**SAMPLE SPECIFICATION for THERMAL INTEGRITY PROFILING (TIP)**

***October 1, 2024***

*The user of this sample specification should recognize that each project has unique requirements. Thermal Integrity Profiling can be applied to cast-in-place elements having a reinforcing cage, center bar, or other means of thermal wire attachment and a heat differential between placement and peak temperature of at least 10 to 15°F. Applicable types of cast-in-place elements for thermal integrity profiling include drilled shafts, auger cast-in-place piles, drilled displacement piles, micropiles, tangent and secant walls, barrettes, and slurry wall panels. This sample specification will therefore refer to all of these cast-in-place types hereafter as deep foundation elements.*

*The project’s deep foundation type, its installation procedures, geometry and reinforcement details, and its purpose and performance requirements should all be considered by the specifier in modifying this sample specification to address and satisfy project specific requirements. For example, the requirements for a heavily loaded end bearing element differ substantially from those of a wall. This sample specification includes commentary throughout to facilitate final specification development by the end user. Contractual items are limited since each owner, agency, or project generally has its own requirements.*

1. **DESCRIPTION**

The Thermal Integrity Profiling (TIP) method uses the heat generated by curing cement *(hydration energy)* to assess the structural integrity of cast-in-place deep foundation elements as well as the extent and location of irregularities, if encountered. TIP assesses the integrity of the concrete or grout both between and surrounding Thermal Wire® Cables*(hereafter referred to as thermal wires or TIP wires)* cast into the element. In circular elements, the expected temperature at any location is dependent on the element diameter, mix design, time of measurement, and distance to the center of the element. TIP measurements can be used to estimate the shape of circular foundation elements. In non-circular elements, a qualitative assessment of the thermal profile can be performed. This includes assessing shape variations, alignment of foundation reinforcement, and potential regions of lower quality concrete. TIP measurements on parallel element faces can be used to assess shape variations. In all cases, the TIP records should be compared with concrete pour logs and construction records to evaluate the overall quality of the deep foundation element.

TIP data is acquired from thermal wires which are zip tied to the rebar cage or center reinforcing bars. For concrete elements, the cage is inserted into the excavation prior to commencing concrete placement. For grout elements, a cage or center bar is typically plunged into the grout filled excavation following auger or drill tool removal. Because the TIP method relies on the heat of hydration, it is essential that TIP wire data collection begin within 2 hours of wire embedment in concrete or grout.

***Commentary:*** *TIP data is generally evaluated between the time of ½ peak to peak temperature. Depending upon the element size and mix properties, this ½ peak to peak temperature window generally occurs 8 to 72 hours after concrete or grout placement. Smaller elements have shorter ½ peak to peak temperature analysis windows, between approximately 4 to 48 hours. Therefore, good communication between Contractor and TIP Consultant is essential so that data is collected during this critical early time window after placement.*

*As noted above, the TIP method uses the heat of hydration to assess structural integrity. For appropriate method use and result interpretation, concrete or grout mixes should therefore have a temperature increase of at least 10 to 15° F between placement and peak temperature. In low heat cement mixes with temperature increases below this threshold, Crosshole Sonic Logging may be a more applicable integrity testing method.*

*Robinson (2024) reviewed thermal integrity profiling results for 2104 drilled foundations and found 15% had anomalies. The quantity and location of detected anomalies within the drilled elements were similar to previous assessments of cross hole sonic logging and gamma-gamma logging integrity testing methods. In the drilled foundations having TIP identified anomalies, 28% had identified anomalies within two diameters of the bottom of the element with 75% of those occurring within one diameter of the bottom.*

TIP measurements that are cooler than normal may indicate inclusions, necks, or reduced quality concrete. Warmer than normal TIP measurements in one but not the corresponding diametrically opposite or parallel face opposite thermal wire locations are indicative of bulges exceeding the normal element shape. Variations in temperature *(one warmer than average, the other cooler than average)* between opposite pairs of thermal wires reveal cage eccentricities, such as cage shifting or misalignment between the cage and excavation. TIP procedures are standardized by ASTM D7949, Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations.

