




**Houston Metro
TPSS SE1 Substation Replacement**

TECHNICAL SPECIFICATION

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SECTION 18020

MAIN TRACTION POWER SUBSTATION

PART 1 – GENERAL

1.01 SUMMARY

- A. Description
 - 1. Traction power substation shall be package-type unit and designed to minimize on-site construction and installation costs. The traction power substation shall match the existing substation dimensions, weight, equipment arrangement and floor opening to utilize existing conduit stub-ups.
 - 2. Substation equipment shall be housed in a self-supporting and transportable enclosure suitable for outdoor installation.
 - 3. All equipment, with like function, shall be interchangeable within and between existing METRO substations.
 - 4. The new substation shall be installed on raised foundations.
 - 5. The traction power supply system is designed with minimum functional life expectancy of 30 years.

1.02 REFERENCES

- A. Equipment Complies with applicable provisions of the following references:

ANSI C2	National Electrical Safety Code
ANSI C29.1	Test Methods for Electric Power Insulators
ANSI C37.04	Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis
ANSI C37.06	Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis
ANSI C37.09	Test Procedures for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

ANSI C37.010	Application Guide for AC High-Voltage Circuit Breaker Rated on a Symmetrical Current Basis
ANSI C37.011	Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
ANSI C37.012	Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis
ANSI C37.1	Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control
ANSI C37.2	Standard Electrical Power System Device Function Numbers
ANSI C37.11	American National Standard Requirements for Electrical Control for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis
ANSI C37.13	Low-Voltage AC Power Circuit Breakers Used in Enclosures
ANSI C37.14	Low Voltage Direct-Current Power Circuit Breakers Used in Enclosures
ANSI C37.16	Low-Voltage Power Circuit Breaker and AC Power Circuit Protectors
ANSI C37.20.1	Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear
ANSI C37.20.2	Metal-Clad and Station-Type Cubicle Switchgear
ANSI C37.21	Control Switchboards
ANSI C37.30	Definitions and Requirements for High-Voltage Air Switches, Insulators, and Busbar Supports
ANSI C37.32	High-Voltage Air Switches, Busbar Supports, and Switch Accessories –Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide
ANSI C37.33	Rated Control Voltages and Their Ranges for High-Voltage Air Switches
ANSI C37.34	Test Code for High-Voltage Test Switches
ANSI C37.35	Application, Installation, Operation, and Maintenance of High-Voltage Air Disconnecting and Load Interrupter Switches
ANSI C37.40	Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fused Disconnecting Switches, and Accessories
ANSI C37.41	Design Tests for High-Voltage Fuses, Distribution enclosed Single-Pole Air Switches, Fused Disconnecting Switches, and Accessories
ANSI C37.46	Specifications for Power fuses and Fused Disconnecting Switches
ANSI C37.47	Specifications for Distribution Fused Disconnecting Switches Fused Supports and Current Limiting Fuses
ANSI C37.48	Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches Fused Disconnecting Switches, and Accessories

ANSI C37.50	Standard Test Procedures for Low Voltage AC Power Circuit Breakers Used in Enclosures.
ANSI C37.54	Indoor Alternating-Current High-Voltage Circuit Breakers Applied as Removable Elements in Metal-Enclosed Switchgear Assemblies –Conformance Test Procedures
ANSI C37.55	Metal-Clad Switchgear Assemblies - Conformance Test Procedures
ANSI C37.58	Indoor AC Medium-Voltage Switches for Used in Metal-Enclosed Switchgear - Conformance Test Procedures
ANSI C37.90	Relays and device Systems Associated with Electric Power Apparatus
ANSI C37.90.1	Standard Surge Withstand Capability (SWC) Tests for Protective devices and device Systems
ANSI C37.97	Protective device Applications to Power System Busbars
ANSI C37.100	Definitions for Power Switchgear
ANSI C39.1	Requirements for Electrical Analog Indicating Instruments
ANSI C57.12.00	General Requirements for Distribution, Power, and Regulating Transformers
ANSI C57.12.01	General Requirements for Dry-Type Distribution and Power, and Power Transformers
ANSI C57.12.10	Requirements for Transformers 23000 Volts and below 833/958 through 60000/80000/10000 kVA, Three Phase
ANSI C57.12.70	Terminal Markings and Connections for Distribution and Power Transformers
ANSI C57.12.91	Standard for Dry-type Transformers
ANSI C57.13	Requirements for Instrument Transformers
ANSI C80.1	Specification for Fittings for Rigid Steel Conduit, Zinc Coated
ANSI C80.3	Specification for Electrical Metallic Tubing, Zinc Coated.
ANSI C80.4	Specification for Fittings for Rigid Metal Conduit and Electrical Metallic Tubing
ANSI C84.1	Voltage Ratings for Electric Power Systems and Equipment
ANSI C92.1	Voltage Values for Preferred Transient Insulation Levels
ANSI X3.15	Standard for Bit Sequencing of ASCII in Serial-By-Bit Data Transmission
ASCII	General American National Standard Code
ASTM A6	Specification for General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Used
ASTM A36	Structural Steel
ASTM A53	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless
ASTM A370	Standard Methods and Definition for Mechanical Testing of Steel Products
ASTM A384	Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies
ASTM A475	Specification for Zinc Coated Steel-Wire Strand
ASTM B3	Specification for Soft or Annealed Copper Wire
ASTM B8	Specifications for Concentric-Lay Stranded Copper Conductor.

ASTM B33	Specification for Tinned Soft or Annealed Copper Wire for Electrical Purposes
ASTM B47	Specifications for Solid Grooved Copper Contact Wire
ASTM B105	Hard-Drawn Copper Alloy Wires for Electrical Connections
ASTM B173	Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors
ASTM B174	Specification for Bunch-Stranded Copper Conductors for Electrical Conductors
ASTM B187	Specification for Copper Busbar, Rod and Shapes
ASTM D149	Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies
ASTM D150	Method of Test for AC Loss Characteristics and Dielectric Constant (Permittivity) of Solid Electrical Insulating Materials
ASTM D229	Rigid Sheet and Plate Material Used for Electrical Insulation
ASTM D256	Impact Resistance of Plastic and Electrical Insulator Materials
ASTM D470	Standard Method for Testing Crosslinked Insulations and Jackets for Wire and Cable
ASTM D495	High Voltage, Low Current Dry Arc Resistance to Solid Electric Insulation
ASTM D638	Test for Tensile Properties of Plastics
EIA RS-232C	Physical Interface between Data Terminal Equipment and Data Communication Equipment
EIA RS-422	Electrical Characteristics of Balanced Voltage Digital Circuit
EIA RS-485	Standard for Data Communication Equipment
IEEE Std 1	General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation
IEEE Std 4	Techniques for High-Voltage Testing
IEEE Std 32	Requirements, Terminology, and Test Procedure for Neutral Grounding Devices
IEEE Std 80	IEEE Guide for Safety in Substation Grounding
IEEE Std 81	Guide for Measuring Ground Impedance of a Ground System
IEEE Std 241	Recommended Practice for Electric Power Systems in Commercial Buildings
IEEE Std 242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
IEEE Std 450	Recommended Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries for Generating Stations and Substation
IEEE Std 472	Guide for Surge Withstand Capability (SWC) Tests
IEEE Std 485	Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations.
IEEE Std 519	Guide for Harmonic Control and Reactive Compensation of Static Power Converter Substations

IEEE Std 525	Guide for Design and Installation of Cable Systems in Substations
IEEE Std 605	Guide for Design of Substation Rigid Busbar Structures
IEEE Std 730	Software Quality Assurance Plans
IEEE Std 802.1	Standard for Overall Architecture of Local Area Network and Internetworking
IEEE Std 802.8	Standard on Fiber-Optic LANS
IEEE Std 829	Standard for Software Test Documentation
IEEE Std 1012	Standard Software Verification and Validation Plans
IEEE Std 1016	Recommended Practice for Software Design Descriptions
IEEE Std 1653.2	Standard for Uncontrolled Traction Power Rectifiers for Substation Applications Up to 1500 V DC Nominal MA-2 Inspection Manual for Hot-Dipped Galvanized Products, Hot-Dip Galvanized Coating
MA-3	The Design of Products to Be Hot-Dipped After Fabrication
MIL-STD-1472	Military Standard-Human Engineering Design Criteria for Military Systems
NEMA 260	Safety Labels for Padmounted Switchgear and Transformers Sited in Public Areas
NEMA AB 1	Molded-Case Circuit Breakers
NEMA AB 2	Procedures for Field Inspection of Molded-Case Circuit Breakers Used in Commercial and industrial Applications
NEMA AB 3	Molded-Case Circuit Breakers and their Application
NEMA AB 4	Guideline for Inspection & Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications.
NEMA BU 1	Busways
NEMA C 1	Electrical Power Connectors for Substations
NEMA EI 2	Instrument Transformers
NEMA EI 21	Instrument Transformers for Metering Purposes, 15 kV and Less
NEMA FB 1	Fittings, Cast Metal Boxes, and Conduit Bodies for Conduit and Cable Assemblies
NEMA ICS 1	General Standards for Industrial Controls and Systems
NEMA ICS 2	Standards for Industrial Control Devices, Controllers, and Assemblies
NEMA ICS 3	Industrial Systems
NEMA ICS 4	Terminal Blocks for Industrial Control Equipment and Systems
NEMA ICS 6	Enclosures for Industrial Control Systems
NEMA L 11	Industrial Laminated Thermosetting Products.
NEMA LA 1	Surge Arresters
NEMA PB 1	Panelboards
NEMA PE 5	Constant-Potential-Type Electric Utility Battery Chargers
NEMA RI 2	General Purpose and Communication Battery Chargers
NEMA RN 1	PVC Externally-Coated Galvanized Rigid Steel Conduit & Intermediate Metal Conduit
NEMA SG 3	Low Voltage Power Circuit Breakers
NEMA SG 4	AC High-Voltage Circuit Breakers.

NEMA SG 5	Power Switchgear Assemblies
NEMA SG 6	Power Switching Equipment
NEMA ST 20	Dry-Type Transformers for General Applications
NEMA TC 2	Electrical Plastic Tubing (EPT) and Conduits (EPC-40 and EPC-80)
NEMA TC 3	PVC Fittings for Used with Rigid PVC Conduit and Tubing.
NEMA TC 6	PVC and ABS Plastic Utilities Duct for Underground Installation
NEMA TR 1	Transformers, Regulators, and Reactors
NEMA VE 1	Cable Tray Systems
NEMA WC 3	Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy, also ICEA S-19-81
NEMA WC 5	Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy, also ICEA S-61-402
NEMA WC 7	Standard to Cross-Linked Thermosetting Polyethylene Insulated Wire and Cable for Transmission and Distribution of Electrical Energy, also ICEA S-66-524
NEMA WC 8	Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy, also ICEA A-68-516
NFPA 70	National Fire Protection Association, National Electrical Code
NFPA 78	National Fire Protection Association, Lightning Protection Code
UL 67	Panelboards
UL 50	Cabinets and Boxes
UL 94	Test for Flammability of Plastic Materials for Parts in Devices and Appliances
UL 486A	Lugs for Used with Copper Conductors Wire Connectors and Soldering
UL 489	Molded-Case Circuit Breakers and Circuit Breaker Enclosures
UL 508	Electrical Industrial Control Equipment
UL 845	Standard for Motor Control Centers
UL 1236	Battery Chargers
UL 1564	Industrial Battery Chargers

1.03 SUBMITTALS

A. Substation Design Report

1. Provide a Substation Design Report including all calculations required for comprehensive substation design. As a minimum, include the following sections in the report:

- a. Design parameters.

- b. Statement of compliance with specified standards and codes to which each item of equipment is designed, manufactured and tested.
- c. Transformer/rectifier unit design calculations, including:
 - 1) Voltage regulation vs. load.
 - 2) Displacement power factor vs. load
 - 3) Efficiency vs. load
 - 4) Harmonic amplitude vs. load for 5th , 7th , 11th , 13th , 23rd , and 25th harmonics
 - 5) Commutating reactance
 - 6) Peak and sustained short circuit current
- d. AC and DC auxiliary system load calculations.
- e. Rating calculations for all AC and DC auxiliary equipment including fuses and molded-case circuit breakers.
- f. Battery and battery charger sizing calculations listing all battery and charger loads.
- g. Wire, control cable, and instrumentation cable sizing calculations.
- h. Wire/cable/terminal designation system.
- i. Substation HVAC system design calculations.
- j. Fully dimensioned substation layout drawing showing equipment clearances under normal operating conditions and when cubicle doors are open.

B. Protective Device Coordination Study Report

1. A device coordination study for LRV operation shall be provided. Manufacturer may use existing protective device setting if adequate for the new equipment.
2. Select type, characteristics, setting ranges, and model number of protective devices for substation DC switchgear, rectifier, transformer, and AC switchgear.
 - a. Develop protective device setting philosophy, perform device coordination calculations for all substation relays, and plot the resulting current versus time characteristics on log/log graph paper.
 - b. Coordinate the substation devices with the power utility devices and add the power utility protection characteristic onto the same graph.
 - c. Identify device mis-coordination, if any, and resolved the conflicts with the power utility.
3. Select type and characteristics of fuses, molded-case circuit breakers, and any other appropriate protective devices for the AC auxiliary power

supply system, signal/communications power supply system, and DC auxiliary power supply system.

- a. Coordinate characteristics of the fuses, molded-case circuit breakers, and protective devices.
 - b. Plot the resulting current versus time characteristics on appropriate graph paper.
4. Prepare a stand-alone study report including, but not be limited to, the following:
- a. Introduction.
 - b. Protective device setting philosophy.
 - c. Short circuit study.
 - d. Data on each protected item of equipment.
 - e. Catalog cut on each protective relay.
 - f. Narrative explanation and calculation of setting of each relay.
 - g. Device setting schedules for each substation indicating protected circuit service, device application, manufacturer and type, device tap block setting, time setting, instantaneous element settings, CT ratio or shunt size, PT ratio, and any appropriate remarks.
 - h. System and substation diagrams showing short circuit current flows and device locations.
 - i. Protective device current versus time coordination curves prepared on log/log or other appropriate graph paper.
 - j. Conclusion.
5. Submitted the report to METRO.

C. Product Data

1. Provide technical product data sheets for all items of the system equipment. Made use of standard equipment product data and specifications where practical. Described functional, design and performance requirements as well as identify the materials, fabrication procedures, factory and field tests and installation procedures. As a minimum include data on the following equipment:

- a. AC and DC circuit breakers.
- b. AC and DC switchgear.
- c. Molded-case circuit breakers.
- d. Rectifier transformers.
- e. Station power transformer.
- f. Rectifier diodes and fuses.
- g. Current and potential transformers.
- h. fuses and fused holders.
- i. Surge arresters.
- j. Protective devices and auxiliary relays.
- k. Instruments and indicating devices.
- l. Transducers and converters.
- m. Annunciators.
- n. Remote terminal units.
- o. Programmable logic controllers
- p. Disconnected switches.
- q. Batteries and battery chargers.
- r. Auxiliary power panelboard.
- s. Signal and communications power supply panelboard.
- t. Negative return/drainage equipment and negative grounding unit.
- u. Busbars, busbar insulation, and busbar connections.
- v. Cables and wires.
- w. Equipment enclosures.
- x. Lighting and temperature control devices.
- y. Fans and motors.
- z. Insulators and insulating materials.
- aa. Raceways.
- bb. Substation housing.
- cc. Control switches.
- dd. Space heaters.
- ee. Terminal blocks and connectors.
- ff. Paint and coating systems.
- gg. Other equipment.

