead.

CWI – Certified welding inspector.

defect – A discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability.

electrode – A device that conducts electricity. In welding, the electrode also can act as the filler metal.

fatigue – Fatigue, as used herein, is defined as the damage that may result in fracture after a sufficient number of stress fluctuations. Stress range is defined as the peak-to-trough magnitude of these fluctuations. In the case of stress reversal, stress range shall be computed as the numerical sum (algebraic difference) of maximum repeated tensile and compressive stresses, or the sum of shearing stresses of opposite direction at a given point, resulting from changing conditions of load.

FCAW (flux cored arc welding) – An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas.

filler metal – The metal or alloy to be added in making a welded, brazed, or soldered joint.

fillet weld leg – The distance from the joint root to the toe of the fillet weld.

flux – A material used to prevent the formation of, or to dissolve and facilitate the removal of, oxides and other undesirable substances.

fusion – The melting together of filler metal and base metal (substrate), or of base metal only, to produce a weld.

fusion-type discontinuity – Signifies slag inclusion, incomplete fusion, incomplete joint penetration, and similar discontinuities associated with fusion.

fusion zone – The area of base metal melted as determined on the cross section of a weld.

GMAW (gas metal arc welding) – An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas.

HAZ (heat-affected zone) – The portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or thermal cutting.

hotbox – A storage oven for electrodes. Proper electrode storage requires a hot box to be at a minimum temperature of 250 degrees Fahrenheit at all times.

interpass temperature – In a multi-pass weld, the temperature of the weld area between weld passes.

inclusion – Entrapped foreign solid material, such as slag or oxide.

joint penetration – The distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement.

joint root – That portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, a line, or an area.

MT – Magnetic particle testing.

NDT – Non-destructive testing.

overlap – The protrusion of weld metal beyond the weld toe or weld root.

peening – The mechanical working of metals using impact blows.

PJP – Partial joint penetration.

porosity – Circular cavity-type discontinuities formed by contamination or loss of shielding gas during solidification of the weld metal.

preheat temperature – The temperature of the base metal in the volume surrounding the point of welding immediately before welding is started. In a multiple-pass weld, it is also the temperature immediately before the second and subsequent passes are started.

PQR (procedure qualification record) – A record of welding variables used to produce an acceptable weld and the results of the tests conducted to qualify a weld procedure.

PT – Liquid penetrant testing, also known as dye penetrant testing.

root face – That portion of the groove face within the joint root.

SAW (submerged arc welding) – An arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the work pieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

shielding gas – Protective gas used to prevent or reduce atmospheric contamination.

slag – Slag is a byproduct of welding and typically adheres to the weld surface. Slag must be removed between passes and upon weld completion.

SMAW (shielded metal arc welding) – An arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering and with filler metal from the electrode.

spatter – The metal particles expelled during fusion welding that do not form a part of the weld.

stringer bead – A type of weld bead made without appreciable weaving motion.

tack weld – A weld made to hold parts of a weldment in proper alignment until the final welds are made.

throat of a fillet weld (actual throat) – The shortest distance between the weld root and the face of a fillet weld.

throat of a groove weld – A nonstandard term for groove weld size.

travel speed – The rate at which the electrode is moved along the joint during welding, measured in inches per minute (IPM).

undercut – A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

underfill – A depression on the weld face or root surface that extends below the adjacent surface of the base metal. Underfill is the failure of the welder to properly fill the joint with metal.

UT – Ultrasonic testing.

weave bead – A type of weld bead made with transverse oscillation.

weld – A localized coalescence of metals or nonmetals produced by heating the materials to the welding temperature, with or without the application of pressure or by the applications of pressure alone and with or without the use of filler material.

weldability – The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

weld axis – A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

weld bead – A weld resulting from a pass. See stringer bead and weave bead.

welder certification – Written certification that a welder has produced welds meeting a prescribed standard of welder performance.

welder performance qualification – The demonstration of a welder's ability to produce welds meeting prescribed standards.

weld face – The exposed surface of a weld on the side from which welding was done.

weld pass – A single progression of welding along a joint. The result of a pass is a weld bead or layer.

weld reinforcement – Weld metal more than the quantity required to fill a joint.

weld root – The points, as shown in cross section, at which the root surface intersects the base metal surfaces.

weld size (fillet weld) – For equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.

weld size (groove weld) – The joint penetration of a groove weld.

weld toe – The junction of the weld face and the base metal.

weldment – An assembly whose component parts are joined by welding.

WPS (welding procedure specification) – The detailed methods and practices including all joint welding procedures involved in the production of a weldment. See MDOT Form 5629 for sample WPS.

WPS qualification – The demonstration that welds made by a specific WPS can meet prescribed standards.

Introduction and Purpose

The purpose of this Field Manual for Pile Welding is to introduce basic welding definitions and concepts, and to provide sufficient understanding of the different types of welds used in splicing piles, in order to assist the inspector in visual inspection and acceptance of pile welds. The Standard Specifications for Construction, Special Provision for Pile Splicing, and American Welding Society (AWS) Structural Welding Code, D1.1 govern field welding of pile splices.