1. **SUBMITTALS**

**2.1 Qualifications of TIP Consultant.** The TIP Consultant shall be an independent testing agency having at least one (1) year of experience in TIP testing and analysis having completed five (5) projects of comparable complexity. The TIP Consultant responsible for performing and interpreting the TIP results shall be a licensed professional engineer in the project location. The TIP Consultant qualifications and the specifications of their proposed TIP testing equipment shall be submitted to the Engineer for approval prior to beginning \_\_\_\_\_\_\_ (*drilled shaft, auger cast-in-place pile, drilled displacement pile, micropile, tangent or secant wall, barrette, or slurry wall)* installation.

**2.2 Thermal Integrity Profiling Method Statement.** Twenty-one (21) days prior to initial element construction, theContractor and their TIP Consultant shall submit a TIP method statement to the Engineer. The method statement shall include proposed thermal wire attachment procedures, any thermal wire splice procedures, and the proposed procedures to check thermal wire functionality before wiring, post wiring and before lifting, and after placement in the element. A summary of the name and location of each deep foundation element to be tested, and the thermal wire order length for that element. The wire attachment procedure to bypass any cage stiffeners or internal rigs shall also be addressed. The method statement shall also describe a proposed replacement procedure should a damaged or non-operating wire be identified before cage lift. The method statement shall include proposed procedures for TAG and TAP-Edge attachment, initiation time of data acquisition, as well as TIP data storage, retrieval, and reporting. The Engineer shall have seven (7) days to review and approve the proposed TIP method statement or request modifications and resubmittal.

***Commentary:*** *A well thought out pre-installation method statement can greatly improve successful implementation of TIP testing by identifying key procedures and potential risks to TIP wire damage. Cage lifting and concrete placement procedures should be reviewed and discussed for potential negative impacts on thermal wires. Cages lifted in multiple sections will require pre-manufactured quick connect splices to be fabricated on the thermal wires.* *Proximity to other cage elements that can cause damage to wires such as cage centralizers or CSL tubes should be identified and avoided. TIP wire locations should also avoid any components that require torch cutting or removal after wire attachment.*

*For thermal wires on center bar reinforcement, the bar pickup and handling procedure should be detailed to avoid wire and node damage that can occur from dragging the bar during pickup or from sling placement over the bar and wire. Significant thermal wire slack to accommodate sling attachment can lead to erroneous TIP results that can be avoided by an appropriate handling plan in the TIP method statement.*

**3.0 MATERIALS AND EQUIPMENT**

**3.1 Thermal Wire Cables.** Each reinforced element shall be equipped with thermal wire to permit possible TIP testing and analysis. The thermal wires shall have digital sensors located one foot apart along the specified embedded length and shall be capable of operating at temperatures up to 221° Fahrenheit. The Contractor shall furnish and install thermal wires in accordance with the manufacturer’s approved attachment procedures. The number of thermal wires to be installed shall be based upon the foundation type, dimensions, and construction sequencing. Refer to Section 3.2 for TIP wire quantity and wire spacing requirements.

***Commentary:*** *The actual cost of the thermal wires is low compared to the cost of the foundation. Installing wires in all foundation elements and collecting thermal data during curing is highly recommended so that any element can be subsequently evaluated in detail if any difficulties or irregularities are noted in the construction records. It is critical to remember that the TIP method requires the data to be collected early in the curing process. Therefore, the decision to require data collection must also be made in conjunction with the decision to install embedded wires. Embedded wires without accompanying data collection during curing provide no value. The decision to perform TIP analysis and reporting on collected data can be made after reviewing construction records. However, TIP analysis cost is a small percentage of the wire, wire installation, and data collection components.*

**3.2 Required TIP Wire Quantities and Wire Spacing.** Depending upon the deep foundation element being constructed, the element may have a circular, rectangular, or other multi-faced shape. In circular reinforced elements, install one thermal wire for every 10 to 14 inches of element diameter. For circular elements less than two feet in diameter constructed with a reinforcing cage, install a minimum of three thermal wires spaced equidistant around the cage. For circular elements less than 30 inches in diameter with only a center reinforcing bar, install one thermal on the center bar. For rectangular or other multi-faced elements, thermal wires shall be placed at each element corner location, and then along the parallel faces with the distance between the cables not exceeding \_\_\_\_ *(typically three)* feet.