D. Contract Drawings

1. Prepare detail design drawings for each traction power substation. All final Contract Drawings are sealed and signed by a Professional Engineer registered in the State of Texas. The Contract Drawings include, but are not be limited to:
 - a. Front cover sheet.
 - b. List of drawings.
 - c. Legend, abbreviations and notes.
 - d. System one-line diagram.
 - e. One line diagrams.
 - f. Substation equipment layout drawings showing, dimensions, aisle space and weights.

- g. Substation housing elevation and plan drawings showing roof, wall and base cross-sections.
- h. AC input and DC output cable connection diagrams.
- i. Schematic diagrams of transformers and rectifiers.
- j. AC and DC schematic diagrams of all AC circuit breaker circuitry including current transformers, voltage transformers, transducers, converters, protective devices, instrumentation, indication, controls and operating systems
- k. AC and DC schematic diagrams of all DC circuit breaker circuitry including, transducers, converters, protective devices, instrumentation, indication, controls and operating systems.
- l. Station power, auxiliary power, and signal/communications power supply system schematic diagrams.
- m. Connection diagrams of each cubicle showing internal wiring, cabling, terminal and connector arrangements, interconnections between cubicles, and connections to external devices.
- n. Interlocking logic diagrams.
- o. Annunciator and remote control equipment schematics.
- p. Substation housing electrical plans including lighting and HVAC circuits and their protection.
- q. Surge protection arrangement drawings.
- r. Equipment nameplate and label design drawings.
- s. Fully dimensioned drawings of each cubicle showing equipment arrangement, spacing, size, bracing and clearances using front, side, rear, and cross-sectional views.
- t. Fully dimensioned drawings of each cubicle showing front panel layout of equipment.
- u. Terminal block designations as well as conductor and cable schedules.
- v. Substation housing and equipment cubicle mounting and anchoring details.

E. Product Samples

- a. Submitted samples of the following products to METRO for approval:
 - b. Cables and wires, terminal blocks, and connectors.
 - c. Insulating materials.
 - d. Paint and coating systems.

1.04 SUBSTATION LOCATION

- A. As shown on Contract Drawings.

1.05 PRIMARY ELECTRICAL POWER SERVICE

A. General

1. Primary electrical power service to the traction power substations is supplied by the local electrical power utility company.
2. The power supply is at 60 Hz, using 12.47 kV, three-phase, four-wire underground cable distribution circuits as shown on Contract Drawings.

1.06 ELECTRICAL POWER UTILITY COMPANY REQUIREMENTS

- A. Receive the latest version of the electrical power utility company requirements for substation input design and complied with these requirements.
- B. Fabricate and purchase apparatus and equipment after completion of the electrical power utility company review and issuance of approval by the electrical power utility company.
- C. Submit three sets of final substation Contract Drawings to the electrical power utility company for review. As a minimum, include the following:
1. A plan showing the location of the service entrance equipment.
 2. A plan and elevation detail of the service entrance equipment including metering facilities and branch or sub-main interrupting devices.
 3. A listing of the major service entrance equipment and materials unless these are detailed on the drawings.
 4. A one-line diagram of the high voltage (primary) electrical system. This drawing included current and potential transformers and DC schematic diagrams of the relaying scheme, as appropriate.
 5. Conduit and manhole details. Interface between the electrical power utility company equipment and the traction power substation input feeder cable.
 6. The electrical power utility company review the drawings for general arrangement and conformity with the electrical power utility company technical requirements. The review and/or approval indicated functional design. By review of the drawings, the electrical power utility company indicated that the design is compatible with its equipment and service. Responsibility for proper design, operation, maintenance and safety of the customer's installation rests solely with the Contractor.
- D. Apply to the electrical power utility company for wiring inspection before work is started by filing the appropriate form. The electrical power utility company will inspect the electrical service entrance equipment when notified by the customer of its installation.

- E. Upon the Contractor request and utility approval of facilities, the City of Houston will submit to the electrical power utility company a certificate or letter of release for the installation and cut-in of each metered location.
- F. Application to and approval by electrical power utility company does not relieve the Contractor from responsibility to meet requirements by local inspection agencies. The electrical power utility company will not connect METRO's installations until the company received certificate of approval by the City of Houston.

1.07 DESIGN PARAMETERS

- A. Designed the traction electrification system taking into account the following parameters.

1. Substation AC input voltages are shown in Table 18020-3

Table 18020-3 - AC System Voltages

AC System Voltages	Voltage (kV)
Nominal Voltage	12.47
Maximum Voltage	13.7
Minimum Voltage	11.2

2. Substation DC output voltages at the nominal input voltage are shown in Table 18202-4.

Table 18020-4 - DC System Voltage

DC System Voltages	Voltage (V DC)
Substation Output No-Load Voltage	795
Substation Output Voltage at Rated Power	750

PART 2 – PRODUCTS.

2.01 UTILITY SERVICE CUBICLE

- A. Bottom Cable Entry

1. Design all traction power substation AC switchgear assembly to have bottom cable entry. The new substation bottom cable entry needs to be in the exact location of the existing cable entry.
2. Provide minimum of forty-two inches (42") of vertical clearance from the end of service conduit to the point where connection is required to install stress cones and terminators.
3. Protect the substation electrical entrance with intermediate class, metal-oxide AC surge arresters with polymer housing.
4. Design the primary connection of the arresters to be accessible for removal, when required for incoming line or cable testing.

B. Underground Utility System Supply

1. Traction Power Substation Isolating Disconnect Switch
 - a. Utility provided three-phase, isolating disconnect switch for service input at all traction power substations supplied by underground feeders.
2. Re-use existing duct bank from the electrical power utility company-metering cubicle to the traction power substation.
3. Select appropriate cable for connection between the electrical power utility company metering cubicle and line side of the Traction Power Substation.

C. Electrical Power Utility Company Metering

1. Metering is at the service voltage of 12.47 kV and was provided by the electrical power utility company.

2.02 AC SWITCHGEAR ASSEMBLY

- A. AC Switchgear Requirements. Provide AC switchgear assembly to conform to or exceed the requirements of ANSI C37.06, ANSI C37.20.2 and NEMA SG5 and to accommodate AC circuit breakers as specified herein.
 1. AC switchgear assembly to deliver, control, and measure the substation power requirements. Select reliable switchgear combining the following characteristics:
 - a) Fast Fault Interruption. To achieve arc interruption at the first current zero. At the time of current interruption, the dielectric strength between the parting contacts are sufficiently high to prevent restrike due to transient voltage recovery.

- b) Low Maintenance. The contacts are sealed in the insulating medium, and therefore, no contact maintenance are necessary.
 - c) Quiet Operation. During switching the interrupter extinguishes the arc quietly. Also, the sound level of the operating mechanism is low.
 - d) Long Service Life. The interrupter contact erosion is the only factor that will limit the circuit breaker life. The contacts are rated for the specified number of fault and load current interruptions.
2. Provide the AC switchgear assemblies in a lineup of dead-front, floor-mounted, freestanding, metal enclosures.
 3. Incorporate within the switchgear enclosures; instrument compartments, cable entrances, isolating switches, fuses for station power transformer protection, and AC circuit breakers.
 4. Divide each enclosure into completely segregated compartments to house the major part of switchgear such as busbars, cable terminations, control circuitry, protective devices, auxiliary relays, instrumentation, indication, annunciation, terminal blocks, fuses, and all other necessary devices.
 5. Completely enclose and segregate the individual equipment compartments by 11 gauge steel barriers.
 - a) Eliminate all unintentional openings between the compartments.
 - b) Enclose all live parts of switchgear equipment within the metal compartments.
 - c) Ensure that opening of the cubicle door exposes no primary circuit components when the interrupter is in the connected position.
 - d) Provide the barriers to isolate instruments, meters, relays, transducers, indicating devices and all control devices and their wiring from all primary circuit elements with the exception of short lengths of wire such as instrument terminals.
 - e) Ground all metal compartments to grounding busbar.
 6. Provide automatic shutters to prevent exposure of primary circuit elements when the circuit breaker is removed from its position.
 7. Cover the busbar conductors and connections with insulating material.
 8. Provide mechanical and/or electrical interlocks to ensure a proper and safe operating sequence.

9. Utilize the front door of the switchgear above the door through which the circuit-interrupting device is inserted into the housing as an instrument panel and as an access to instrumentation and control compartment within the housing.
10. Provide all switchgear components to be accessible from the front or top of the cubicle.
11. Furnish the switchgear with sufficient auxiliary contacts to provide for operation of the breaker control circuitry, indication, and interlocks. Provided at least four spare contacts, two normally open and two normally closed, each wired to an accessible terminal block.

B. Fuses for Station Power Transformer Protection

1. Protect the station power transformer by draw out fuses, or pull down fuses. Select fuses with blown fused indicators.
2. Provide interlocking device to prevent opening of the fused compartment when the circuit breaker on the secondary winding of the station power transformer is closed.
3. Provide the fused compartment with suitable insulation to enable the fuses to be safely removed while they are supplying the transformer magnetizing current. Prevent exposure of maintenance staff to high voltage parts during fused replacement.

C. Fuses for Potential Transformer Protection

1. Protect the substation potential transformers by draw out fuses. Selected fuses with blown fused indicators.
2. Provide the fused compartment with suitable insulation to enable the fuses to be safely withdrawn while they are supplying the transformer magnetizing current. Prevented exposure of maintenance staff to high voltage parts during fused replacement.

D. AC Circuit Breaker Type and Rating

1. Provide three-phase, horizontal draw-out, metal-clad, vacuum type AC circuit breakers with ratings as shown in Table 18020-5.

Table 18020-5 - AC Circuit Breaker Rating Data

Characteristic	15 kV Switchgear
Rated Maximum Voltage	15 kV
Rated Continuous Current	1,200 A

Characteristic	15 kV Switchgear
Low Frequency Withstand	36 kV
Full Wave Withstand - Basic Impulse Level	95 kV
Rated Voltage Range Factor K	1.3
Rated Short Circuit Current	18 kA
Maximum Symmetrical Interrupting Capability and Rated Short Circuit Current	23 kA
Closing and Latching Capability	62 kA
Rated Interrupting Time	5 cycles

E. AC Circuit Breaker Components. Provide each circuit breaker to consist of the following components;

1. Interrupter. Provide interrupter incorporating vacuum chamber with contacts to extinguish electrical arc during switching.
 - a. Provide the interrupter contacts inside the arc chamber housing built with a vacuum of 10^{-7} torr, minimum. Provide the chamber to maintain this vacuum level for at least 20 years.
 - b. Provide the interrupter contacts with high conductivity copper alloy. Construct the contacts to diffused the arc during switching and prevent local overheating of the contact pieces.
 - c. Use high quality metal bellows to enable movement of the moving contact. Guarantee the bellows for 30,000 operations.
2. Interrupter Support. Mount the interrupter on a flame retardant, track resistant, and high mechanical strength material support. Provide adequate insulation to ground, and to firmly position and hold the interrupter in placed with correct contact alignment.
3. Operating Mechanism. Use one basic and simple, spring-charged, stored-energy or solenoid operated mechanism for all AC circuit breaker types. Include in the mechanism all necessary equipment required for the circuit breaker operation, such as electrical spring charging motor, mechanical gears, linkages, closing solenoid, tripping solenoid as well as closing, opening and contact pressure springs. Provide the mechanism with the following features:
 - a. Operation of the circuit breaker through one close/open cycle on one motor charging.
 - b. Automatic motor charge of all springs upon completion of the close/open cycle to prepare the circuit breaker for the next close/open cycle.
 - c. Motor charging operation not exceeding 12 seconds.
 - d. Mechanically and electrically trip free mechanism.
 - e. Electrical operation.

- f. Manual cranking capability to permit spring charging should the motor power be lost.
 - g. Manufacturing with high quality parts with close tolerances to achieve operating consistency, reliability and the specified service life.
 - h. A non-resettable four digit mechanical operation counter on each circuit breaker.
4. Truck. Mount the circuit breaker components on a rugged, welded steel truck. Provide the truck as a precision-crafted and rigid assembly.
 - a. Provide the truck with guide rails and wheels to permit easy rolling-in and drawing out of the circuit breaker.
 - b. Ground the truck of each circuit breaker through a ground contact shoe.
5. Disconnecting Contacts. Provide power connections between the removable circuit breaker and the stationary switchgear structure with automatic, self-aligning, and self-coupling disconnecting devices.
 - a. Primary Contacts. Provide primary contacts for the main power connections. Provide the primary contacts using silver-plated, spring-biased, hard copper fingers installed on the draw out element and stationary cell studs on the stationary structure. Recessed the stationary contacts within insulated supports. Provide the contacts to have sufficient cross-sectional area of copper to permit removal of heat from the fingers and the studs, to avoid localized high loads, and to maintain high conductivity.
 - b. Secondary Contacts. Provide secondary contacts for control, auxiliary, and interlocking power circuits. Provide the secondary contacts to consist of multi-contact receptacles and plugs with a sufficient number of contacts to accommodate all secondary circuits and spares, without the used of auxiliary relays.
6. Circuit Breaker Positions. Provide the circuit breaker positions on an indicator located on the cubicle door. Provide each circuit breaker with the following positions:
 - a. Connected Position: Both primary and secondary disconnecting contacts are connected permitting operation of the circuit breaker during normal and fault conditions.
 - b. Test Position: The primary disconnecting contacts are disconnected and the secondary disconnecting devices are connected permitting testing of the circuit breaker operation.
 - c. Disconnected Position: Both primary and secondary disconnecting devices are disconnected permitting the circuit breaker withdrawal.

7. Draw Out Mechanism. Provide each circuit breaker with a manual, horizontal draw out mechanism.
 - a. Provide the mechanism to move the circuit breaker between connected and test positions and from test to disconnect positions with the cubicle door opened or closed. This is accomplished mechanically by insertion of a suitable crank through an opening in the cubicle door or front panel.
 - b. Provide the gear ratio of the mechanism so that one man can rack in or out the circuit breaker within one minute.
 - c. Provide the circuit breaker to be withdrawn from the switchgear housing when the breaker element, complete with its operating mechanism, is in the fully racked-out position.
 - d. Truck automatically disengages the draw out mechanism at the end of the circuit breaker travel to prevent any over-travel. Additionally, prevents over-travel by installed positive mechanical stops.
 - e. Provide interlocks to ensure that the circuit breaker can be drawn-out or rolled-in only when it is in open position.

2.03 RECTIFIER TRANSFORMER

A. Transformer Type. Provide dry-type, self-cooled, extra heavy duty traction power transformer suitable for installation in the substation enclosure.

B. Core Design

1. Steel Type. High-grade, cold-rolled, heat-treated, grain-oriented, high efficiency, high electrical resistance, high magnetic permeability, low sulfur and carbon content, non-aging, electrical grade silicon steel alloy with low no-load and load losses.
2. Laminations. Provide appropriate thickness of laminations to restrain eddy current losses in the transformer core, and to maintain adequate mechanical strength of the core. Provide only flat laminations with no waviness to minimize stresses when the sheets are pressed flat in a core.
3. Dimensions. Cut laminations for step-lap mitered joints. Provide core geometry to minimize core losses and sound level and to keep flux density below saturation point.
4. Core Supports. Provide adequate core supports so that the transformer can withstand the highly fluctuating load currents and the high occurrence of short circuits on the system without overheating, decrease in life expectancy, or injury. Provide special clamps and braces to strengthen the core to withstand mechanical and thermal stresses without damage. Provide additional heavy steel plates and

system of wedging and blocking as necessary. Provide the core to balance, restrain, and withstand frequent pulsating axial and radial electromagnetic forces in the transformer. Supports prevent any movement of the core and the windings, and eventual transformer failure.