Modern driven pile deep foundation systems support different types of bridges and require piles to resist different types of loads with varying magnitudes. While some piles may only be subjected to axial compression or tension, others may be subjected to bending forces due to thermal, braking, expansion, wind, horizontal earth pressure, and frame/arch action loadings acting on the bridge. Therefore, while some bridges may allow for the use of pile splicing channels, other bridges may require a full penetration groove weld to develop the full bending capacity of the pile section that was modeled during design.

Understanding the bending stresses and cyclic loading that some piles may be subjected to is critical to understanding the importance of a quality welded pile splice. Requiring the weld to survive the stresses induced by the pile driving operation is not the driving force behind the strength requirement of the welded pile splice.

Types of Welds and Processes

WELD TYPES

The MDOT Bridge Design Guides provide the designer with standard pile welding details utilizing three different weld types:

- ***Complete joint penetration (CJP) groove welds***
- ***Partial joint penetration (PJP) groove welds***
- ***Fillet welds***

A CJP groove weld is also known as a full penetration groove weld. When properly designed a CJP groove weld is stronger than the base metal of the sections it has joined. To create a successful CJP groove weld, back gouging or a backer bar is used to ensure filler metal from the electrode is deposited throughout the entire cross section of the weld. CJP welds are used for the H-Pile splice detail and the Pipe Pile detail. Figure 1 shows the cross section of a CJP groove weld.

A PJP groove weld is similar to a full penetration groove weld with the exception that the base metal sections being joined are only partially penetrated by the weld metal. Since the weld metal is not designed to penetrate through the entire cross section, the use of a backer bar or back gouging is not required. PJP welds are used for the H Pile alternate splice detail with channel splicers. Figure 2 shows the cross section of a PJP groove weld.

A fillet weld is used to join sections of base metal lying in different planes and is used for the H-Pile alternate splice detail with channel splicers. Figure 3 shows the cross section of a fillet weld.

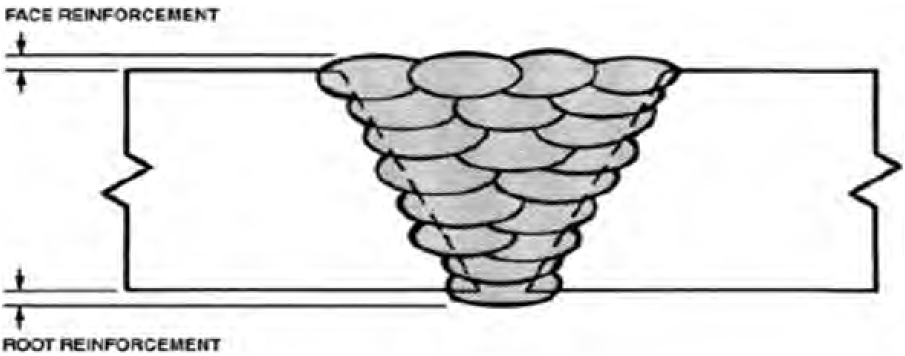

Figure 1. Cross section of a CJP groove weld showing individual weld passes and reinforcement.

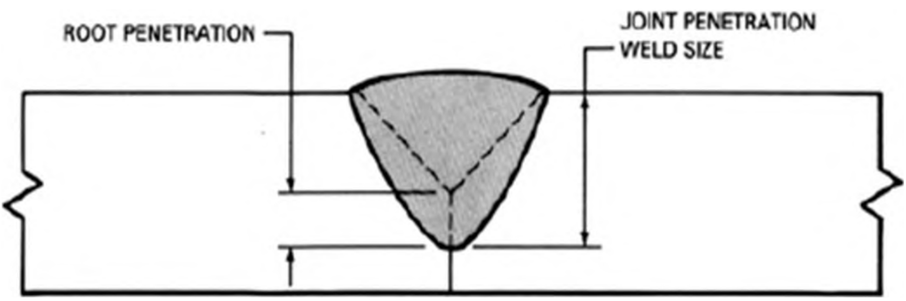

Figure 2. Cross section of a PJP groove weld or incomplete joint penetration CJP groove weld.

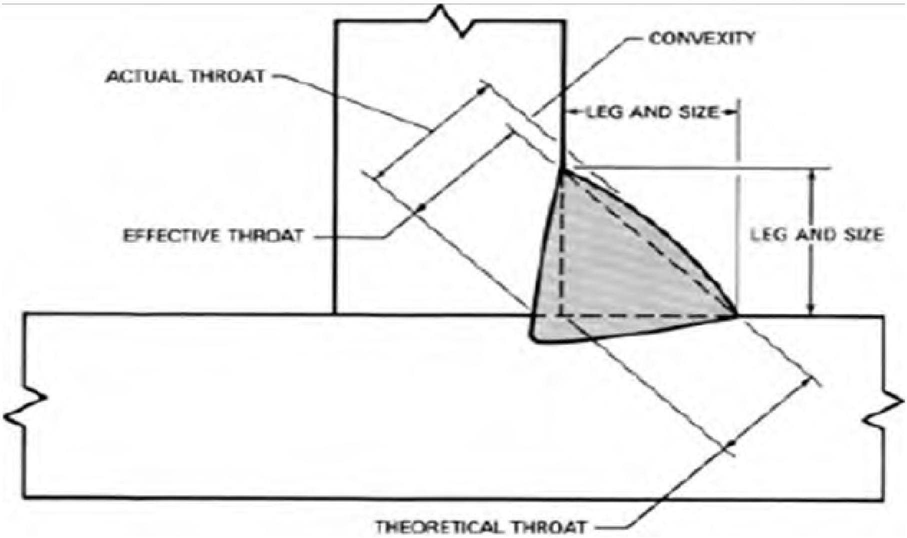

Figure 3. Cross section of a convex fillet weld. Fillet weld size and leg dimension are equal.