***Commentary:*** *Drilled shafts, auger cast-in-place piles, drilled displacement piles, and tangent walls often have circular reinforcing cages. Secant walls frequently have unreinforced circular primary elements subsequently intersected by reinforced circular secondary elements. Micropiles and small diameter cast-in-place piles may only have center bar reinforcement. Barrettes may be constructed as reinforced rectangular,* T, L, +, *or* H *shapes. Slurry wall panels are typically reinforced and rectangular. Thermal wires quantities and wire spacing therefore varies depending upon the foundation element type and its’ reinforcement. For rectangular and multi-faced elements, the number of thermal wires and their locations shall not exceed the maximum spacing requirements in Section 3.2 and be in accordance with the approved Thermal Integrity Profiling method statement.*

Thermal wires shall be installed uniformly and equidistantly around the element circumference or perimeter such that each wire is spaced parallel for the full length and at the maximum distance possible from each adjacent wire. Wire lengths shall extend from the bottom node located one inch above the bottom of the cage or center bar to the top node located above the top of poured concrete or grout surface. All parties working on or around the cage shall be informed that thermal wires shall be given the appropriate care so that they are not damaged, or their top connector embedded in concrete or grout during installation of the reinforcement cage and concrete or grout placement. Extra wire length with nodes is appropriate to accommodate foundation length overruns or over pouring above planned top of foundation.

***Commentary:*** *Many specifications prohibit the reinforcing cage from resting on the bottom of the foundation excavation. It is important for the bottom thermal wire node elevation on the reinforcing cage or center bar to be clearly known relative to the elevation of the excavation bottom. This is particularly important for correct result interpretation when results indicate potential anomalies at the foundation base. It is common for the bottom node to be located at or within 1-inch from the bottom of the suspended cage or center bar. ASTM D7949* *requires embedded thermal sensors to be placed within 6 inches of the bottom of the foundation element.*

*If significant foundation element length variability is anticipated during drilling, the TIP wire order lengths with nodes should be increased to include the expected variation. Longer wires will allow the requisite number of thermal nodes to capture the top and bottom temperature roll-offs throughout the embedded foundation element length.*

*Unplanned splicing of thermal wires in the field to increase the wire length cannot be accommodated as each wire is programmed with a unique serial number and total node count when manufactured. Planned splices, such as required for cage sections, can be accommodated using thermal wires manufactured with splice connections per Section 3.3.*

**3.3 Thermal Wire Splices.** Reinforcing cages may be furnished in sections and spliced over the excavation. When sectional cages are used, thermal wires shall be furnished in appropriate section lengths and spliced using planned splice couplings at the cage joint. Construction records shall document the location of each splice and the number of overlap nodes per Figure 1.

***Commentary:*** *For spliced cages, alignment and field splicing of the thermal wires must be properly planned and implemented. The location of the wires on the reinforcing element must align in the upper and lower sections. Horizontal node locations above and below the splice must be planned so that the vertical distance between the top lower cage node and bottom upper cage node is one foot. The cable shall be looped at the splice to provide slack and satisfy node tolerance requirements. An example splice detail with overlap nodes is provided in the attached Figure 1. Reinforcing cage splices must be carefully planned to reduce injury risk to the field crew from cage slippage during wire splicing.*

*The use of full-length TIP wire runs in spliced cages should not be permitted. TIP wire must be installed on the inside of the cage to reduce the risk of damage caused by cage contact with the excavation sidewall. This greatly complicates wire extension as cage sections are added over an open excavation. Transitioning thermal wire attachment from the interior to the exterior of the cage at a cage splice also increases the risk of inoperable wires from wire damage.*

**3.4 TIP Equipment.** Provide a Thermal Integrity Profiler (TIP) system manufactured by Pile Dynamics, Inc., 30725 Aurora Road, Cleveland, OH 44139, USA; [www.pile.com/pdi](http://www.pile.com/pdi); email: info@pile.com; phone: +1 216-831-6131 or equivalent. The thermal integrity profiling equipment shall include:

1. TIP Data Acquisition System with TAG and TAP-Edge units and cloud access to automatically monitor, collect, and store temperature versus time data at 15-minute intervals*.*
2. Thermal Aggregator for Wires (TAG) with cellular functionality for cloud capability. Provide a minimum quantity of one TAG unit per each element to be tested concurrently. At least one spare TAG unit should also be available on site.
3. Thermal Acquisition Port (TAP-Edge) with TAG communication capability. Provide a minimum quantity of one TAP-Edge unit per wire for each element to be tested concurrently. At least one spare TAP-Edge unit shall also be available on site.
4. **Thermal Wire Tester Box for Wires. Provide a m**inimum quantity of one Tester Box available on site.