5. Ground the core by means of flexible grounding strap.

C. Winding Design

1. Type. Provide circular winding design wound on epoxy-glass tubes using high purity, high conductivity, and insulated copper conductors.
2. Rating. Provide the primary winding to be consistent with the electrical power utility supply voltage. Select appropriate ratio between the primary and secondary windings to provided 750 VDC nominal voltage at the rectifier output at rated load and at rated primary voltage.
3. Connection. Provide the windings to supply 12-pulse rectifier. Connect one secondary winding in delta and one in wye to obtain 30E electrical phase shift between the secondary windings. Take into consideration inductive coupling of the windings and its effects on voltage regulation, impedance and short circuit current magnitude.
4. Electromagnetic Forces. Provide windings to minimize axial and radial
 - a. electromagnetic forces during load, overload, and short circuit conditions.
5. Supports. Provide adequate winding supports so that the transformer can withstand the highly fluctuating load currents and the high occurrence of short circuits on the system without overheating, decrease in life expectancy, or injury. Provide special clamps, braces to strengthen the windings to withstand mechanical and thermal stresses without damage. Provide additional system of wedging and blocking as necessary. Provide the windings to balance, restrain, and withstand frequent pulsating axial and radial electromagnetic forces in the transformer and prevent any movement of the windings, and eventual transformer failure. Provide adequate bracing to all winding leads.
6. Cooling. Provide adequate spacers to form cooling ducts to allow free passage of cooling air.
7. Taps. Provide the transformer with seven (7) 1.25% full capacity taps; four above and two below the nominal primary voltage. In order to maintain high integrity of the windings, install the taps by taking the winding conductors outside of the winding and construct the taps outside of the transformer coils.

D. Insulation

1. Provide winding insulation to withstand dielectric tests in accordance with ANSI standards for the voltage class.
2. Provide class H 220EC winding thermal insulation. Provide transformer for average winding temperature rise of 80EC over 40EC ambient temperature at rated power.

E. Winding Processing

1. Type. During manufacture and upon completion of the transformer windings, protect the windings against moisture and increase the winding mechanical strength with Vacuum Pressure Impregnation (VPI) process and epoxy end caps. Select non-flammable and self-extinguishing insulating material with high electrical, mechanical and thermal strength, such as polyester, epoxy, or silicone varnish.
2. VPI Process. Thoroughly dry and pre-heat the windings to remove moisture. Place windings in vacuum and allow the windings to draw the insulating material into the windings. Apply positive pressure to drive the insulating material into the windings to remove all air pockets. After the impregnation, bake the windings to cure the insulating material and to form a solid and sealed structure.
3. Epoxy Endcaps. Seale both ends of high voltage and low voltage windings with epoxy resin mixture to protect the windings from moisture, humidity, and industrial contaminants.

2.04 RECTIFIER

- A. Type. Indoor, silicon diode type, natural convection-cooled rectifier consisting of full-wave bridges providing 12-pulse rectification.
- B. Design. Provide the rectifier as a complete operating assembly consisting of silicon diodes, heat sinks, internal busbars, connections, diode fuses, and all other necessary components and accessories.
- C. Diodes. Connect the rectifier diodes as per approved ANSI 31 circuit.
 1. Provide and built the rectifier with sufficient number of hermetically sealed diodes to supply the load cycle and short circuit currents with one diode in each leg out of service and without exceeding the allowable junction temperature of the remaining diodes in service. Provide the diodes with adequate heat sinks.
 2. Provide naturally current-balanced rectifier design without using external devices and without individual selection of diodes. Select the

diode type so that the current unbalance between parallel diodes in each rectifier leg is within 15% and the current unbalance between rectifier legs is within 10% at rated load.

- D. Voltage Rise. Provide the rectifier so that the voltage rise between 0% and 100% rated load is within the DC equipment continuous rating.

2.05 TRANSFORMER/RECTIFIER DESIGN

A. Transformer/Rectifier Regulation

1. Select inductive coupling of the transformer windings so that the transformer/rectifier units exhibit the following features:
 - a. Maintain satisfactory regulation between 100% rated load and 450% rated load.

Load (%)	Rectifier Output Voltage (V)	Regulation (%)
0	795	
100	765	3.92
150	735	4.08
300	705	4.26
450	625	12.80

- b. Provide sufficient short circuit current to enable an overhead system fault anywhere between two adjacent substations to be cleared by protective devices of both substations.

- B. Transformer/Rectifier Rating. Provide the transformer/rectifiers to enable the substations to supply the continuous and overload ratings as specified herein.

1. Continuous Rating. Traction power substations are rated as specified in Table 18020-6.

Table 18020-6 - Continuous Substation Ratings

Substation	Number of Transformer/Rectifier Units	Transformer/Rectifier Rating (kW)	Substation Rating (kW)
	1	1,500	1,500

2. Overload/Short Circuit Capability. After constant temperature of all equipment at a substation is reached following operation at 100% rated power, the substations shall be capable of supplying the following overload/short circuit cycle:

- a. Two hours at 150% of rated load with five evenly spaced periods of one minute each at 300% of rated load, followed by,
 - b. Fifteen second period at 450% of rated load, followed by,
 - c. Maximum short-circuit current. Take into account two types of short-circuit conditions:
 - 1) Bolted faults at the rectifier terminals where the rectifier diodes are not subjected to reverse voltage.
 - 2) Resistance faults where the diodes are required to block reverse voltage.
 - d. Provide the transformer/rectifiers to withstand both types of short circuits for duration of time corresponding to the time, which is required by the AC breaker to clear the particular type of short circuit.
3. Provide the transformers and rectifiers so that the average and hot spot temperature rises are such that the transformer and rectifier life expectancy shall not be shortened when supplying the specified overload and short circuit cycle on a regular basis.
- C. Design Optimization. Provide the transformer/rectifier to achieve an overall efficiency of 98% or higher at rated output.

2.06 DC SWITCHGEAR ASSEMBLY

- A. DC Switchgear Requirements. Provide DC switchgear assembly to conform to or exceed the requirements of IEEE C37.14, IEEE C37.16, and IEEE C37.20.1 to accommodate DC circuit breakers as specified herein.
1. Provide DC switchgear to deliver, control, and measure power requirements of the DC distribution system. Select reliable switchgear combining fast fault interruption, low maintenance, quiet operation, and the specified service life.
 2. Provide the DC switchgear assemblies in a lineup of dead-front, floor mounted, freestanding, metal enclosures to accommodate circuit breakers with ratings specified herein.
 3. Divide each enclosure into completely segregated compartments to house the major equipment parts of the switchgear such as the circuit breaker interrupting element, busbars with cable terminations, control circuitry, protective relays, auxiliary relays, instrumentation, indication, annunciation, terminal blocks, fuses, and all other necessary devices.
 4. Completely enclose and segregate the individual equipment compartments by 11 gauge steel barriers.
 - a. Eliminate all unintentional openings between the compartments.

- b. Enclose all live parts of switchgear equipment within the metal compartments.
 - c. Ensure that opening of the cubicle door exposes no primary circuit components when the interrupter is in the connected position.
 - d. Provide the barriers to isolate instruments, meters, relays, transducers, indicating devices and all control devices and their wiring from all primary circuit elements with the exception of short lengths of wire such as at shunt and instrument terminals.
 - e. Bond all metal compartments to continuity busbar.
5. Provide automatic metal shutters to prevent exposure of primary circuit elements when the circuit breaker is removed from its position.
 6. Cover the busbar conductors and connections with 2 kV insulating material.
 7. Provide mechanical and/or electrical interlocks to ensure proper and safe operating sequence.
 8. Use the front door of the switchgear above the door through which the circuit-interrupting device is inserted into the housing as an instrument and device panel and as an access to instrumentation and control compartment within the housing.
 9. Provide all switchgear components to be accessible from the front or top of the cubicle.
 10. Furnish the switchgear with sufficient auxiliary contacts to provide for operation of the breaker control circuitry, transfer trip circuitry, indication, and interlocks. Provided at least four spare contacts, two normally open and two normally closed, each wired to an accessible terminal block.
 11. Provide the DC switchgear assemblies to have bottom feeder cable entry.

B. DC Circuit Breaker Type and Rating

1. Provide single-pole, horizontally draw-out, high-speed DC circuit breakers with ratings as shown in Table 18020-7.

Table 18020-7 - DC Circuit Breaker Rating Data

Characteristic	Rating	
Rated Maximum Voltage	800	VDC
Maximum Operating Voltage	900	VDC
AC Dielectric Withstand Voltage	3,700	V

Characteristic	Rating	
Continuous Current, Main Circuit Breakers	2,000	A
Continuous Current, Feeder Circuit Breakers	1,600	A
Rated Momentary and Peak Current, All Circuit Breakers	To be determined by the Contractor based on the transformer/rectifier rating and impedance.	
Sustained Short Circuit Current, All Circuit Breakers		
Rated Interrupting Time (shunt trip)	0.030	Seconds

C. DC Circuit Breaker Components. Provide high-speed, single pole, air circuit breakers consisting of the following components.

1. Interrupter. Provide each breaker to supply the specified load cycle currents and interrupt the rated short circuit current. Include air puffers, magnetic blowout, or other approved equipment to ensure interruption of low level currents.
2. Interrupter Support. Mount the interrupter on a flame retardant, track resistant, and high mechanical strength material support. Provide the support to provide adequate insulation to ground, and to firmly position and hold the interrupter in placed with correct contact alignment.
3. Operating Mechanism. Use one basic and simple, spring-charged, stored-energy or solenoid-operated mechanism for all DC circuit breaker types. Include in the mechanism all necessary equipment required for the circuit breaker operation, such as mechanical gears, linkages, closing solenoid, tripping solenoid as well as closing, opening and contact pressure springs. Provide the mechanism with the following features:
 - a. Operation of the circuit breaker through one close/open cycle on one motor charging.
 - b. Automatic motor charge of all springs upon completion of the close/open cycle to prepare the circuit breaker for the next close/open cycle.
 - c. Motor charging operation not exceeding 12 seconds.
 - d. Mechanically and electrically trip free mechanism.
 - e. Electrical operation.
 - f. Manual cranking capability to permit spring charging should the motor power be lost.
 - g. Manufacturing with high quality parts with close tolerances to achieve operating consistency, reliability and specified service life.
 - h. A non-resettable four digit mechanical operation counter on each circuit breaker.
4. Truck. Mount the circuit breaker components on a rugged, welded steel truck. Construct the truck as a precision-crafted and rigid

assembly. Provide the truck with guide rails and wheels to permit easy rolling-in and drawing out of the circuit breaker.

5. Disconnecting Contacts. Provide power connections between the removable circuit breaker and the stationary switchgear structure with automatic, self-aligning, and self-coupling disconnecting devices.
 - a. Primary Contacts - Provide primary contacts for the main power connections. Provide the primary contacts using silver-plated, spring-biased, hard copper fingers installed on the draw out element and stationary cell studs on the stationary structure. Recessed the stationary contacts within insulated supports. Provide the contacts to have sufficient cross-sectional area of copper to permit removal of heat from the fingers and the studs, to avoid localized high loads, and to maintain high conductivity.
 - b. Secondary Contacts. Provide secondary contacts for control, auxiliary, and interlocking power circuits. Provide the secondary contacts to consist of multi-contact receptacles and plugs with a sufficient number of contacts to accommodate all secondary circuits and spares, without the used of auxiliary relays.
6. Circuit Breaker Positions. Show the circuit breaker positions on an indicator located on the cubicle door. Provide each circuit breaker with the following positions:
 - a. Connected Position: Both primary and secondary disconnecting contacts are connected permitting operation of the circuit breaker during normal and fault conditions.
 - b. Test Position: The primary disconnecting contacts are disconnected and the secondary disconnecting devices are connected permitting testing of the circuit breaker operation.
 - c. Disconnected Position: Both primary and secondary disconnecting devices are disconnected permitting the circuit breaker withdrawal.
7. Draw Out Mechanism. Provide each circuit breaker with a manual, horizontal draw out mechanism.
 - a. Provide the mechanism to move the circuit breaker between connected and test positions and from test to disconnect positions with the cubicle door opened. Accomplish the withdrawal mechanically by rotation of a spring-loaded handle.
 - b. Provide the gear ratio of the mechanism so that one man can rack in or out the circuit breaker within one minute.
 - c. Provide the circuit breaker to be withdrawn from the switchgear housing when the breaker element, complete with its operating mechanism, is in the fully racked-out position.
 - d. Automatically disengaged the draw out mechanism at the end of the circuit breaker travel to prevent any over-travel.

- e. Provide interlocking to ensure that the circuit breaker can be drawn-out or rolled-in only when it is in open position.

2.07 NEGATIVE RETURN AND DRAINAGE ASSEMBLY

- A. Assembly Equipment. Provide a negative return and drainage assembly with negative disconnect switch and provisions for; negative return cables, negative drainage cables, negative grounding unit, and other associated equipment.
 1. Negative Disconnect Switch
 - a. Provide manually operated, single-pole, single-throw, no-load break negative disconnect switch with insulated handle and silver-plated copper contacts.
 - b. Interlock the disconnect switch with the DC main circuit breaker. Prevent operation of the switch when the DC main circuit breaker is closed.
 2. Provision for Negative Return Cables.
 - a. Provide busbar for connection of negative return cables.
 3. Provision for Negative Drainage Cables
 - a. Provide for connection of at least four negative drainage cables.
 - b. Equip each drainage cable connection point with a diode, variable resistor, shunt, and current limiting fused.
 4. Provision for Negative Grounding Unit.
 - a. Following the Ground Fault Test, METRO decided the Negative Grounding Unit as specified in section PROTECTIVE DEVICES was required.
 - b. Upon determination that the ground faults were not adequately cleared, provided the negative grounding unit in each substation.
- B. Equipment Rating
 1. Provide rating of all equipment at the DC system rated voltage.
 2. Provide rating of all equipment, except the negative grounding unit and the provisions for negative drainage cables, to withstand, without damage, the continuous, the overload, and rated short circuit currents.
 3. Provide rating of the negative grounding unit and the provisions for negative drainage cables to withstand without damage ground fault short circuit currents.

2.08 AC STATION POWER SYSTEM

- A. General Requirement

1. Provide AC station power system for each traction power substation to supply power to the following:
 - a. Traction power substation auxiliary loads.
 - b. Signal system facilities located in separate house adjacent to the traction power substations.
 - c. Communications system facilities located in separate house adjacent to the traction power substations.

B. System Design

1. Identify all traction power substation auxiliary loads, including:
 - a. Lighting
 - b. HVAC units
 - c. Convenience receptacles
 - d. Anti-condensation heaters
 - e. Battery charger
 - f. AC control power
2. Identify loads of signal and communications system instrument houses.
3. Perform calculations for sizing of the traction power substation auxiliary, signal, and communications power supply systems. Define the following system parameters:
 - a. System voltages and currents
 - b. Maximum feeder currents
 - c. Feeder cable ratings and sizes
 - d. Panelboard sizes
 - e. Type and sizes of protective molded-case circuit breakers
4. Prepare design calculations for the system and submitted to METRO for approval.