Weld Processes

Field welding of piles is limited to the shielded metal arc welding (SMAW) process by Section 705 of the Standard Specifications for Construction. The SMAW process is shown in Figure 4 and is also commonly referred to as stick welding. SMAW electrodes consist of a core of filler metal that is covered with flux, which produces gas and slag to protect the weld from contamination during welding. The slag byproduct, which is deposited on top of the weld metal, must be removed after each weld pass.

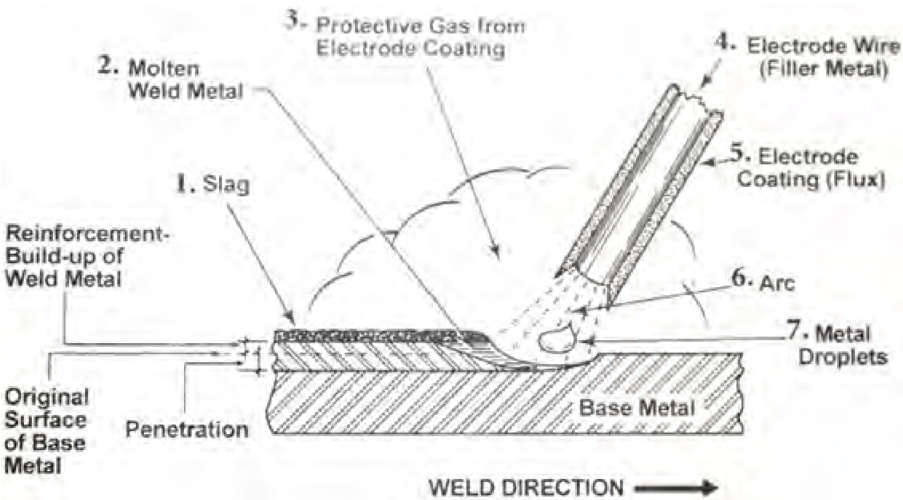

Figure 4. SMAW electric arc process.

On rare occasions the flux core arc welding (FCAW) process has been used for field welding. FCAW is a wire-fed process that uses flux in the core of the wire to shield the weld. FCAW can be used with or without an additional shielding gas. The gas metal arc welding (GMAW) process is also wire-fed but is not suitable for field welding because the gas used to shield the weld can be blown away by wind and enclosures are not effective.

The submerged arc welding (SAW) process is typically used in fabrication shops for welding bridge main and secondary members. SAW produces a very sound weld and is sometimes used in the field for welding of bridge main members, but the equipment is more suitable for production welding in a shop. Figure 5 shows a typical SMAW welding machine.

Figure 5. SMAW electric arc welding machine.

Acceptance Criteria

The standard MDOT method for acceptance of non main member pile welds is visual testing (VT) inspection. VT involves inspection before, during, and after welding has been completed, and is performed by MDOT and the contractor. If the contract allows cope holes to be used in conjunction with a CJP groove weld for a pile splice, then the contractor is also required to perform PT inspection in accordance with the contract. Continue through the remainder of this section for acceptance requirements of non-main member pile splicing.

Acceptance of main member pile welds follows AWS D1.5 and requires a CWI to perform VT inspection and other non-destructive testing (PT, MT, and/or UT) by qualified technicians. See AWS D1.5 for acceptance requirements of main member pile splicing.

Safety Notes

- ***The electric arc gives off ultraviolet and infrared radiation that can cause severe sunburn type injuries, which could lead to blindness, therefore: DO NOT WATCH THE ARC!***
- ***Both welding and grinding produce sparks. Always wear eye protection around welding and grinding. Keep flammable materials away from the welding area.***

Inspection

Although acceptable to do so, it is not necessarily required to inspect the weld after each pass, but the MDOT inspector should periodically visually observe the welding process with sufficient frequency to verify the skills of the welder, joint preparation, preheat, typical root and intermediate passes, back gouging, and visual quality of the final weld passes. The inspector should perform VT inspection on the first weld done by each welder and then randomly sample completed welds to verify conformance to the project requirements. Additionally, the inspector should randomly inspect the weld setup (immediately prior to welding the root pass) and intermediate weld passes.

Each welder is required to VT inspect their own work in accordance with the contract and contractor's MDOT-approved pile welding quality control plan (QCP). The MDOT inspector performs their inspection after the contractor performs their quality control (QC) and accepts the weld. The inspector should verify that the contractor QC personnel are present, and welding is in accordance with the contract documents and the contractor's MDOT approved QCP. The frequently used Special Provision for Quality Control Plan for Welding Pile Splices (20SP-705A) will be included in all projects requiring non main member pile foundations and requires the contractor to complete MDOT Forms 5627, 5628, and 5629. Contractor welding and QC personnel are required to be qualified to understand visual acceptance requirements in AWS D1.1 and when welds display unacceptable visual discontinuities. Each weld pass of every weld must be inspected by the welder with contractor QC personnel inspecting and signing off on all welds in accordance with their MDOT-approved QCP. MDOT's inspector monitors the welding operation and performs a detailed random inspection and VT of completed welds.