Commentary: *The number of TAG and TAP-Edge devices is dependent upon the foundation installation schedule and distance between curing foundation elements. Batteries on the TAG and TAP-Edge devices also require periodic recharging which should be considered in the quantities required to meet the construction schedule. Multiple TAG and TAP-Edge units are typically required. One Thermal Wire Tester Box should always be available where wires are being installed.*

**4.0 TESTING**

**4.1 Foundation Information.** Within 6 hours after concrete or grout placement, the Contractor / Foundation Subcontractor shall provide the following information to the TIP Consultant for each foundation element to be tested:

* as-constructed foundation lengths,
* as-constructed concrete top and bottom elevations,
* installed TIP wire lengths and positions,
* cage and TIP wire splice locations,
* construction dates,
* detailed construction records including casing, auger, and excavation details, etc.,
* concrete pour log.

**4.2 Contractor Wire Attachment and Assistance.** The Contractor shall provide suitable safe access to the site, reinforcing cage or center bar, and the foundation elements to be TIP tested. The Contractor shall provide all labor and plastic zip ties for TIP wire attachment in accordance with the approved TIP procedures. The TIP Consultant shall be present on site for the first foundation element wired and installed, and for additional training whenever the site personnel installing TIP wire changes. The TIP Consultant shall provide training and assistance to the Contractor’s personnel on TIP wire attachment procedures, Tester Box usage, TAG and TAP-Edge equipment attachment and Cloud communication, cable splicing (if required), and required documentation for TIP analysis.

TIP wire shall be laid naturally along a longitudinal bar in a protected location adjacent to the bar. Thermal wires shall not be pulled and pre-tensioned before attachment to a bar. The Contractor shall use plastic zip ties to secure each thermal wire cable to the adjacent reinforcing bar at one-foot intervals along the bar. Each zip tie shall be located equidistance from the TIP nodes and be snug tight at the mid-point between sensors but not overtightened. The TIP wire nodes shall be positioned and attached at the same vertical location in the cage from top to bottom. TIP wires shall not be trimmed, nor attached using steel tie wire. Spliced thermal wire shall match the factory assigned serial numbers and follow the manufacturer’s assigned section sequences. The Contractor may use a PEX Gun to facilitate TIP wire attachment on up to 2-inch diameter bars.

***Commentary****: Thermal wires should be attached snug tight to the bars such that a wire can move no more than 3/8 inch perpendicularly from the longitudinal bar in any direction (3/4 inch total movement) between node locations. This should accommodate minor flexing of the cage or bar during lifting while maintaining node location placement on the cage.*

*Thermal wire splice sections are sequenced by the manufacturer and must be spliced together using the assigned wires in the assigned order. Failure to pair the correct sections together in the correct order will result in inoperable wires and lost data.*

**4.3 Data Analysis Quantities.** TIP data analysis shall be performed on \_\_\_ *(all, a number, or a percentage)* of the deep foundationelements. The elements to be analyzed shall be chosen after installation by the Engineer.If significant irregularities are identified, the number of elements analyzed may be increased by the Engineer.

***Commentary:*** *If only a percentage of elements are to be analyzed, the elements selected for analysis should be based on construction records. Additional foundation elements should be selected for analysis at random by the Engineer. When one foundation consists of multiple elements, the number of elements analyzed should increase as the number of elements decreases due to reduced redundancy in the foundation.* *For sensitive or critical structures, or for those with minimal foundation redundancy, every element should be analyzed.*

**4.4 TIP Procedure.** Thermal Integrity Profiling must be performed during the curing process. The Contractor shall connect the TAG and TAP-Edge units to each tested element no later than two (2) hours after concrete placement or grout embedment. The Contractor shall confirm that the TAG and TAP-Edge units are operational and collecting TIP data.