C. Station Power Transformer.

1. Provide dry-type, self-cooled, single-phase, transformer with primary voltage to be consistent with the utility supply voltage.
 - a. Secondary voltage: 120 V/240 V.
 - b. Taps: Four 2.5% full capacity taps; two above and two below the nominal primary voltage.
 - c. Rating: Adequate to supply all envisaged loads with 15% spare capacity.
2. Protect the transformer with draw-out or flip-down fuses.

D. Station Power Panelboard

1. Provide single-phase, three-wire AC panelboard of appropriate size in each substation. Protect the panelboard with a main molded-case circuit breaker feeding the panelboard.
2. Provide the necessary number of branch feeders. Protect each feeder by a molded-case circuit breaker. Installed at least 25% of spare circuit breakers.
3. Provide the necessary number of branch feeders, including:
 - a. Traction power substation auxiliary loads.
 - b. Signal system facility.
 - c. Communications system facility.
4. Protect each feeder by a molded-case circuit breaker. Installed at least 25% of spare circuit breakers.
5. Locate the panelboard within the traction power substation.

E. Power Distribution

1. Provide separate three-phase, AC switch for the signal power system feed to the Bungalow.
2. Provide power distribution cabling and circuit devices within the substation.

2.09 DC AUXILIARY POWER SYSTEM

A. System Design

1. Identify all DC auxiliary power system loads in the substation, including:
 - a. DC control power
 - b. Substation electronic devices
 - c. Annunciation
 - d. Emergency lighting
2. Perform calculations for sizing of the DC auxiliary power supply and distribution systems. Define the following system parameters:
 - a. Wire and cable voltages and currents
 - b. Wire and cable ratings and sizes
 - c. Panelboard size
 - d. Type and sizes of protective molded-case circuit breakers
3. Prepare design calculations for the station battery and battery charger size in accordance with IEEE 485 and submit to METRO for approval. Provided the battery and battery charger to perform properly under the entire range of temperatures to be expected within the substation.

B. Source of DC Auxiliary Power - Station Battery

1. Provide an ungrounded, maintenance free, 125 V, sealed, lead-acid battery. Equipped the battery with battery rack, accessories, and all connections necessary to provide a fully operating battery system. Arranged the battery cells on racks or in a freestanding modular unit to optimize the used of space in the substation.
2. Provide battery that requires no watering, no special ventilation, and no special battery room. Select replaceable battery cells, which contain no cadmium, or other hazardous materials, which would require special disposal arrangements. Provide battery that under normal conditions vents no gas. Provide a sealed pressure relief vent to alleviate pressure build-up in the cells. Select flame retardant, leak-proof and spill-proof battery cell containers. Use stainless steel, standard English measure, hex-head bolt connectors. Use lead-plated copper straps for the inter-unit connections.
3. Mark the battery cells to indicate the cell manufacturer and type. Identified the polarity of the terminal posts by red and black terminal rings and by positive and negative signs molded or engraved into the cell in the proximity of the terminals.
4. Provide the battery to supply sufficient power to close and trip all substation circuit breakers after it has supplied the substation DC auxiliary power requirements for 8 hours with the AC station power panelboard de-energized. Provided the battery to deliver output voltage not be less than 105 V at the end of this discharge period.

C. Source of DC Auxiliary Power - Battery Charger

1. Provide an automatic, silicon-controlled rectifier, convection-cooled, constant-voltage type battery charger to recharge the station battery. Selected charger manufactured or approved by the battery manufacturer. Supply the charger from the substation auxiliary power panelboard.
2. Size the charger to recharge the battery while supplying the continuous loads of the battery at the same time. Size the battery to supply the remainder of the heavy, short-time current demands.
3. Provide a charger capable of recharging a fully discharged station battery within 8 hours. Select a charger to provide a constant voltage output within $\pm 1\%$ of nominal voltage over the complete load range for an input voltage variation of $\pm 10\%$. Provide the charger to be current limiting, adjustable from 80% to 120% of rated load and factory set at 110%.

4. Equip the battery charger with the following provisions:
 - a. AC circuit breaker, two pole
 - b. AC surge suppressor
 - c. Float and high rate adjustment potentiometer
 - d. Manual float/equalize switch
 - e. DC voltmeter
 - f. DC ammeter
 - g. DC blocking diode and reverse polarity protection diode
 - h. DC circuit breaker, two pole
 - i. DC surge suppressor
 - j. Switchboard wiring 600 V, 90EC rated
 - k. Devices and accessories required for remote SCADA supervision
 - l. LED indication and SCADA contacts for the following functions:
 - 1) AC voltage high/low indication
 - 2) Charger failure indication
 - 3) DC voltage high/low indication
 - 4) Positive and negative ground detection

D. DC Panelboard

1. Provide two-wire DC system panelboard of appropriate size in each substation and protected the panelboard with a main molded-case circuit breaker feeding the panelboard.
2. Provide the necessary number of branch feeders. Protected each feeder by a molded-case circuit breaker. Installed at least 25% of spare circuit breakers.

E. DC Power Distribution

1. Provide substations with dedicated two-conductor, ungrounded DC power distribution circuits.
2. Install the distribution circuits in protective raceway, and terminated all wires and cables on terminal blocks at the loads served.

2.010 CURRENT TRANSFORMERS

- A. Provide current transformers (CTs) to accurately transform the system currents for metering and relaying. Select the current transformers to satisfy ANSI and IEEE requirements for metering and relaying accuracy classification under the burdens imposed by the metering and protective devices.
- B. Select ring core type current transformers with toroidally wound and fully distributed secondary windings.

- C. Select current transformers insulated with structural grade thermoplastic to withstand dielectric test levels of the switchgear and to carry the currents occurring during rated load, overload, and short circuit currents without excessive heating or injury.
- D. Provide each current transformer with a mounting frame, which attaches securely to the switchgear bushings. Run secondary wiring from the current transformer terminal studs to terminal blocks. Provide the current transformer terminal blocks with covers having integral shorting bars.

2.011 POTENTIAL TRANSFORMERS

- A. Provide potential transformers (PTs) to accurately transform the system voltages for metering and relaying. Select the potential transformers to satisfy ANSI and IEEE requirements for metering and relaying accuracy classification under the loads imposed by the metering and protective devices.
- B. Select dry-type potential transformers with physically strong protective cases and with superior insulating properties.
- C. Select potential transformers with adequate insulation to withstand the dielectric test levels of the switchgear and to carry their load continuously without excessive heating or injury.
- D. Protect the primary circuits of all potential transformers by means of non-renewable cartridge-type fuses. Provide indication for the blown fuses. Locate the primary fuses in roll-out carriages equipped with disconnecting devices. Protect secondary circuits of all potential transformers by molded-case circuit breakers mounted in the cubicle control compartment.

2.012 TRANSDUCERS AND CONVERTERS

- A. Provide compact transducers and converters to convert input variables into proportional DC output signals within accuracy of 0.1% or better. Select transducer and converter inputs to be compatible with the magnitude of the input variable.
- B. Install the transducers and converters in a suitable enclosure.

2.013 PROTECTIVE DEVICES.

- A. Provide a comprehensive protective scheme to protect the substation equipment and the overhead distribution system as well as provide back up to the vehicle protective devices. Base the protective scheme design on the load, overload, and short circuit currents. Select the characteristics and

- ranges of all protective devices to ensure satisfactory coordination of all devices and a fast fault clearance.
- B. Use only high quality, utility-type, draw-out, microprocessor-based protective devices enclosed in rustproof, dustproof, high-impact cases with integral test switches and solid-state contacts.
 - C. Annunciate operation and failure on the device with targets.
 - D. Arrange all protective devices to be conveniently accessible, easily visible, and logically grouped. Locate devices of related functions in proximity to each other. Install the protective devices semiflush on the cubicle door.
 - E. Arrange all provisions for device setting and testing to be readily visible, accessible, and adjustable from the front of the device.
 - F. Provide the protective scheme to be immune to maloperation due to electrical noise, electromagnetic fields, harmonic distortion, traveling waves, and current transformer saturation. Provide all protective schemes fail-safe.
 - G. The Contract Drawings show the protective schemes and are intended to serve the protective scheme functional requirements. The Contract Drawings do not show all components such as auxiliary devices, isolating diodes, fuses and other similar devices required for a complete protection system installation. Perform all final design including selection of device characteristics, model numbers, style, connections, and settings.
 - 1. AC Switchgear Protection. Equip the AC switchgear assembly with the following protective devices:
 - a. Time Overcurrent Device with Instantaneous Element, Device 50/51, for high current phase fault protection.
 - b. Time Overcurrent Device, Device 51, for low current phase fault protection.
 - c. Time Overcurrent Device with Instantaneous Element, Device 50/51 N, for ground fault protection.
 - d. Undervoltage Device, Device 27, for loss of AC supply annunciation.
 - e. Fuses for protection of station power transformer.
 - 2. Rectifier Transformer Protection. Equip the rectifier transformer with the following protective devices:
 - a. Winding Overtemperature Device, two stage, Devices 49-T1 and 49-T2. Equip the devices with temperature detection devices embodied in the transformer windings. Each stage setting is adjustable.
 - 3. Rectifier Protection. Equip the rectifier with the following protective devices:

- a. Diode Fuses. Provide high speed current limiting fuses in series with each diode, complete with an indicator to show a blown fuse, Device 98. Select fuse size to protect the rectifier against internal faults resulting from a diode losing its blocking ability. Select fuses with fast fault current interruption to prevent spreading of faults to adjacent diodes. Provide fuses that shall not open or fail during external faults or rated overload conditions.
 - b. Overtemperature Protective Devices, Devices 26-R1 and 26-R2. Provide two stage monitoring of the heat sink temperature. Mounted the device thermal sensors in the hottest location of the rectifier.
 - c. Surge Protection. Equip the rectifier with an surge protection devices to limit the reverse voltage across the diodes to a value lower than the peak reverse voltage rating of the diodes. The devices protect the rectifier irrespective of whether the surges originate in the AC or DC power circuits.
 - d. Door Position Contacts, Device 33. Provide all rectifier enclosure doors with position contacts. Upon opening of the enclosure doors, the contacts trip the AC circuit breaker and the DC main circuit breaker and initiate annunciation. The AC and DC main breakers do not close unless all rectifier enclosure doors are closed.
4. Transformer/Rectifier Single-Phase Operation Protection.
- a. Provide the transformer/rectifier units to withstand operation under a phase-to-phase condition and provided additional protective devices, as necessary, to protect the transformer/rectifier units against damage.
5. DC Switchgear Protection. Furnish the DC switchgear with the following protective devices:
- a. Reverse Current Instantaneous Device, Device 32. Each DC main circuit breaker is equipped with unidirectional direct-acting overcurrent trip, set as low as practically possible and reacting on reverse currents only.
 - b. Direct-acting Overcurrent Trip, Device 176. Each DC feeder breaker is equipped with a bi-directional direct-acting release overcurrent trip set to open the breaker on short circuit currents.
 - c. Time Overcurrent device or Thermal device, Device 151. Each DC feeder breaker is equipped with a device protecting the distribution system from overloads and from arcing and high resistance faults. The device characteristic closely follows the maximum permissible DC current overload characteristic of the distribution system to prevent conductor annealing during sustained overloads or faults.

- d. Rate-of-Rise Device, Device 150 R. Each DC feeder breaker is equipped with unidirectional rate-of-rise relay. The device has operating characteristics and adjustable ranges to trip the DC feeder circuit breaker for remote short circuits and discriminates against current inrush occurring during starting of trains.
 - e. Auto-reclosing Equipment, Devices 182 and 183. Each DC feeder circuit breaker is furnished with automatically reclosing equipment. The equipment consists of voltage devices, load measuring devices, fault test equipment, and time sequence devices.
 - 1) The circuitry provides for three successive attempts to close the circuit breaker. The time period between the attempts is adjustable.
 - 2) The circuit breaker is allowed to close onto a line, which is energized.
 - 3) The circuit breaker is allowed to close onto line which is de-energized but which is identified by the fault test equipment as clear line without a fault.
 - 4) The circuit breaker is not allowed to close onto a line which is de-energized and which was identified by the fault test equipment as faulty.
 - 5) The autoreclosing feature is capable of being switched off. The autoreclosing sequence is blocked if the circuit breaker has been tripped manually.
 - f. Transfer Trip, Device 85. Equipped each DC feeder circuit breaker with fully functional transfer trip protective scheme.
 - 1) Following a distribution system fault, the feeder circuit breakers supplying the short circuit current are tripped as shown on Contract Drawings.
 - 2) Provide all necessary transfer trip interconnecting cables and substation to substation communications circuitry.
 - g. Incomplete Sequence Relay, Device 48. Furnish each DC feeder circuit breaker with an incomplete sequence device. This device detects the circuit breaker failure to clear a fault within a predetermined time and operates the AC lock-out device (device 86H) to de-energize the entire substation. The circuit breaker in the adjacent substation feeding the fault is opened via the transfer trip system.
6. DC Enclosure Protection. Protect the rectifier, the DC switchgear, and the negative return and drainage assembly enclosures by high-resistance protective scheme which includes the following devices:
- a. Enclosure Live Protection, Device 64 L. Selected a highly sensitive device 64L to operate in the event that any part of the DC enclosures becomes energized.
 - b. Enclosure Grounded Protection, Device 64 G. Selected a highly sensitive device 64 G to operate in the event that any part of the DC enclosures becomes grounded.

7. Station Power, Auxiliary Power, Signal and Communications Power Supply Systems. Protected all circuits and connected equipment with molded-case circuit breakers.
 - a. Coordinate characteristics of all molded-case circuit breakers protecting the AC power systems.
 - b. Coordinate characteristics of all molded-case circuit breakers protecting the DC power systems.

8. Negative Grounding Unit, Device 57.
 - a. Provide the negative grounding unit to ground the negative bus should the voltage between the DC system negative bus and ground exceeds a predetermined value. Increased voltages between the negative bus and the ground may occur during vehicle acceleration or during uncleared system ground faults.
 - b. Manufacture the negative grounding unit using gate-turn-off (GTO) thyristors and associated devices and control circuitry. Refer to Contract Drawings for simplified one-line diagram and operational flow chart.
 - c. Provide protective devices with adjustable time delays so that the unit is insensitive to transients, allows the distribution system faults to be cleared and, once the feeder breakers are cleared, permits three successive attempts to auto-reclose the breakers.
 - d. Determine the thyristor rating and the voltage level at which the negative grounding unit shall operate.
 - e. Equip the unit with a failure indicator, close/open status indicator, and with a non-resettable operations counter. Provide manual switching of the unit on and off.

9. Surge Protection. Furnish suitable surge arresters and transient voltage suppression devices as determined in the Insulation Coordination Study. Protect all electronic equipment in the substation and applied protection to the power supply and data lines as appropriate.
 - a. As a minimum, protect the following equipment:
 - 1) Programmable logic controller
 - 2) SCADA system equipment
 - 3) Electronic relays
 - b. Select the protective equipment voltage rating, energy dissipation rating, and other characteristics compatible with the equipment to be protected.