Acceptance

Refer to the contractor's MDOT-approved QCP, this manual, and the contract documents when conducting inspection and accepting welds. QC personnel are responsible for inspecting and signing off on all welds and shall notify the inspector when welds are ready for their inspection for acceptance. MDOT Form 1161L (or 1161 for projects design to AASHTO Load Factor Design) will be used by the inspector to identify which welds they inspected. It is not necessary for the inspector to perform VT inspection on every weld, but a minimum of 10 percent of the splices are recommended to be inspected and can be increased at the inspector's discretion. It is recommended that the splices receiving MDOT inspection are randomly distributed throughout the duration of the project, while it is also important that each welder have his first weld VT inspected by MDOT's inspector.

Certification

All welders must be certified in order to weld on MDOT projects and must carry a copy of their certification. Certifications must be submitted per Section 705 of the Standard Specifications for Construction. The certification will show which positions and welding type the welder is qualified for. Qualifying in certain positions will permit the welder to weld in other positions. Figures 6 and 7 illustrate the different welding positions, and Table 1 shows which test positions qualify a welder for which production positions. For example, qualifying in the 2F position only qualifies production welding in the flat and horizontal positions for fillet welding, and qualifying in the 3G and 4G positions qualifies production welding in all positions for full penetration groove welding, partial penetration groove welding, and fillet welding.

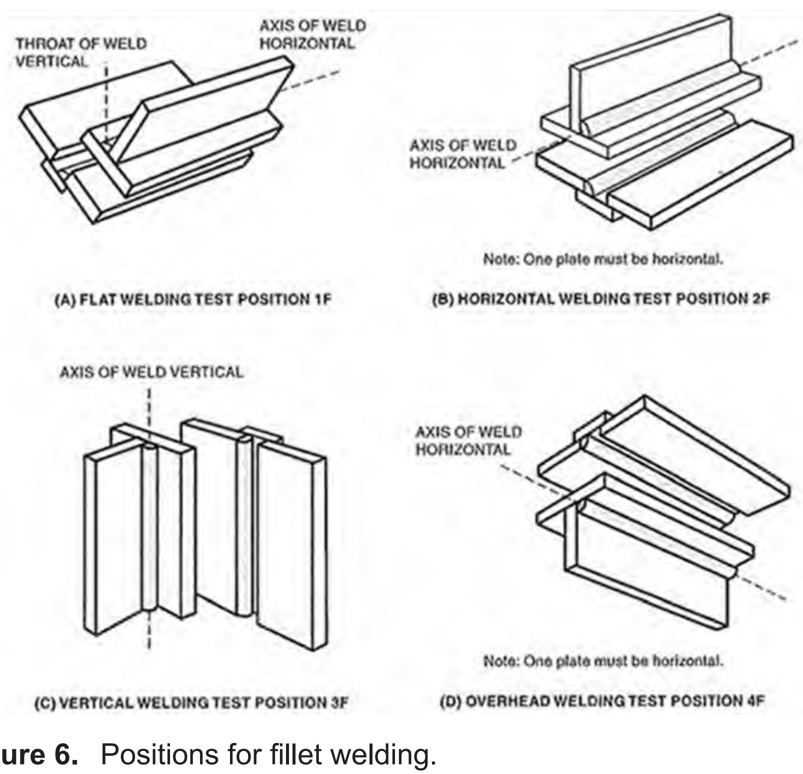

Figure 6. Positions for fillet welding.

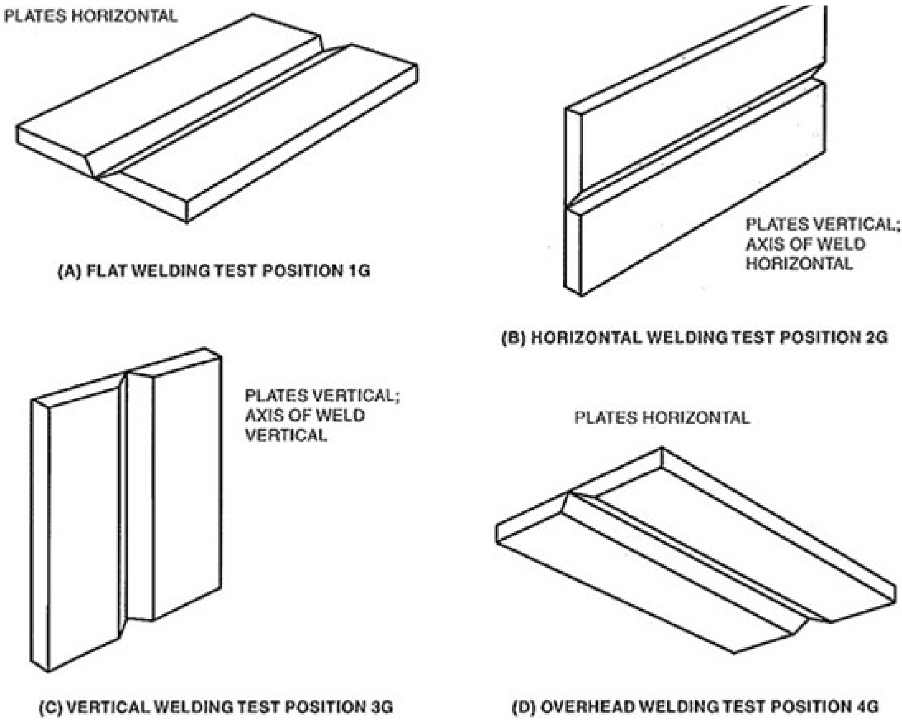

Figure 7. Positions for groove welding.