***Commentary:*** *Experience indicates the best analysis time occurs between ½ peak temperature to peak temperature which typically occurs between 8 to 72 hours of concrete or grout placement in larger elements and 4 to 48 hours in smaller elements. Once the foundation cools and normalizes to ambient conditions, thermal integrity profiling data cannot be assessed for integrity.*

Data shall be collected every 15minutes. The TIP Consultant can approve disconnecting the TAG and TAP-Edge units once the collected data has clearly exceeded peak temperature. The TIP Consultant shall promptly notify the Engineer if potential anomalies are indicated by locally low temperatures relative to the average temperature at that depth, or average temperatures significantly lower than the average temperatures at other depths.

TAG and TAP-Edge units shall remain connected to the thermal wires until directed by the TIP Consultant. If the site location does not support use of a Cloud based system, the TIP data must be manually connected to a main TIP data acquisition unit and the data files periodically downloaded and reviewed. The TAG and TAP-Edge units must be reattached to the same serial number thermal wire if data review suggests reattached is required. Alternatively, the TAG and TAP-Edge units can be left attached to the element for a time 25 percent beyond the historical time to peak temperature at the site for that element size and mix.

**5.0 ANALYSIS AND REPORTING**

**5.1 TIP Results.** Results of the Thermal Integrity Profiling tests shall be presented in a written report within five working days of completion of testing the foundation element. The final analysis and report shall include:

1. Graphical displays of all temperature measurements versus depth.
2. Graphical display and discussion of the top of shaft (TOS) and bottom of shaft (BOS) adjustments to temperature vs depth plots for end effects.

***Commentary:*** *The TOS and BOS adjustments are required for all foundation shapes and types. The TOS adjustment addresses the environmental affect at the top of the element as heat is dissipated radially into the soil and upward from the exposed top surface into the air. The BOS adjustment addresses the environmental affect at the base as heat is dissipated radially into the soil as well as downward from the foundation base into the soil.*

*The scale BOS and TOS adjustments in feet are approximately 0.4 times the square root of the elapsed time in hours since concrete placement. The generally acceptable lower and upper limit for this value is 0.3 and 0.5, respectively. Any deviation from the manufacturer’s guidelines should be reported and justified in the report.*

1. Graphical display and discussion of any mid-shaft adjustments to temperature vs depth plots for other environmental effects.

***Commentary:*** *Mid-shaft adjustments may be required for any foundation shape and type. Mid-shaft adjustments address additional environmental boundary effects occurring along the shaft length such as transitions from air to water, water to soil, casing created air gaps inside or outside of casing to soil or other clearly identifiable boundary transitions. Mid-shaft adjustments should only be performed when clearly justified by the boundary conditions and in accordance with manufacturer’s guidelines. Any deviation from the manufacturer’s guidelines should be reported and justified in the report.*

1. Discussion of unusual temperatures, particularly significantly cooler local deviations of the average at any depth from the overall average over the entire length.
2. Discussion of any significant *(greater than 10°F)* variations in temperature between thermal wires *(at each depth)* which in turn correspond to variations in cage alignment.

1. Any significant variation in the overall average temperature compared to other similar foundation elements at the site.

***Commentary:*** *In circular elements, temperature is proportional to the effective average radius computed from the actual total concrete or grout volume installed (assuming a consistent mix throughout). The effective radius at any point can then be determined from the temperature at that point compared to the overall average temperature. The term effective radius is sometimes misinterpreted as a measured geometric radius. It is more accurately interpreted as an indication of the foundation element property EA, where E is the elastic modulus and A is the cross-sectional area. Hence, an increase or decrease in the effective radius may represent a change in either the modulus or cross-sectional area of the element. When accurate volume information is provided for a mix with consistent properties, changes in the effective radius may be used to characterize changes in cage offset, alignment, and cover.*

**5.2 TIP Interpretation Criteria.** The interpretation criteria for integrity evaluation using the TIP method shall follow the recommendations published by Piscsalko et. al., (2016) with modification suggested by Belardo et al., (2021). TIP integrity results are Satisfactory (S) if the effective average radius reductions range from 0 to 6% and the local cover criteria is met. Results require Further Evaluation (FE) if the effective average radius reduction exceeds 6%, or if the local cover criteria is not met.