10. Other Protection. Provide the following additional protective devices:
 - a. Undervoltage Device, Device 27 A. Used the device to annunciate loss of station power supply.
 - b. Fire Detector. Use the fire detector device to de-energize and lock out all substation circuit breakers in the event of fire.
 - c. Auxiliary Devices, Devices 86 H, 186 H and 94. Arrange protective devices to trip the circuit breakers via hand-reset

lockout device 86 H, and 186, and via tripping device 94 as shown on the Contract Drawings. Provide the lockout device with handle and mechanical target to indicate the device position.

2.014 INSTRUMENTATION

- A. Provide high quality, metal case, semiflush, four and one-half inches (4½") square, switchboard type meters with accuracy of one percent of full-scale value. Calibrate all instruments to match the input signals. As a minimum, provided the following instrumentation in each substation:
 - B. AC Switchgear
 - 1. AC feeder voltmeter within the Siprotec display
 - 2. AC feeder ammeter within the Siprotec display
 - C. Rectifier Transformer
 - 1. Winding temperature instrument.
 - D. Rectifier
 - 1. Rectifier output voltmeter.
 - 2. Rectifier output ammeter.
 - 3. Terminal blocks for monitoring and recording negative drainage cable currents.
 - E. DC Switchgear
 - 1. DC feeder voltmeter, within the DPU.
 - 2. DC feeder ammeter, one for each feeder. Protected the ammeters against reverse current flow.
 - F. Substation Enclosure
 - 1. Substation high ambient temperature detector.
 - 2. Thermometer.
 - G. Equip each instrument with test blocks to permit connection of portable recording and testing equipment.

2.015 INDICATION

- A. Provide separate illuminated indication of each circuit breaker opened and closed positions. The indications are by light emitting diodes (LEDs) located on the switchgear cubicle doors.
- B. Provide each circuit breaker with operating mechanism charged/discharged status indicator.
- C. Provide each AC circuit breaker with a contact wear indicator.

2.016 ANNUNCIATION

- A. Provide substation with internal annunciation system consisting of convection cooled modular design, solid state, and programmable annunciator. Provide the annunciator with LED indicating lamps, test switch, as well as other associated equipment.
- B. Display the following functions:
 - 1. AC power loss.
 - 2. Transformer overtemperature.
 - 3. Rectifier overtemperature.
 - 4. DC enclosure live.
 - 5. DC enclosure grounded.
 - 6. AC station power loss.
 - 7. DC auxiliary power loss.
 - 8. Substation lockout device operation.
 - 9. Rectifier reverse current protection operation.
 - 10. Substation air temperature high.
 - 11. Fire alarm.
 - 12. Intrusion alarm.

2.017 SUBSTATION EMERGENCY SHUTDOWN

- A. Provide emergency shutdown pushbuttons with shrouds on the interior and the exterior of each substation. Installed one interior shutdown pushbutton next to each entrance. Install the exterior shutdown pushbutton next to the entrance approved by METRO.
- B. Connect the emergency shutdown pushbuttons to provide a loop circuit of contacts wired in series, which energizes a summary device. Interruption of the series circuit causes the substation to shutdown by:
 - 1. Tripping and locking out the main AC circuit breaker.

2. Tripping and locking out all DC feeder circuit breakers.
 3. Transfer tripping and locking out the corresponding circuit breakers at adjacent substations to achieve deenergization of the distribution system conductors.
- C. Use heavy duty, industrial grade, pushbutton operator and contact block with a large, red, mushroom shaped actuating head, with protective shroud.
- D. Provide the pushbuttons to be lockable so that substations cannot be energized locally or from SCADA system unless the pushbutton has been manually reset.
- E. Install the pushbuttons in a weatherproof enclosure integrated within the substation enclosure. The enclosure is provided with a front door continuously hinged from the side. Provided the door to be lockable with a heavy duty hasp.

2.018 PROGRAMMABLE LOGIC CONTROLLERS

A. General

1. Provide a programmable logic controller (PLC) system in each traction power substation to control, protect, and monitor operation of substation equipment and establish an interface with the SCADA system.
2. Include in the PLC system all the necessary hardware, software, and diagnostics equipment to ensure a fully operational and coordinated system.
3. Program the PLCs specifically for the traction power substation application. Used the PLCs to replace the conventional hard-wired interfaces in the substation and program the PLC to integrate the following functions into a single, high-speed Central Processing Unit (CPU):
 - a. Relaying logic including reclosing, transfer trip, and associated logic.
 - b. Electrical interlocks.
 - c. Substation annunciation.
 - d. Substation control.
 - e. SCADA system.
4. The PLC system does not replace the following:
 - a. Protective relays.
 - b. Lockout relays.

B. PLC Hardware

1. Include in the PLC is, all necessary control system electronics, Operator Control Panel interface, self-protection, diagnostics, monitoring, and recording equipment. Equipped the PLC with a CPU and sufficient memory modules to store the PLC software.
 - a. Provide the PLC with single processor CPU.
 - b. Store the PLC software in the processor memory such as RAM.
 - c. As an additional back up, stored the PLC program in a non-volatile EEPROM, which shall provide maximum protection against program loss or program alteration due to battery drain, processor malfunction, or electromagnetic interference.
2. Input/Output (I/O) Units
 - a. Provide remote input/output (I/O) units with the following capabilities:
 - 1) Signal and data acquisition and transmission to the master controller.
 - 2) High-speed communication.
 - 3) Reduced interconnecting wiring.
 - 4) Central and distributed fault diagnostics.
 - b. Provide all I/O units with high quality electronic terminators to allow the I/O modules to be changed without disturbing substation wiring.
 - c. Mechanically "key" each I/O module to its base unit to allow only a module with the proper key code to be inserted in the base unit.
 - d. Provide I/O units with sufficient capacity for all inputs and output points as well as sufficient spare points.
3. Electronic Circuitry
 - a. Locate all control circuitry on printed circuit boards inserted into a rugged printed circuit board frame.
 - b. Made all connections to the modules and to the frame via reliable pin and socket electronic connectors.
4. Operator Control Panel
 - a. Provide Operator Control Panel to monitor and intervene in the operation of the substation.
 - b. Select the Operator Control Panel to be suitable for diagnostic purposes, for monitoring, storing and displaying the substation alarms and events, and for checking or evaluating equipment parameters, such as modifying time settings and values of analog signals.
 - c. Furnish the Operator Control Panel with an easy-to-use Operator interface panel and a color CRT monitor.

5. PLC Enclosures

- a. Install the PLC in a dustproof, rustproof, high quality enclosure designed to protect the PLC electronic equipment in the substation environment that is not maintained by temperature, air conditioning, or humidity control equipment.
- b. Provide the PLC enclosures with a terminal for connection to the substation ground.
- c. Paint all electronic enclosures with standard color.

6. Surge Protection

- d. Provide surge protection to comply with IEEE C.37.90.1.

C. Power Supplies

1. Provide the PLC to remain operational in the event of substation input AC power failure or the substation AC auxiliary power failure.
2. Supply power to the PLC from the substation DC auxiliary power supply system either directly or via a suitable DC to DC inverter module.

D. PLC Software

1. Provide the PLC software to independently organize data flow in each substation, including:
 - a. Communication within the equipment cubicles including interface with the Operator Control Panel for data acquisition and logging.
 - b. Communication between equipment cubicles.
 - c. Communication with the SCADA system.
2. Provide the PLC software to switch in, switch out, reconfigure, and troubleshoot the substation equipment. Provide software with the following capabilities:
 - a. Failure monitoring and protection.
 - b. Remote monitoring and control.
 - c. Transient fault recording to capture analog and digital pre-fault and post-fault data to enable review of system history.
 - d. Control and monitoring of equipment during substation set-up, commissioning, testing, and equipment checkout during maintenance.

E. SCADA Points and PLC Programming

1. Provide the SCADA system with the following supervisory, control, and measurement points:
 - a. Supervisory Points
 - 1) AC utility power on.
 - 2) AC utility power off.
 - 3) AC auxiliary power on.
 - 4) AC auxiliary power off.
 - 5) Circuit breakers opened (for each circuit breaker).
 - 6) Circuit breakers closed (for each circuit breaker).
 - 7) Circuit breaker control switch in remote operation position (all circuit breakers).
 - 8) Circuit breaker control switch in local operation position (all circuit breakers).
 - 9) Transfer trip module failed (all DC circuit breakers).
 - 10) Transfer trip communication failed (for each adjacent pair of substations).
 - 11) Transformer overtemperature.
 - 12) Blown rectifier diode.
 - 13) Lockout device tripped.
 - 14) Lockout device set.
 - 15) Tripping device operation.
 - 16) DC auxiliary power on.
 - 17) DC auxiliary power off.
 - 18) Main substation battery charger, AC voltage high.
 - 19) Main substation battery charger, AC voltage low.
 - 20) Main substation battery charger, failure.
 - 21) Main substation battery charger, DC voltage high.
 - 22) Main substation battery charger, DC voltage low.
 - 23) Main substation battery positive grounded.
 - 24) Main substation battery negative grounded.
 - 25) DC enclosure live.
 - 26) DC enclosure grounded.
 - 27) Substation temperature high alarm.
 - 28) Intrusion alarm.
 - 29) Fire alarm.
 - 30) Negative grounding unit:
 - a) Negative grounding unit opened.
 - b) Negative grounding unit closed.
 - c) Negative grounding unit failure.
 - 31) PLC/SCADA module failure.
 - b. Control Points
 - 1) Open each circuit breaker.
 - 2) Close each circuit breaker.
 - 3) Emergency substation trip.
 - c. Measurement Points
 - 1) Primary AC voltage, each phase individually and three-phase average.

- 2) Primary AC current, each phase individually and three-phase average.
 - 3) Main DC busbar voltage.
 - 4) Current in each DC circuit breakers, each feeder individually.
 - 5) Negative bus to ground voltage.
 - 6) Current in the negative grounding unit.
2. Program the PLC to show the following functions at the PLC and at the Train Control Center.
 - a. Indication of all supervisory points.
 - b. Analog and digital displays of all measurement points.
 - c. The substation one-line diagram showing the following:
 - 1) Status of all circuit breakers
 - 2) Primary AC voltage three-phase average, digital display.
 - 3) Primary AC current three-phase average, digital display.
 - 4) Main DC busbar voltage, digital display.
 - 5) Current in each DC circuit breaker, each feeder individually, digital display.
 - 6) Negative bus to ground voltage, digital display.
 - 7) Substation power demand and substation power factor, digital display:
 - a) Instantaneous.
 - b) Fifteen minute running average in one minute increments.
 - 8) Current in the negative grounding unit, digital display.
 3. Program the PLC to enable control of all control points from the PLC and from the Train Control Center.

2.019 SCADA SYSTEM INTERFACE

- A. Provide and furnished connection between the PLC and the SCADA system. Provided at least 25% of spare I/O modules and conductors for future use.
- B. Provide the system to communicate all PLC functions to the Train Control Center.

2.020 CONTROL SWITCHES

- A. Provide rotary type control switches for circuit breaker open/close operation and circuit breaker local/remote operation.
- B. Install the control switches on the switchgear front panel. Provided rectangular, engraved escutcheon plate showing the switch position.

- C. Provide self-cleaning, readily renewable type switch contacts with adequate insulation and contact surface.

2.021 LIGHTING

A. Indoor Lighting

1. Provide substation indoor lighting using LED lights providing lighting level of 50-foot candles minimum at the floor level.
2. Locate the lighting fixtures to illuminate satisfactorily the vertical surfaces of the substation equipment. Illuminate the rectifier cubicle to enable inspection of blown diode indicators without opening of the rectifier door.
3. Select locations of lighting fixtures to avoid interference with overhead raceways, wiring, and maintenance access.
4. Supply the indoor lighting from the AC panelboard. Control the lighting from two switches, one switch located near each door.

B. Emergency Indoor Lighting

1. Provide substation emergency lighting using incandescent lighting fixtures providing a lighting level of five foot-candles minimum at the floor level.
2. Supply the emergency lighting from the DC panelboard. Energizing the emergency lighting manually by switch upon failure of AC power.

C. Outdoor Security Lighting

1. Provide outdoor security lighting using LED fixtures. Located one fixture above each substation doorway and as shown in the Contract Drawings. Provided vandal resistant fixtures.
2. Control the outdoor security lighting by a photoelectric cell with a by-pass switch located inside the substation.

2.022 TEMPERATURE CONTROL SYSTEM

- A. Provide substation HVAC system to control the substation ambient temperature using two HVAC units. Rated each unit to supply 100% of cooling requirements of the whole substation operating under power overload condition.

- B. Control the units by adjustable thermostats installed on the substation wall. Provided the control circuitry to operate the units alternatively. Both units operate simultaneously only at ambient temperature above 90F.
- C. Provide the system to maintain the substation ambient temperature at no less than 20F lower than the outside temperature.

2.023 BUSBARS AND BUSBAR CONNECTIONS

- A. Provide busbars made of solid, high electrical conductivity copper. Insulate and braced the busbars with high strength insulators.
- B. Silver-plated and bolted all busbar connection surfaces. Provide conductivity of each joint at least equal to that of the busbar.
- C. Provide all busbars and busbar connections to withstand, without damage to the busbar or enclosure, the thermal and mechanical stresses occurring during the specified load cycle and the system short circuit currents.
- D. Select busbar cross-sectional area not to exceed maximum current density of the busbars of 1,000 A per square inch.
- E. Busbar Types
 - 1. AC Busbar. Provide three-phase AC busbar in the utility service cubicle and AC switchgear assembly.
 - 2. Traction Transformer to Rectifier Busbar. Provide two sets of three-phase cables suitable for connection to the 12-pulse rectifier.
 - a. The transformer to rectifier connection is accomplished by suitably rated and insulated cables.
 - 3. DC Switchgear Positive Busbar. Provide a positive busbar for the DC switchgear assembly. Connected the DC circuit breakers, protective devices, and instrumentation to the busbar.
 - 4. Negative Return and Drainage Assembly Busbar. Provide a negative busbar for the negative return system. Connected negative return cables, negative disconnect switch, negative grounding unit, protective devices, and other instrumentation to the busbar. Connection of the drainage assembly is accomplished by suitably rated cables.
 - 5. Continuity Busbar. Provide a continuity busbar to bond all DC equipment enclosures. Extend the busbar the entire length of the enclosures. Connect each enclosure, the enclosure live protection, and the enclosure grounded protection to the busbar.

6. Grounding Busbars. Provide grounding busbars to ground the substation equipment. Connect equipment grounding conductors, cable shields, and grounding grid conductors to the busbar.

2.024 ELECTRICAL INSULATION

- A. Select self-extinguishing insulating materials that do not produce gases harmful to personnel when exposed to flames or electrical arcing.
- B. Floor Insulation
 1. Electrically insulate the rectifier, the DC switchgear, and the negative return from the floor by at least $\frac{1}{4}$ inch of chemically inert epoxy compound. Extend the insulation across the floor of the dc section of the substation.
 2. Provide insulation with smooth, non-slip surface without any gaps and steps between insulated and non-insulated parts of the substation. The insulation shall not crack under the mechanical and thermal stresses expected during transportation and during the repeated process of racking breakers.
 3. Mount the DC equipment enclosures on the floor with insulated fasteners of sufficient mechanical strength. Select the dielectric strength of the fasteners to be compatible with the insulating strength of the floor insulation.
- C. Enclosure Insulation
 1. Insulate the rectifier, the DC switchgear, and the negative return and drainage assemblies from the substation walls and from the AC enclosures.
 2. Extend the insulation sheet between the DC and AC enclosures to prevent a person simultaneously touching both DC and AC cubicles.
- D. Component Insulation
 1. Mount all metal-enclosed devices as well electrical and electronic components in the DC cubicles on insulating material boards.
 2. For safety of personnel, used potential transformers, current transformers, and transducers to electrically separate high voltage components from front panels. Provide connections of all front panel mounted instrumentation, indication, annunciation, and control devices to have an input at voltage below 130V. Located all devices to minimize conductor runs at high voltage.