Table 1. Positions qualified by testing

Qualification Test		Qualified Production Welding		
Weld Type	Positions	Full Pen. Groove	Partial Pen. Groove	Fillet
Groove	1G 2G 3G 4G 3G + 4G	F F, H F, H, V F, OH All	F F, H F, H, V F, OH All	F F, H F, H, V F, OH All
Fillet	1F 2F 3F 4F 3F +4F	-	-	F F, H F, H, V F, OH All

(F = flat, H = horizontal, V = vertical, OH = overhead)

Note that welding in a vertical downward direction is never permitted, only vertically in the upward direction (starting at the bottom and working toward the top).

Storage

Proper storage and use of electrodes are critical. The standard electrode used for pile welding is E7018, as shown in Figure 8. The first two digits of E7018 designate the minimum tensile strength of the weld metal, the third digit designates the welding position it may be used in (1 = all positions), and the last digit designates the type of electrode coating (8 = low hydrogen). Therefore, an E7018 electrode has a minimum tensile strength of 70 ksi, can be used in all welding positions, and has a low hydrogen coating.

Figure 8. E7018 SMAW 1/8-inch (common size) electrodes.

Hydrogen is one of the major causes of weld defects. Care must be taken to ensure no moisture is picked up in the coating of the electrodes as this can add hydrogen to the coating and cause discontinuities in the weld. Electrodes exposed to the atmosphere upon removal from drying or storage ovens (see Figure 9) or hermetically sealed containers (see Figure 10) must be used within two hours, or re-dried at a minimum temperature of 500 degrees Fahrenheit for a minimum of two hours. Electrodes can only be re-dried once, and any electrode that becomes wet cannot be re-dried. Electrodes taken from a hermetically sealed container or drying oven that are not going to be used within two hours should be stored in a portable oven, also known as a "hot box" (see Figure 11), at a minimum temperature of 250 degrees Fahrenheit. The welder should take out only as many electrodes from the hot box as can be used within that two-hour period.

The following are examples of improper electrode storage:

- ***Leaving electrodes out for more than two hours***
- ***Open partially used cans of welding rod***
- ***Electrodes laying on the ground***
- ***Hot boxes with the tops left open***
- ***Hot boxes not plugged in overnight***
- ***Hot boxes not plugged in during work or generators not running***
- ***Hot boxes at a temperature less than 250 degrees Fahrenheit***

Figure 9. Drying and storage oven for electrodes.

Figure 10. Hermetically sealed welding electrode containers.

Figure 11. Hot boxes for welding electrode storage.

Weld Preparation

The first step in making a sound weld is to make sure the joint is correctly cleaned and then preheated (if necessary) prior to welding. Cleaning the joint can be accomplished by using a stiff wire brush. All surfaces to be welded must be free from all loose or thick scale, slag, rust, moisture, grease, or other contaminants. Mill scale that can withstand a vigorous wire brushing, or anti-spatter compound may remain prior to welding.

The pieces to be joined should be checked for flatness and dimensional accuracy. Likewise, alignment, root opening, fit-up and joint, straightness preparation should be examined. Finally, process and procedure variables should be verified, including electrode size and type and equipment settings. These variables should be listed in the weld procedure.

Preheating is the required practice of providing localized heat to the weld zone. The preferred method of preheating is using a manual torch. Preheating to and maintaining the steel temperature at a minimum of 70 degrees Fahrenheit is required if the ambient temperature is below 32 degrees Fahrenheit. Preheat shall be applied for a distance of 3 inches in all directions from the weld joint. Welding is not permitted when the ambient temperature is below 0 degrees Fahrenheit.

Tack welds or other pieces of steel may be utilized to align the piles before or during welding but must be removed from the final weld by grinding. Any arc strikes must also be removed by grinding to sound metal.

Welds should be cleaned between every pass and after the final pass. A finished weld should have a clean appearance. Cleaning is typically accomplished by using a stiff wire brush in conjunction with a chipping hammer to remove slag and splatter. The grinder is also a very common and useful tool for cleaning. Grinders are to be used with care to avoid doing more harm than good to both finished welds and the base metal.

Figure 12. Wire brush used to prepare surface prior to welding and to clean between weld passes.

Figure 13. Chipping hammers used to remove slag.

Figure 14. Grinder used to prepare joints, clean before and after weld passes, and to back gouge.

Inspection

Visual inspection of the finished weld is critical. Many weld deficiencies can be detected by proper visual inspection throughout the welding process, which also minimizes the time and cost to make repairs. The finished weld should be checked for both dimensional deficiencies and common weld discontinuities, as shown in the next section.