***Commentary:*** *When classified as Further Evaluation (FE),* *the TIP Consultant and project team should determine the possible cause of the anomalous zone. Critical analysis input details such as the concreted length, volume placed, cage diameter, and distance of the bottom node of the TIP wire to the element bottom should be checked. The clarified information should be provided to the Engineer of Record for further assessment based on the foundation elements loading conditions and performance requirements.*

*Placed volumes are a critical input into the TIP calculated effective radius and cover. It should be recognized that some inaccuracy is inherent in estimating the placed volume. The exact volume of material lost for sampling, pump truck priming, overpouring, etc., are often unaccounted for or underestimated. Actual partial truck volumes installed in the foundation element can also be difficult to accurately assess. This should be considered in the application of the interpretation criteria.*

*Too frequently, designs use the minimum specified cover assuming that can be readily achieved without allowing for any deviation in cage alignment. If a minimum cover of 3-inches is required for durability, a cover greater than 3-inches should be incorporated in the design to accommodate cage shifting or sidewall variations that regularly occur. Depending upon the foundation diameter and the aggressiveness of the surrounding environment, specifications often specify a minimum cover of 3 to 6 inches with a cover tolerance of -1.5 inches to -3 inches.*

**5.3 Temperature vs Time Plots.** Plots of temperature vs time shall be prepared at any location within a foundation element where TIP data indicates a FE result. At the anomalous location, the temperature versus time plot shall include the individual temperature of each wire and the average of all wires. A comparison of temperature vs time data for the node location of concern should be compared to other “normal” or “expected” temperature vs time data from element nodes in similar conditions with no integrity concerns.

***Commentary:*** *Temperature vs time plots are extremely valuable in identifying “soft bottom” conditions and base anomalies as well as characterizing anomalies at other locations. Examples illustrating the usefulness of temperature vs time plots can be found in Coleman and Belardo (2023). Some specifications require a temperature vs time plot for the lower two nodes on each tested element to be included as part of the TIP report.*

**6.0 FOUNDATION INTEGRITY ACCEPTANCE**

The Engineer of Record shall have five working days to evaluate the results and determine whether the foundation element integrity is acceptable. The Contractor shall not perform any load testing or other construction associated with the foundation elements until after integrity acceptance by the Engineer. If the element integrity is accepted by the Engineer, the Contractor may then proceed with construction. If the Engineer determines the element integrity is not acceptable, the element shall be cored, repaired, remediated, or replaced by the Contractor.

**7.0 MEASUREMENT AND PAYMENT**

**7.1 Basis of Measurement.** Thermal Integrity Profiling tests shall be measured per each foundation element tested and accepted by the Engineer. Quantities of Thermal Integrity Profiling tests will be as shown on the plans.

**7.2 Basis of Payment.** The completed TIP results and report shall be paid for at the contract price for “Thermal Integrity Profiling” per each foundation element tested, per linear foot, or per day of TIP testing. This shall constitute full compensation for all costs incurred relating to the TIP testing including, but not limited to procurement, preparation and installation, conducting the tests, and subsequent reporting of test results.

***Commentary:*** *Payment for thermal wire data collection is dependent on the TIP Consultant’s involvement with the process. If the TIP Consultant is on site to personally install wires or collect data, the “per day of testing” basis is considered the most equitable. If the Contractor performs the wiring and the equipment pushes the data to the cloud or it is collected by the contractor and electronically transmitted, then a “per shaft tested” basis may be more equitable.*

**REFERENCES**

ASTM D7949-14 (2014*). “Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations,”* ASTM International, W. Conshohocken PA. [www.astm.org](http://www.astm.org).

Belardo, D., Robertson, S., Coleman, T. (2021). *“Interpretation and Evaluation of Thermal Integrity Profiling Measurements,”* DFI 46th Annual Conference on Deep Foundations, Las Vegas, NV.

Coleman, T. and Belardo, D., (2023). “*Drilled Shaft Base Quality Reductions Identified with Thermal Integrity Profiling,”* DFI 48th Annual Conference on Deep Foundations, Seattle, WA.

Piscsalko, G., Likins, G., and Mullins, G., (2016). “*Drilled Shaft Acceptance Criteria Based on Thermal Integrity Profiling,”* DFI 41st Annual Conference on Deep Foundations, New York, NY.

Robinson, B., (2024). *“Frequency of Observed Anomalies in Drilled Piles Integrity Tested by Thermal Methods,”* The International Foundation Conference and Equipment Exposition, IFCEE, Dallas, TX

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**Figure 1. Overlap and Offset Detail at Splice**