2.025 ELECTRICAL GROUNDING

- A. Provide all grounding connections to be capable of carrying the rated short circuit current. Run all grounding connections via the shortest and straightest possible route.
- B. Connect AC switchgear assembly equipment enclosures, cases, doors, and frames to the grounding busbar. Connected all metal conduits, raceways, pull boxes and cable shields to the grounding busbar, unless otherwise indicated.
- C. Equip the rectifier transformer with two, two-hole, NEMA standard grounding pads located at diagonally opposite corners of the transformer.
- D. Connect DC switchgear enclosure live and enclosure grounded protection to grounding busbar.
- E. Equip the substation housing with a minimum of two grounding pads located on diagonally opposite corners of the housing.

2.026 EQUIPMENT ENCLOSURES**A. General**

- 1. Enclose all equipment in rigid, rust resistant, welded or bolted enclosures. Fabricate equipment enclosures using structural frame and sheet metal of sufficient strength to support equipment during transportation and installation and to endure mechanical stresses under normal operation and short circuit conditions.
- 2. House the AC switchgear, the rectifier transformer, the DC switchgear, and the negative return and drainage assembly in freestanding enclosures. Fabricate the enclosures, their doors and their panels of heavy gauge rolled steel No. 11 gauge, minimum, with No. 7 gauge, minimum, floor pans.
- 3. Provide adequate anchoring of the enclosures to the substation floor and to the substation walls.
- 4. Provide adequate ventilating opening in accordance with NEMA and NEC standards for ventilated enclosures.

B. Internal Enclosure Doors

- 1. Provide all substation equipment enclosures with hinged doors.
- 2. Provide the traction power rectifier and the negative return and negative drainage enclosures with hinged doors.

3. Fabricate all doors and panels of heavy gauge steel to prevent twisting, distortion and vibration of the doors and panels during opening and closing. Furnish all doors with appropriate heavy duty hinges. Provide secure fasteners to hold doors in closed position and to hold doors in open position.
4. Mount all doors semi-flush.

C. External Doors and Panels

1. Provide hinged rear access doors for enclosures with equipment requiring periodic inspection and maintenance from the outside of the substation, such as the cable entry cubicle and the AC switchgear cubicle. Equip the doors with handles and locks or padlocks.
2. Provide removable rear wall panels for enclosures with equipment requiring removal from the outside of the substation.
3. Coordinate all rear doors and panels of the equipment enclosures with the substation housing doors.

2.027 SUBSTATION HOUSING

- A. Provide weatherproof substation housing. Fabricate the housing to prevent driving rain, snow and sleet from entering the substations and to provide a dry and condensation-free environment for the electrical equipment
- B. Provide the housing to withstand stresses caused during transportation, installation and during the maximum specified wind loading.
- C. Provide and manufactured the housing of structural steel.
 1. Erect the housing on a steel base frame. Provide the base frame with removable lifting lugs to enable lifting fully equipped substation module.
 2. Construct all doors, walls and roof panels using heavy gauge steel and reinforcing and stiffening members to provide a rigid housing.
 3. Manufacture the substations in one shipping module.
- D. Provide housing with rigid non-slip floor, ¼" steel plate minimum, suitable for installation of the floor insulation.
- E. Provide double wall and double roof housing to accommodate insulation material to reduce heat transfer. Select the thermal insulation level taking into account the climatic conditions encountered in the substation location and the temperature range inside the substation. Provide the insulation to enable

- satisfactory operation of all substation equipment during extremes of outside temperature.
- F. Provide substation housing with two outward opening entry doors for maintenance personnel access in accordance with the NEC. Located the doors at the opposite ends of the substation enclosure. Equipped each door with crash-bar safety latch to permit opening from within. Keyed all doors alike to a keying system approved by METRO. Provided door stops to hold the door in the open position.
 - G. Provide hinged, watertight exterior access door behind each equipment cubicle or other equipment requiring rear access for cable makeup, routine inspection, or maintenance. Provide the door and hinges to be able to open all doors simultaneously to a position perpendicular to the housing without interference of the adjacent doors and hinges
 - H. Select aesthetically acceptable wall mounted HVAC units of proven design and performance. Selected HVAC units designed to prevent rain, snow and vermin from entering the substation. Provide units with replaceable filters.
 - I. Provide housing to meet fire-rating requirements of the site where the substation is located.
 - J. Prior to substation delivery to site, arranged for Interstate Building Commission (IBC) certification.

2.028 EQUIPMENT ARRANGEMENT

- A. The traction power substation shall match the existing substation dimensions, weight, equipment arrangement and floor opening to utilize existing conduit stub-ups.
- B. Provide each substation to consist of two sections:
 - 1. AC section including the AC switchgear assembly, and the rectifier transformer.
 - 2. DC section including rectifier, DC switchgear assembly, and negative return and drainage assembly.
- C. Provide adequate area to accommodate all electrical equipment and ancillary components as shown on Contract Drawings and listed in this Specification.
- D. Position equipment to permit maintenance, removal, and replacement of any item of equipment without the necessity of moving other items. Provide space to open doors, remove panels, and withdraw switchgear without interference of other units.

- E. Provide ceiling heights and size of structural openings to permit entry and removal of the largest components installed in the housing.
- F. Provide working and electrical clearance in the substation compliant with the NEC.

2.029 NAMEPLATES, LABELS, AND WARNING SIGNS

A. Nameplates:

- 1. Provide all major items of equipment, such as transformers, rectifiers and circuit breakers, with permanent nameplates identifying the equipment, relevant parameters, manufacturer, and other appropriate information such as serial numbers.
- 2. Provide the nameplates in accordance with applicable ANSI and NEMA standards.

B. Labels

- 1. Provide equipment cubicles and wall mounted equipment with black lamincoid labels. Provided primary equipment description using white lettering two inches (2") high and secondary description using lettering $\frac{3}{4}$ inch high.
- 2. Identify all external and internal equipment mounted on enclosure doors and panels, such as protective relays, auxiliary relays, control switches, instruments, transducers, indicating lights, test blocks, terminal blocks, and fused blocks with labels. Securely attached labels in the vicinity of the equipment.
- 3. Submit the text of all labels to METRO for approval.

C. Warning Signs

- 1. Provide graffiti-, stain-, and airborne pollutant-resistant signs. Selected easily cleanable signs with high resistance to abrasion, bleaching cleaning agents, and fading due to UV radiation present in sunlight.
- 2. Provide warning signs, size not less than 12" x 12", at following locations and with text as indicated:
 - a. Front panel of rectifier transformer: "Danger - High Voltage."
 - b. Front panel of each switchbox: "Danger - High Voltage."
 - c. Substation interior: "Danger - High Voltage."
 - d. Substation exterior: "Danger - High Voltage."
- 3. Provide warning signs, letter size not less than $\frac{1}{2}$ inch high, at following locations and with text as indicated:

- a. Locations of substation emergency shutdown push buttons:
“Substation Emergency Shutdown.”
- D. Attach all nameplates, labels, and warning signs with non-corrosive screws.

2.030 MISCELLANEOUS REQUIREMENTS

- A. Provide all auxiliary devices necessary for reliable and safe operation as well as for preventive and corrective maintenance of the substation. Included the following:
1. Anti-condensation Heaters. Provided thermostatically controlled space heaters in equipment enclosures, except in the rectifier transformer enclosure, to prevent condensation on equipment at low temperatures.
 2. Circuit Breaker and Control Switch Spare Contacts. Provided at least four spare contacts, two normally open and two normally closed, to allow for field modification of control logic.
 3. Test Points. Provided test points for connecting testing and recording equipment to monitor all substation equipment.
 4. Fire Extinguisher. Furnished two multi-purpose, wall mounted fire extinguishers at each substation.
 5. Telephone
 - a. Provide a commercial grade telephone in each substation to interface with the public telephone system.
 6. Receptacles. Installed two standard duplex, ground fault circuit interrupter type outlet receptacles, 120 V, 20 A each, and one standard 240 V, 20 A, ground fault circuit interrupter type outlet receptacle inside each substation.
 7. Document Cabinet. Installed a wall mounted cabinet with shelves for storage of instruction books, records, log books, switching tags, and other pertinent documents. Furnished the cabinet with doors and closing and latching mechanism.
 8. Spare Parts Cabinet. Installed a wall-mounted cabinet to store small spare parts. Furnished the cabinet with doors and closing mechanism.
 9. Work Table. Installed a wall mounted, fold-down, work table. The table locks in the up position. Provided replaceable, non-conducting composition board work table surface.

10. Miscellaneous Items. Provided the following items in each substation:

- a. Hook for hanging circuit breaker racking handle.
- b. Broom
- c. Vacuum cleaner
- d. Ladder
- e. First aid kit

B. Provide step(s) at each entrance to the substation

2.031 FOUNDATION

A. Line Section Designers designed and constructed substation foundations. Coordinated the requirements for the foundation design with the Line Section Designers. Provide equipment locations, footprints, and loading.

PART 3 – EXECUTION

3.01 GENERAL

- A. Perform all phases of substation manufacture by qualified and experienced personnel using proper tools and equipment under competent supervision.
- B. Used only new components for substation manufacture.
- C. Used only products and materials free of asbestos and other potentially harmful substances.

3.02 SUBSTATION INSTALLATION

- A. Deliver substation to the site and placed onto the foundation. Aligned and leveled the unit and attached tie-downs to the foundation.
- B. Extend conduit stub-ups to equipment openings in floor for power and communications.
- C. Connect substation AC power cables

1. Underground utility line.

- a. At substations supplied from an underground utility line, pulled AC substation supply cable into the ductline between the substation and the utility interface point.

- b. Terminate and insulate the cable at the traction power substation entrance terminations. Connections at the utility interface point to be performed by the utility.
- D. Pull all positive and negative DC cables into ductbanks and terminate the cables at the traction power substation.
- E. Make all grounding connections.
- F. Seal all cable entrance openings into the substation.

3.03 ARRESTER INSTALLATION.

- A. Connections between the ground busbar or ground grid are by copper conductors.

3.04 SUBSTATION GROUNDING

- A. Connect neutral of the substation supply cable to the substation grounding busbar where required by Utility Company.
- B. Connect the rectifier transformer grounding pads to the substation grounding grid at TPSS. Other substations were connected at the factory.
- C. Connect the substation housing grounding pads to the substation grounding grid.
- D. Connect the AC equipment grounding busbar to the substation grounding grid at TPSS.
- E. Run all grounding connections via the shortest and straightest possible route.

3.05 PROTECTIVE DEVICE SETTINGS

- A. Set all protective devices in accordance with the results of the Protective Device Coordination Study.

3.06 TESTING

- A. AC Cable Entrance Cubicle
 - 1. Design Tests. Perform the following tests on one cable entrance cubicle of each voltage and short circuit rating in accordance with ANSI C37.20.2 unless waived:
 - a. Dielectric tests
 - b. Rated continuous current tests
 - c. Short-time current withstand tests

- d. Mechanical endurance tests
 - e. Flame resistance test
 - f. Rod entry test
 - g. Paint qualification test
2. Production Tests. Perform the following tests on all utility service cubicle in accordance with ANSI C37.20.2:
 - a. Dielectric tests
 - b. Mechanical operation tests
 - c. Grounding of instrument transformer cases test
 - d. Electrical operation and control wiring tests

B. AC Switchgear Assembly

1. Design Tests. Perform the following tests on one AC switchgear assembly of each voltage and short circuit rating in accordance with ANSI C37.20.2 unless waived:
 - a. Dielectric tests
 - b. Rated continuous current tests
 - c. Short-time current withstand tests
 - d. Short-circuit/momentary current withstand tests
 - e. Mechanical endurance tests
 - f. Flame resistance test
 - g. Rod entry test
 - h. Paint qualification test
2. Production Tests. Perform the following tests on all AC switchgear assemblies in accordance with ANSI C37.20:
 - a. Dielectric tests
 - b. Mechanical operation tests
 - c. Grounding of instrument transformer cases test
 - d. Electrical operation and control wiring tests

C. AC Circuit Breaker

1. Design Tests. Perform the following tests on one AC circuit breaker of each voltage and short circuit rating in accordance with ANSI C37.09 unless waived:
 - a. Rated maximum voltage test
 - b. Rated voltage range factor test
 - c. Rated frequency test
 - d. Rated continuous current test
 - e. Rated dielectric strength test
 - f. Short circuit rating test
 - g. Load current switching test

- h. Rated control voltage test
 - i. Mechanical life test
 - j. Porcelain components test
2. Production Tests. Perform the following test on all AC circuit breakers in accordance with ANSI C37.09:
 - a. Current transformer test
 - b. Name plate check
 - c. Resistors, heaters and coils test
 - d. Control and secondary wiring test
 - e. Clearance and mechanical adjustment test
 - f. Mechanical operations test
 - g. Timing test
 - h. Stored energy system test
 - i. Electrical resistance of current path test
 - j. Low frequency withstand voltage test

D. Rectifier Transformer

1. Design Tests. Perform the following tests on one rectifier transformer of each voltage and power rating in accordance with ANSI C57.12.91 and ANSI C57.18:
 - a. Temperature rise test
 - b. Impulse test
 - c. Power factor test
 - d. Insulation resistance test
 - e. Audible sound level test
 - f. Short circuit capability test
2. Production Tests. Perform the following tests on all rectifier transformers in accordance with ANSI C57.18 and IEEE 1653.2:
 - a. Resistance measurements
 - b. Ratio test
 - c. Polarity and phase relationship test
 - d. Excitation current and no-load losses test
 - e. Percentage impedance, commutating impedance and load losses tests. The load losses are determined in accordance with IEEE 1653.2 and in ANSI C57.18 for loads specified in the Transformer/Rectifier Loss Schedule
 - f. Applied voltage test
 - g. Induced voltage test
 - h. Partial discharge test

E. Rectifier

1. Design Tests. No design tests were required for the rectifier assembly. Furnish the following certified data for the rectifier diodes:

- a. RMS forward current rating
 - b. Average forward current rating
 - c. Non-repetitive surge forward current rating
 - d. Repetitive peak reverse current
 - e. I_{2t} for fusing
 - f. Repetitive peak reverse voltage rating
 - g. Non-repetitive peak reverse voltage rating
 - h. Forward voltage drop
 - i. DC reverse voltage
 - j. Forward power loss
 - k. Maximum operating junction temperature
 - l. Thermal resistance - junction to case
 - m. Thermal resistance - case to fin
 - n. Performance curves
 - 1) Allowable peak surge current versus frequency
 - 2) Average power dissipation versus average forward current
 - 3) Instantaneous forward current versus instantaneous forward voltage
 - 4) Transient thermal impedance (junction to case) versus time
 - 5) Allowable case temperature versus average forward current
2. Production Tests. Perform the following tests on each rectifier in accordance with IEEE 1653.2:
 - a. Dielectric strength test
 - b. Rated voltage test
 - c. Electrical operation and control wiring test

F. Transformer/Rectifier Assembly

1. Connect one transformer/rectifier package as a complete operable assembly including interconnecting cabling in its operating configuration. Subject the assembly to the following tests to confirm compliance with the System Specification requirements.