The only way to check the integrity of a completed CJP weld after the fact is through a destructive test, or NDT. Below are common types of NDT:

- ***PT***
- ***MT***
- ***RT***
- ***UT***

PT and MT inspection can both identify surface defects and near-surface defects (MT only), but only RT or UT can identify all volumetric deficiencies throughout a completed weld with weld edge/boundary limitations. These methods are commonly used in fabrication shops for accepting welds. UT can be done in the field if there are concerns about the integrity or quality of the weld. UT may be ordered by the engineer. Note that NDT does not provide mechanical information (fusion, soundness, tensile, toughness, etc.) that can only be obtained from destructive testing.

The techniques and issues surrounding weld inspection are broad. If a problem is suspected, consult with the Bureau of Bridges and Structures. It is always better to err on the side of caution. In the next section, some common weld discontinuities are described.

Common Weld Discontinuities

There are many different types of weld discontinuities that can occur as a result of improper procedures, materials, techniques, or conditions. It is important to remember that a small discontinuity in the weld can become a crack initiation and failure location. However, most discontinuities can be repaired and do not require an entirely new weld. A checklist has been prepared in the next section to assist with visual inspection. If unsure about the severity of a discontinuity, or how it should be repaired, consult with the Bureau of Bridges and Structures.

The following are the most common types of weld discontinuities.

Cracks - Any crack is unacceptable regardless of size or location. If a crack is found it must be removed, and NDT may be necessary to verify that all discontinuities have been removed before re-welding.

The two types of cracking most likely to occur are hot cracking (just after the weld has solidified) and cold cracking (which occurs near ambient temperature after the weld has cooled).

Craters - Craters are the ends of weld passes where the weld is not filled to its full cross section, typically caused by pulling the electrode away too soon. The stress concentrations that are caused by the unfilled crater may cause crater cracks to form because of tension on the weld in the affected area. All welds must have full cross section the entire length of the weld.

Dimensional discontinuities - Dimensional discontinuities can be found by verifying the weldment against drawings and specifications. Figures 15 and 16 show acceptable and unacceptable weld profiles for fillet welds and CJP groove welds.

Discontinuities may include the following:

- ***Misalignment of base metal***
- ***Incorrect root opening***
- ***Warping of base metal***
- ***Incorrect weld size***
- ***Weld profile discrepancies***

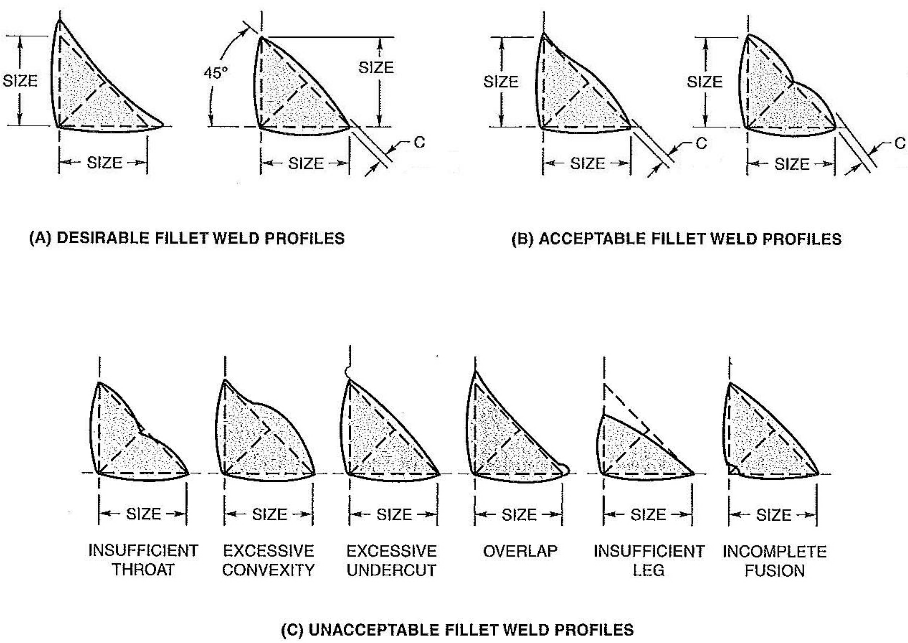

Figure 15. Fillet weld profiles. (c = convexity)

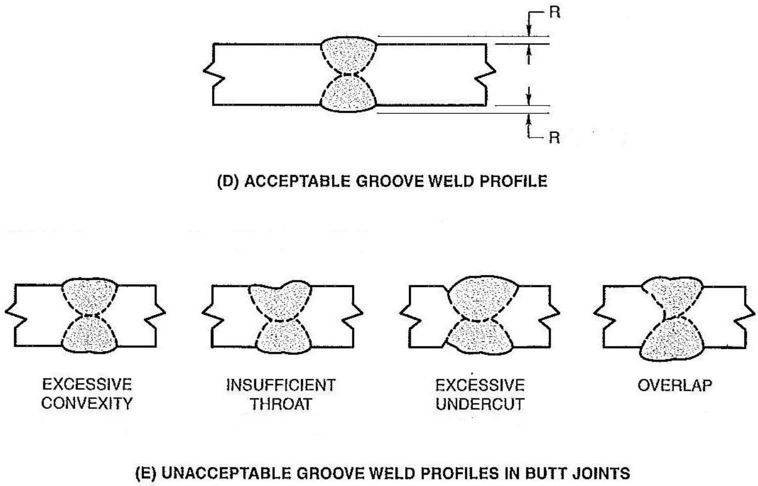

Figure 16. CJP groove weld profiles. (R = reinforcement)

Fillet welds are designed based on their leg sizes. If the plans show a fillet weld size of 5/16 inches, then each leg of the weld needs to measure to that dimension. If either leg is under the specified dimension, then the strength required for that joint will be less than what the joint was designed for and weld metal must be added. The throat of the weld should also be checked. The leg is in the vertical and horizontal dimensions and the throat is the distance between the legs, known as the hypotenuse. A fillet weld gauge (see Figure 17) is the standard tool to check fillet weld sizes.