- a. Transient Surge Test
 - 1) Energize and de-energize the transformer rectifier assembly at the rated voltage by operating the AC circuit breaker.
 - 2) Record voltage waveforms at all transformer and rectifier terminals and at critical points in the surge protection network.

- 3) Repeat the test a minimum of ten times to obtain the maximum transient surge.
 - 4) The maximum crest of transient surge impressed on the rectifier did not exceed 75% of the repetitive peak reverse voltage rating of the diodes.
 - b. Voltage Regulation Test. Perform a test to demonstrate that the transformer/rectifier meets the specified voltage regulation.
 - c. Current Unbalance Test. Perform tests at rated power and take measurements to determine the following:
 - 1) Current and voltage unbalance in each AC phase.
 - 2) Current unbalance in diodes in each rectifier leg and between rectifier legs.
 - d. Load and Short Circuit Test
 - 1) Remove one fused in each leg to cause the most onerous conditions in the remaining diodes. Determine the current and power loss in each rectifier diode. Identified six diodes, which operate at the highest junction temperature.
 - 2) With one fused removed in each leg, apply rated load current until constant temperature of the transformer windings and the diode junctions is reached.
 - 3) Apply the specified load cycle followed by short circuit within one second after the load cycle end.
 - 4) Monitor rectifier commutation on an oscilloscope and
- B. Continuously record the traction transformer winding temperature, diode case temperature and any other appropriate parameters. Produce a junction temperature versus time graphs for the diodes with the highest junction temperature.
 - e. No-Load Loss Test
 - 1) Determine lumped transformer/rectifier no-load losses
 - 2) Determine rectifier no-load losses by subtracting the transformer no-load losses from the lumped no-load losses.
 - f. Load Losses Test
 - 1) Determine lumped transformer/rectifier load losses including all transformer/rectifier auxiliary loads in accordance with IEEE 1653.2.

- 2) Determine the rectifier load losses by subtracting the transformer load losses at that load from the lumped losses at the corresponding load.
- g. Power Factor Test. Determine the transformer/rectifier assembly power factor at rated power.
- h. Harmonic Spectrum Analysis. Perform harmonic spectrum analysis to determine the harmonic components of the AC input voltage and current at rated power. Record harmonics up to 50th harmonic. Provided Total Harmonic Distortion (THD) and Total Demand Distortion (TDD) at the rated output.

G. DC Switchgear Assembly

1. Design Tests. Perform the following tests on one DC switchgear assembly in accordance with ANSI C37.20.1:
 - a. Dielectric tests
 - b. Rated continuous current tests
 - c. Short-time current withstand tests
 - d. Short-circuit/momentary current withstand tests
 - e. Mechanical endurance tests
 - f. Flame resistance test
 - g. Rod entry test
 - h. Paint qualification test
2. Production Tests. Perform the following tests on all DC switchgear assemblies in accordance with ANSI 37.20.1:
 - a. Dielectric tests
 - b. Mechanical operation tests
 - c. Grounding of instrument cases test
 - d. Electrical operation and control wiring tests

H. DC Circuit Breaker

1. Design Tests. Perform the following tests on one DC circuit breaker of each type in accordance with ANSI C37.14:
 - a. Sequence 1
 - 1) Short-time current test
 - 2) Continuous current test
 - 3) Low load level current switching test
 - 4) Endurance test
 - 5) AC dielectric withstand test
 - b. Sequence 2
 - 1) Trip device calibration check tests
 - 2) AC dielectric withstand tests

- 3) Peak current tests
 - 4) Short-circuit current tests
2. In addition, perform the following design tests:
 - a. Maximum Energy Interrupting Test. Determine the maximum energy stored in the distribution system inductance which the circuit breaker will be expected to dissipate during interruption of short circuit current.
 - b. Connect the circuit breaker to a dummy circuit representing this condition and performed tests to demonstrate that the circuit breaker is capable of dissipating this maximum level of energy during opening.
 3. Production Tests. Perform the following tests on all DC circuit breakers in accordance with ANSI C37.14:
 - a. Calibration test
 - b. Control, secondary wiring and device check
 - c. Dielectric withstand voltage test
 - d. No-load operation test
- I. Negative Return and Drainage Assembly
1. Design Tests. Test the negative grounding unit to confirm that its operation is in accordance with the Specification.
 2. Production Tests. Perform the following production tests:
 - a. Dielectric test
 - b. Electrical operation test
- J. Insulating Floor
1. Test the floor resistance using high voltage Megger prior to switchgear installation. Connect one lead of the Megger to a copper plate and the other lead to the substation steel floor. Use a salt solution of a volume of salt and b volume of water as a conductive medium between the copper plate and the floor insulation.
 2. Took one resistance reading for each three feet by three feet (3' x 3') area of insulated floor. The average of all resistance readings was at least 10 megaohms
- K. Other Equipment
1. Perform applicable tests on the following substation equipment:

- a. Indicating Instruments. Test indicating instruments in accordance with ANSI C39.1.
- b. Devices and Transducers. Test devices and transducers in accordance with ANSI C37.90 and ANSI C37.90.1.
- c. Instrument Transformers. Test instrument transformers in accordance with ANSI C57.13 and NEMA EI 21.
- d. Annunciators. Test Annunciators in accordance with ANSI C37.90.
- e. Programmable Logic Controllers. Test PLCs in accordance with the applicable requirements of the Instrument Society of America (ISA).
- f. Batteries. Test batteries in accordance with IEEE 450. All cells are pressure tested prior to shipment.
- g. Battery Chargers. Test battery chargers in accordance with NEMA PE5.
- h. Station Power Supply Transformers. Test the station power supply transformers in accordance with ANSI C57.12.91.
- i. Insulated Wires and Cables. Test wires and cables in accordance with ASTM B 3, ASTM B 33, ASTM D 470, NEMA WC 3, NEMA WC 5, NEMA WC 8, and IEEE 383 Standards.
- j. Busbars. Tested busbars in accordance with ANSI C37.20.2 and NEMA BU 1.
- k. Disconnect Switches. Test disconnect switches in accordance with ANSI C37.34.
- l. Surge Arresters. Test surge arresters in accordance with ANSI C62.11.
- m. Cable Trays. Test cable trays in accordance with NEMA VE 1.
- n. Panelboards. Test panelboards in accordance with NEMA PB 1.
- o. Molded-Case Circuit Breakers. Test molded-case circuit breakers in accordance with NEMA AB 1, NEMA AB 2 and NEMA AB 3

L. Traction Power Substation

1. Perform the following tests and checks on all completely assembled substations:
 - a. Functional and operating tests of all devices and circuits.
 - b. Verification of protective device settings and trip circuit operation, including:
 - 1) Settings of all devices in accordance with the approved protective device coordination study.
 - 2) Checking of each AC and DC switchgear and circuit breaker protective system using primary injection test.
 - 3) Simultaneous verification of the current transformer, the voltage transformer, or the shunt ratio, the secondary winding polarity, the device operation, the integrity of tripping circuit, and the circuit breaker operation.

- 4) Verification of correct operation of autoreclosing and transfer trip devices.
- c. Correct operation of all interlocks.
- d. Correct operation of annunciator. From each annunciated function initiated each possible status change and verified that the corresponding information is correctly annunciated.
- e. Correct operation of SCADA system.
 - 1) Initiate a status change at each supervised, controlled and measured item of equipment at traction power substations and verified that the status change was correctly transmitted to the SCADA system and correctly displayed on console monitor at the Train Control Center.
 - 2) Apply a control signal at the Train Control Center for each controlled point and verified that the controlled item of equipment responded correctly.
- f. Correct operation of the PLC. Test PLC settings and verified operation of all PLC functions.
- g. Proper operation of thermostats, anti-condensation heaters, and HVAC system to demonstrate that the specified temperature was maintained.
- h. Proper operation of lighting system.
- i. Rain tested substation housing in accordance with ANSI C37.20.2.

END OF SECTION

SECTION 18201

WIRE AND CABLE FOR TRACTION POWER

PART 1 – GENERAL

1.01 SUMMARY

- A. This section specifies furnishing, installation and testing of wire and cable.

1.02 REFERENCES

- A. Codes, Regulations, Reference Standards and Specifications shall follow the quality system and regulatory requirements including the following:
- B. Comply with the latest edition of the applicable standards, Codes and regulations of the Authority Having Jurisdiction.
1. National Electrical Code: (NEC) 2012.
 2. IEEE 383-2015 – Standards for Qualifying Electrical Cable and Splices.
 3. Insulated cable Engineers Association (ICEA): S-94-649, S-97-682, S-105-692, S-95-658, S81-570 T-33 - 655.
 4. IEEE: 383. Standard for Type Test of Class IE Electrical Cable, Field Splices, and Connections for Nuclear Power Generating Stations, IEEE 1202-1991 Standard for Flame Testing of Cable for Use in Cable Tray in Industrial and Commercial Occupancies.
 5. National Electrical Manufacturing Association (NEMA): BU1, WC-55, WC-57, WC-70, WC-71, WC-74.
 6. American Standard of Testing and Material (ASTM): B3-95 Standard Specifications for Soft Annealed Copper Wire; B8-99 Standard Specifications for Concentric Layer Stranded Copper Conductors, Hard, Medium Hard and Soft; D471-98e1 Standard Test Method for Rubber Property –Effect of Liquids; B173, E662-97. Standard Test Method for Specific Optical Density of Smoke Generated by Solid Material
 7. Underwriters Laboratory (UL): 44 Thermo-set Insulated Wire and Cable; 857 Electric Bus ways and Associated Fittings; 1072 Standard for Medium Voltage Power Cable; 1569 Standard for Metal-clad cable; 1685 Standard for Vertical Tray Fire Propagation and Smoke Release Test for Electrical and Optical Fiber cable; 1581 Standard for Electrical Wires, cable and Flexible Cords ; 224 Extruded Insulating Tubing.
 8. NFPA 262: Standard method of test for flame travel and smoke of wires and cables for use in air handling spaces.

1.03 SUBMITTALS

- A. Submit the following for approval in accordance with the Contract Documents and with additional requirements as specified:
 - 1. Shop Drawings: Submit shop drawings for each type of cable.
 - 2. Certification:
 - a. Certified flame retardancy test reports and data for tests performed not more than 12 months prior to submittal, for materials which are identical to those of cable furnished.
 - b. Submit smoke-density test reports and data from tests performed not more than 12 months prior to the submittal for materials which are identical to those of the furnished cable.
 - c. Certified test reports demonstrating that cable complies with specified requirements and those of referenced applicable Standards.
 - d. Certificates from manufacturers and UL verifying that products conform to specified requirements. Include certificate with submittal of shop drawings and with each cable shipment.
 - e. Certificates from manufacturers verifying that wire and cable systems used for emergency lighting are listed and have a minimum one hour fire-resistive rating in accordance with UL2196.

1.04 QUALITY ASSURANCE

- A. Qualifications: Select a manufacturer who is regularly engaged in production of similar wire and cable, particularly to Railway or Transit industry in USA.

1.05 NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) REQUIREMENTS

- A. All wire and cable installed in substation shall meet the requirements of the 2010 Edition of NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail System.
- B. In the event that compliance with NFPA 130 will produce non-compliance with the requirements of this Specification, NFPA 130 shall take precedence.

1.06 DELIVERY, STORAGE, AND HANDLING

- A. Mark each cable to show UL Type, Listing/Certifications, size, voltage, manufacturer and number of conductors or phases in accordance with NEC requirements. Additional marking at the ends and 50ft interval shall include project identification for which the cable is being supplied.
- B. Mark each reel or spool with the length of the cable wound on it, and with the total weight of the reel or spool including the cable.
- C. Ship each unit securely packaged and labeled for safe handling and shipment.

- D. Store products in a dry and secure facility.

PART 2 – PRODUCTS

2.01 MATERIALS

- A. General Requirements for Single-Conductor and Multiple Conductor Traction Power Cable:
1. Type and size: Type I cable having low smoke – generating characteristics as shown on contract drawings.
 2. Conductors: Type I cable having low, zero halogen-generating characteristics.
 - a. ASTM B3 or ASTM B8 annealed copper
 - b. Size 10 AWG and smaller: Solid or Class B or Class C stranded.
 - c. Size 8 AWG and larger: Class B stranded, unless otherwise specified.
 - d. Other constructions as specified.
 3. Standards: Except as modified, wires and cable complying with the following standards:
 - a. Cross-linked polyethylene (XLPE) insulated cable: S-94-649, S-97-682, WC70, WC71 and WC74.
 - b. Other cable: ICEA S-94-649; S-105-692; WC-70; WC71; and WC74.
 4. Nonmetallic jacket for single-conductor cable
 - a. Cross-linked polyethylene (XPLE) or cross-linked polyolefin unless otherwise specified.
 5. Cross-linked polyolefin complying with the following physical requirements. Properties tested in accordance with S-95-658, S-96-639, if ethylene propylene-rubber (EPR) insulation is used and ICEA S-95-658 (NEMA WC 70), ICEA S-96-659 (NEMA WC71), ICEA S-93-639 (NEMA WC74), ICEA S-94-649; S-97-682 if, cross linked polyethylene insulation is used. Jacket material free of PVC and PVC-based compounds.
 - a. Tensile strength, minimum pounds per square inch 1,700 (1,500 for 600V).
 - b. Elongation at rupture, minimum percent: 150 (100 for 600V).
 - c. Aging requirement: After 168 hours in air oven test at 100 degrees Celsius, plus or minus one degree Celsius:
 - i. Tensile strength, minimum percentage of unaged value: 100.
 - ii. Elongation at rupture, minimum percentage of unaged value: 80.

- d. Oil immersion: 18 hours at 121 degrees Celsius, plus or minus one degree Celsius, ASTM D471, Table 1, IRM 902:
 - iii. Tensile strength, minimum percentage of unaged value: 60.
 - iv. Elongation at rupture, minimum percentage of unaged value: 70 (60 for 600V).
 - e. Jacket materials other than cross-linked polyolefin complying with ICEA – S-94-649; S-97-682; S-95-658 and S-93-639-. Jacket material free of PVC and PVC-based compounds.
6. Flame retardancy: Single-conductor and multiple-conductor cable tested by Independent Agency demonstrating flame retardancy in accordance with NFPA 130.
- a. Single-conductor cable and individual conductors of multiple-conductor cable passing vertical wire (VW1) flame test In accordance with UL-1685 or ICEA S-95-658. Cable size for testing: 14 AWG.
 - b. Single-conductor cable, Size 1/0 AWG and larger, passing vertical tray flame test, using ribbon gas burner in accordance with IEEE 1202, UL 1581 or IEEE-383-1974. Cable size for testing: 1/0 AWG.
 - c. Multiple-conductor cable passing vertical tray flame test, using ribbon gas burner in accordance with IEEE 1202, or IEEE 383-1974. Cable size for testing: 7/C or 9/C with 12 AWG or 14 AWG conductors.
7. Applied Voltage testing:
- a. Single-conductor cable and individual conductors of multiple-conductor cable to be given applied AC voltage dielectric strength test, i.e., six-hour water immersion test.
 - b. For single conductors of multiple-conductor cable, conduct tests prior to assembly as multiple-conductor cable
 - c. Test procedures:
 - v. Polyethylene-insulated conductors: In accordance with ICEA-S-94-649; S-97-682; ICEA S-95-658 (NEMA WC-70); ICEA S-96-659(NEMA WC71) and ICEA S-93-639(NEMA WC74), as applicable.
 - vi. Other conductors: In accordance with IEEE S-94-649; S-97-682; S-105-692.
- B. Smoke generation: Single-and-multiple-conductor cable jacket materials demonstrating low-smoke generation when tested in accordance with NFPA 130.
- C. Conduct tests on specimens of overall jacket material for multiple-conductor cable and of jacket material for single-conductor cable.