The fillet weld gauge blade must be flush to the base material with the tip touching the vertical member. For convex welds, use the single arc corners for measurement. Place the single arc edge flush to base material so the blade tip touches vertical member. If the tip touches the vertical member, the weld size is as indicated (see Figure 18a). For concave welds, use the double arc corners for determining if the welds are excessively concave (see Figure 18b). If they are, more filler material is required to build weld throat to the size where the tip between the double arcs touch. Place the double arc edge flush to the base material so the tip touches the vertical member. If the tip between the double arcs touches the center of the weld, the weld is the profile desired and is the size indicated.

Figure 17. Fillet weld gauges.

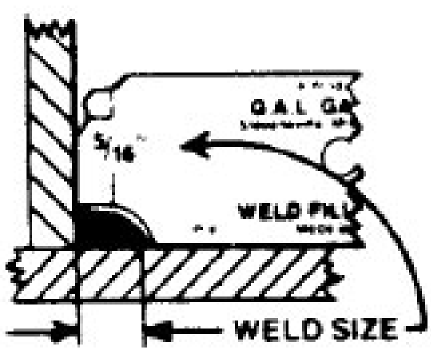

Figure 18a. Fillet weld gauge measuring a convex fillet weld.

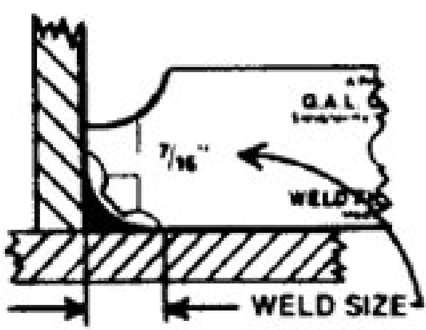

Figure 18b. Fillet weld gauge measuring concave fillet weld.

For convex fillet welds where the width of the weld face is greater than 5/16 inch and less than 1 inch, the maximum allowable convexity is 1/8 inch. For CJP groove welds where the thickness of the plates being joined is less than or equal to 1 inch, the maximum allowable convexity is 1/8 inch. For PJP groove welds where the throat size is less than or equal to 1 inch, the maximum allowable convexity is 1/8 inch.

Dimensional discontinuities can be avoided by proper fit up and by producing a weld of the proper size and profile. Be sure to check the plans and specifications before beginning, and weld size and profile after welding.

When channel splicers are used, a common dimensional discrepancy is a gap between the channel and the pile section(s). If the gap is larger than 1/16 inch, then the fillet weld size must be increased by the amount of the gap to compensate, up to 3/16 inch. Once the gap exceeds 3/16 inch, the weld cannot be accepted.

Incomplete Fusion - Lack of fusion occurs when the base metal fails to melt or mix with the weld material. Surface oxides, such as rust or scale, often cause this, as can insufficient welding heat and improper technique. In some cases, these discontinuities can be identified by a small gap between the fillet and the base metal or along the toe edge.

If no visual discrepancies are observed and if proper material preparation and welding practices are observed, it is generally assumed that complete fusion has occurred.

Incomplete Penetration - A CJP groove weld is designed to develop the full capacity of the pile section. Incomplete penetration can result from insufficient welding heat or insufficient weld material placement between passes. It is also critical that the CJP groove weld be back gouged to sound metal before welding from the backside. Lack of back gouging can trap slag in the weld and result in inadequate penetration at the root of the weld. UT can detect incomplete penetration on a completed weld, but the easiest way to ensure complete penetration is to verify the weld was back gouged to sound metal before completing the weld on the back side, and that the variables of the WPS are being followed.

Overlap - Overlap is a sharp surface connected discontinuity that forms a severe mechanical notch because the weld metal protrudes or flows beyond the toe of face of the weld without fusion. Overlap can occur as a result of improper preparation of the base metal or failure to control the welding process.

Porosity - Porosity is a cavity in the weld that is formed by gas escaping from the molten weld metal during solidification. It is commonly caused by contamination of the base metal or electrode but can also be caused by improper weld technique or too fast of a travel speed.

Porosity requirements are as follows:

- ***CJP groove welds shall have no porosity other than permitted by AWS.***
- ***For all other groove welds and for fillet welds, the frequency of porosity shall not exceed one in 4 inches of length, and the maximum diameter shall not exceed 3/32 inch.***

Undercut - A notch in the base metal along a leg characterizes a weld undercut. Excessive current or improper technique can cause undercut.

Allowable undercuts are as follows:

- ***Undercut shall be no more than .01 inches deep when the weld is transverse to tensile stress under any loading condition.***
- ***Undercut shall be no more than 1/32 inch deep for all other cases.***

Underfill - Underfill is a depression on the face of the weld extending below the surface of the adjacent base metal, resulting from the welder not filling the weld joint. Underfill is not acceptable, and the finished weld must meet the specified size.

Slag Inclusions - Slag inclusions result from non-metallic solid material being entrapped in the weld metal, between passes, or between weld and base metal. In general, slag inclusions result from faulty welding technique, failure to clean properly between weld passes, failure to back gouge, and conditions that lead to limited access for welding within the joint. Lighter than the weld material, they tend to float to the top of the molten metal. If the slag cannot escape, they become trapped in the weld. The welder should pay close attention to properly working the molten puddle to ensure that the slag rises to the top. The risk of slag inclusions can also be reduced by properly preparing the weld surfaces. This may include grinding joint boundaries or between weld passes to ensure no slag is caught in sharp notches or gaps.

Visual Inspection and Test Checklist

All the necessary information to successfully perform VT inspection on pile welds can be found in the contract plans, standard specifications as amended by the frequently used Special Provision for Structural Steel and Aluminum Construction, and this manual.

Before Welding

- ✓ ***Ensure welders adhere to MDOT's Welder Certification Program (non main member piles only) or Welder Qualification Program (non main member and main member piles).***
- ✓ ***Verify the WPS has been approved. WPS for non main member piling is included in Form 5627.***
- ✓ ***Check that joint preparation, alignment, root openings, bevels, and fit-up follow approved WPS and contract plans.***
- ✓ ***Ensure all weld surfaces are cleaned to remove all coatings, oil, grease, rust, dirt, mill scale, moisture, or other contaminants within the weld zone.***
- ✓ ***If the ambient temperature is below 32 degrees Fahrenheit, the pile splice area must be preheated and maintained at 70 degrees Fahrenheit. Welding is not permitted when the ambient temperature is below 0 degrees Fahrenheit. The engineer may approve heating and housing.***
- ✓ ***Ensure contractor QC is present and in accordance with the contractor's MDOT approved QCP.***

During Welding

- ✓ ***Verify proper electrode storage, including the following:***
  - ***Electrodes to be used in a short time should be removed from a hermetically sealed container or a hot box kept at a minimum of 250 degrees Fahrenheit.***
  - ***Any electrodes exposed to the atmosphere for more than two hours must be re-dried for a minimum of two hours at a minimum of 500 degrees Fahrenheit.***
  - ***Electrodes not to be used within two hours should be stored in a hot box at a minimum of 250 degrees Fahrenheit.***
  - ***Electrodes that have been wet may not be re-dried.***
  - ***Electrodes that have been dropped on the ground, exposed to rain, or not stored properly must be discarded and cannot be used.***
- ✓ ***Verify any tack welds used during fit up are ground to sound metal and not included in the final weld.***
- ✓ ***Verify the welder is following the MDOT approved WPS and contractor QCP and inspecting his/her own work.***
- ✓ ***Verify the welder is cleaning between passes and removing all slag and repairing any rejectable discontinuities between passes. All weld deficiencies and subsequent corrections must be noted on Form 5629.***
- ✓ ***Verify the welder is back gouging to sound metal for CJP groove welds before welding the backside..***

Final Weld Inspection

Final inspection of the completed weld should not begin before the weld has cooled to ambient temperature.

- ✓ ***Verify all slag, spatter, and debris have been removed from the weld surface.***
- ✓ ***Verify the weld size, length, and profile meet requirements.***
- ✓ ***Verify any arc strikes have been ground smooth to sound metal.***
- ✓ ***Check the final weld for any cracks, porosity, undercut, underfill, overlap, lack of penetration, or lack of fusion.***
- ✓ ***Do not accept welds with rejectable discontinuities. These welds must be repaired or replaced. Welds with no rejectable discontinuities shall be accepted and recorded as such on MDOT Form 1161L (or 1161 for LFD projects).***

Photo Examples – Acceptable

Figure 19. Fillet weld using stringer beads.

Figure 20. Fillet weld using weave bead.

Figure 21. H-Pile beveled for a full penetration groove weld.

Figure 22. Good fit up and alignment.Groove weld showing progression of passes.

Figure 23. Groove weld showing progression of passes.

Figure 24. Back gouged to sound metal.

Figure 25. Back gouging with a die grinder.

Figure 26. Welding in process. Note slag to be removed to sound metal by back gouging.

Figure 27. Root pass of a full penetration groove weld free of slag and ready for additional passes.

Figure 28. Additional passes being added to the root pass.

Figure 29. Back gouging to sound metal before welding the back side.

Figure 30. Completed full penetration groove weld. Note that all slag and arc strikes have been removed. Grinding and additional weld metal was added on the flange edges to correct minor misalignment.

Photo Examples - Unacceptable

Figure 31. Improper root opening, unprepped surfaces, pile misalignment.

Figure 32. Excessive gap between splicer and pile, incorrect location of fillet welds.

Figure 33. Insufficient back gouging and incomplete penetration.

Figure 34. Porosity.

Figure 35. Misalignment, arc-strikes, unacceptable profile, contaminated surfaces, slag, undercut, porosity, etc.

Figure 36. Misalignment, unacceptable profile, slag.

Figure 37. Slag, undercut, underfill, and arc strikes.

Figure 38. Underfill and use of an unapproved wire fed process (GMAW). Note wire protruding from weld.

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