1. Prepare slab specimens for each material .100 inch, plus-or-minus .005-inch thick, identical to those of finished cables and meeting minimum physical requirements specified.
 2. Prior to testing, submit six-inch square portion of each specimen. Tag sample with manufacturer's jacket or insulation identification code or number.
 3. Test values for cross-linked polyolefin not to exceed the following:
 - a. Flaming mode:
 - vii. Uncorrected maximum specific optical density during first four minutes of test: 50.
 - viii. Uncorrected maximum specific optical density for entire 20-minute test: 250.
 - b. Non-flaming mode:
 - ix. Uncorrected maximum specific optical density during first four minutes of test: 50.
 - x. Uncorrected maximum specific optical density for entire 20-minute test: 350.
 - xi. Other conductors: In accordance with NFPA 130.
- D. 15-kV Single-Conductor Cable:
1. Rated voltage: 15-kV
 2. Conductor: As specified and with an extruded semi-conducting strand screen. Annealed uncoated copper compact stranded per ASTM B-496.
 3. Insulation: Ethylene-propylene rubber, 133 percent insulation level, with an extruded semi-conducting insulation screen. Rated for 105 degrees Celsius continuous 140 degrees Celsius for emergency loads and 250 degrees Celsius for short circuit, suitable for dry and wet locations. Meets or exceeds electrical and physical requirements of ICEA S-93-639/NEMA WC74 & S-97-682, AEIC CS8 AND UL 1072.
 4. Insulation Screen: Extruded semiconducting EPR insulation screen meets or exceeds electrical and physical requirements of ICEA S-93-639/NEMA WC74 & S-97-682, AEIC CS8 AND UL 1072.
 5. Shield: A concentric neutral shield consisting of 5 mil solid bare copper wires helically applied with 25% minimum overlap over the insulation shield.
 6. Jacket: Meet or exceeds electrical and physical requirements of ICEA S-93-639/NEMA WC74 & S-97-682, CSA C68.3 and UL 1072 for polyvinyl chloride jackets. UL Listed and sunlight resistant in accordance to UL 1072. Resistant to flame, oil, acids, and most chemicals.

7. Additional requirements:
 - a. Passes the Vertical Tray Flame Test requirements of UL1072 and IEEE 383 and 1202
 - b. In compliance with CSA FT4
- E. 2000-Volt Single-Conductor Cable:
 1. Rated voltage: 2000 Volts.
 2. Conductor:
 - a. Standard 500 KCMIL cable, Class D stranded for traction power feeder installed in conduit and cable tray.
 3. Insulation: Ethylene-propylene rubber, ICEA Type II, 90 degrees Celsius continuous 130 degrees Celsius for emergency loads and 250 degrees Celsius for short circuit, suitable for dry and wet locations.
 4. Jacket: Low smoke, low toxicity, zero halogen nonmetallic jacket of S-95-658 thermoset type II or cross-linked polyolefin.
 5. UL labeling: Type RHW-2.
 6. Additional requirements:
 - a. Insulation power factor: Two percent maximum.
 - b. Bond jacked to insulation to prevent moisture pockets. Minimum peel strength of the jacket from insulation: Four pounds per inch width for cross-linked polyolefin, and 10 pound per inch for heavy-duty neoprene.
- F. 600-Volt, Single-Conductor Cable:
 1. Rated voltage: 600 Volts.
 2. Insulated with ethylene-propylene-rubber with nonmetallic jacket material demonstrating low smoke, zero halogen characteristics UL-labeled Type XHHW-2 or RHW-2.
 3. Color coding: In accordance with paragraphs 200-6, 200-7 and 210-5 of the NEC.
 4. Cross-linked polyolefin complying with the following physical requirements. Properties tested in accordance with S-95-658, S-96-639, if ethylene propylene-rubber (EPR) insulation is used and ICEA S-95-658 (NEMA WC 70), ICEA S-96-659 (NEMA WC71), ICEA S-93-639 (NEMA WC74), ICEA S-94-649; S-97-682 if, cross linked polyethylene insulation is used. Jacket material free of PVC and PVC-based compounds.
 - a. Tensile strength, minimum pounds per square inch 1,500.
 - b. Elongation at rupture, minimum percent: 100

- c. Aging requirement: After 168 hours in air oven test at 100 degrees Celsius, plus or minus one degree Celsius:
 - xii. Tensile strength, minimum percentage of unaged value: 100.
 - xiii. Elongation at rupture, minimum percentage of unaged value: 80.
 - d. Oil immersion: 18 hours at 121 degrees Celsius, plus or minus one degree Celsius, ASTM D471, Table 1, IRM 902:
 - xiv. Tensile strength, minimum percentage of unaged value: 60.
 - xv. Elongation at rupture, minimum percentage of unaged value: 60
- G. 600-Volt, Nonmetallic Sheathed Multiple-Conductor Cable:
- 1. Individual conductors:
 - a. Rated voltage: 600 Volts.
 - b. Number of conductors: As shown or required.
 - c. Construction: Complying with one of the following:
 - xvi. Insulated with ethylene-propylene-rubber, with XLPO jacket.
 - xvii. Insulated with composite compound of ethylene-propylene-rubber and polyethylene, UL Class EPCV, without outer jacket.
 - xviii. Insulated with filled cross-linked polyethylene without outer jacket.
 - d. Phase and neutral conductors: Individually insulated.
 - e. Neutral conductors: Same size as phase conductors.
 - f. Insulated ground conductors: Sized in accordance with the NEC, unless otherwise shown.
 - g. UL-listed as Type RHW-2 or XHHW-2.
 - 2. Conductors assembled with non-wicking, flame-retardant filler to form cable of circular cross section.
 - 3. Multiple-conductor cable provided with overall nonmetallic jacket of T-33-655 Table 4-2 thermoset type II or cross-linked polyolefin.
 - 4. Cable UL-listed as follows:
 - a. Nonmetallic-sheathed cable: Type TC, suitable for wet and dry locations.
 - 5. Color coding:

- a. Power cables: In accordance with paragraph 200-6, 200-7 and 210-5 of the NEC.
 - b. Control cables: In accordance with ICEA S-73-532, Table E-2.
- H. Instrumentation Cable: 2/C, twisted pairs:
1. Individual conductors:
 - a. Rated voltage: 600 Volts.
 - b. Number of conductors: As shown.
 - c. Construction: Insulated with polyethylene insulation.
 2. Conductors twisted and covered with a tinned copper braided shield; Class B stranded.
 3. Provided with XLPO overall jacket.
- I. Bare Conductor: ASTM B3, annealed copper conductor; 8 AWG and larger, Class B stranded.
- J. Medium Voltage Cable Terminations:
1. Except as otherwise specified, heat shrinkable tubing kit type, with grounding accessory kits, in accordance with the characteristics of the medium voltage cable shall be furnished.
 - a. Shrinkable tubing kits to be pre-stretched shrinkable tubing and shall contain all necessary components to reinstate cable insulation, metallic shielding/grounding system and overall jacket.
 - b. Qualified and meets per IEEE-48 as Class I terminations

PART 3 – EXECUTION

3.01 INSTALLATION

- A. Install all wiring continuous, without splices, between terminations, except as otherwise noted or approved by the engineer.
- B. Install single-conductor cable in conduit or cable tray as shown. Install UL Type TC multiple-conductor cable in cable trays. Install UL Type MC multiconductor cable and ground cable on channel inserts, cable trays or racks, using straps and fasteners. Install UL Type MC multiple-conductor cable in conduit where shown or required. On walls or ceilings, fasten cable directly to channel inserts, or use expansion bolt anchors to attach to concrete and toggle bolts to attach to concrete masonry walls.
- C. Use nylon straps to bundle and secure wire and cable located in panel boards, cabinets, switchboards, switchgear and control panels.
- D. Minimum bending radius 12 times outer diameter of the cable. Where shown, use shorter bending radius as permitted by NEC ICEA and cable manufacturer.

- E. To facilitate pulling cable, use UL-listed lubricant recommended by cable manufacturer.
- F. Use polyethylene or other suitable non-metallic rope for pulling cable. Attach to cable by means of either woven basket grips or pulling eyes attached directly to the conductors.
- G. In damp and dusty indoor locations, manholes and outdoor locations, seal cable at conduit termination using duct seal compound.
- H. Support cable installed in manholes at each invert location with cable brackets, racks and insulators. Provide brackets of suitable length with one insulator for each cable.
- I. Support traction power cable installed in vertical risers with nonmetallic cable grip support at top of riser and with nonmetallic or aluminum multiple segment wedging plus type cable support at intermediate pull box provided.
- J. Where shown or necessary, install cable seal fitting specified in Section compound.
- K. Terminate medium voltage cable, using the specified termination kits, in accordance with the manufacturer's recommendations.
- L. The splicing of power and control cables is not permitted in the ductbanks, cable troughs or cable trenches. However, if permitted, make watertight splices as approved.
- M. 500 KCMIL traction power cables shall be hooked up at switchgear end and trackside (negative and positive rails).
- N. All 500 KCMIL cables shall be secured at every rung on the cable tray with tie wraps.
- O. Identify cable terminations, feeders, power and control circuits using the following:
 - 1. Cable Tags: Stainless steel tags punched with conduit or cable number as shown.
 - 2. Wire Labels: Sleeve-type, heat shrinkable, flame retardant Raychem TMS product line, Type XPE or equal and conforming to UL 224. Wire identification same as corresponding terminal block identification unless otherwise shown. The labels on 1000 KCMIL cable shall be clear, heat shrinkable with ½" height yellow lettering stamped on inside. The labels shall have reference of substation or tie breaker station breaker supervisory control ID number and cable sequence in the branch of the feeder (e.g. BRK. 32-A) at both ends.
 - 3. Attach tags to cable with slip-free plastic lacing or nylon bundling straps. Use designation shown.

3.02 FIELD QUALITY CONTROL

- A. Furnish equipment required to perform tests. Prior to insulation and high potential tests, disconnect instruments and equipment which might be damaged during such tests.
- B. Submit test procedure for approval and perform approved tests. Do not perform tests without approved test procedure. Tests include but not limited to the following:
 - 1. 600-Volt non-metallic sheathed multiple-conductor cable:
 - a. Test continuity of cable conductors using ohmmeter.
 - b. Proof-test insulation resistance to ground and between insulated conductors for minimum of one minute using 1000-Volt megger. Insulation resistance: One megohm minimum, corrected to 15.6c. Testing procedure shall be as follows:
 - xix. Disconnect all wires of the cable under test at both ends and tape the far end of the wire under test with insulation tape of 600-Volt class. Connect the bare end of the wire under test to the positive terminal of 1000-Volt megger.
 - xx. Connect the negative terminal of 1000-Volt megger to the nearest available ground terminal.
 - xxi. Measure the insulation resistance of the wire under test by cranking the megger.
 - c. When the cable shows insulation resistance of less than one megohm, perform high potential test at 80 percent of factory DC test voltage or as recommended by cable manufacturer. A gradual decrease of leakage current with time indicates an acceptable installation.
 - 2. 600-Volt single conductor cable:
 - a. Test continuity of conductors using ohmmeter.
 - b. Disconnect cable under test at both ends. Proof-test insulation resistance between each cable and the conduit in which the cable runs. While conducting the test, all other cables installed in the same conduit with the cable under test shall be connected to ground at one end. Insulation resistance shall be measured with a 1000-Volt megger for minimum of one minute between the cable under test and the ground. Insulation resistance: One megohm minimum corrected to 15.6 degrees Celsius.
 - c. When cable shows insulation resistance of less than one megohm, perform high potential test at 80 percent of factory DC test voltage or as recommended by cable manufacturer. A gradual decrease of leakage current with the time indicates an acceptable cable installation.

3. 2000-Volt single-conductor cable:
 - a. Test continuity of conductors using ohmmeter.
 - b. Proof-test insulation resistance to ground of the cable under test for a minimum of one minute using a 2500-Volt three terminal megger. Insulation resistance: 500 megohms, minimum, corrected to 15.6 degrees Celsius. Testing shall be done prior to termination of the cables at the two ends. Terminal lugs shall be installed prior to cable testing. Testing procedure shall be as follows:
 - xxii. Proof-test the system insulation resistance to ground of the cable under test using step-voltage testing method.
 - xxiii. Insulation resistance: 500 megohms, corrected to 15.6 degrees Celsius. Testing shall be done after all cables have been installed and lugged.
 - xxiv. Isolate all cables at trackside and in the switchgear.
 - xxv. Secure each cable under test and connect the positive test lead of the megger to one end of the cable under test. Connect the megger ground lead to one the station ground busbar.
 - xxvi. Apply a 1000-Volt DC test voltage to the cable for one minute and record the end test reading on the data sheet.
 - xxvii. If the megger reading is greater than or equal to 500 megohms, proceed with testing the next cable in the test plan. If the test value is lower than 500 megohms, proceed with the step-voltage test as described below.
 - xxviii. Step-voltage test:
 - a) *Examine and clean cable termination for presence of moisture or contamination.*
 - b) *Make a second megger test at 1000-Volts DC for one minute and record end test reading on a data sheet. If reading is less than 500 megohms, proceed with step (c) below, otherwise record new test reading on data sheet with comments depicting corrective action and proceed with testing next cable in the test plan.*

- c) *Increase the meager test voltage in increments of 500 Volts starting at 1500 Volts DC up to 2500 Volts DC and perform one minute insulation resistance measurement tests. Record end test readings on data sheet for each incremental test.*
 - d) *Compare insulation test readings at all levels of test voltage. A decrease of insulation resistance from the 1000 Volts DC test voltage to the 2500 Volts DC test voltage indicates the cable insulation has incipient weakness and the cable shall be replaced at no cost to the Contractor.*
- xxix. Repeat the above procedures for all the positive and negative traction power cables.
4. 15-kV single-conductor cable:
- a. Test continuity of conductors using ohmmeter.
 - b. Proof-test insulation resistance between conductor and the metallic shield. While conducting the test, the metal shield shall be tied to ground. Insulation resistance shall be measured with 2500-Volt megger for minimum of one minute. Insulation resistance: 500 megohm minimum corrected to 15.6 degrees Celsius.
 - c. High pot test shall be performed at the voltage level recommended by the cable manufacturer.

END OF SECTION

SECTION 18220
DC SURGE ARRESTERS

PART 1 – GENERAL

1.01 SUMMARY

A. Description

1. Installed DC surge arresters to protect traction power substation equipment against lightning and switching surges.

1.02 REFERENCES

A. Complied with applicable provisions of the following references:

1. ANSI C62.1 Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits
2. ANSI C62.2 Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems
3. ANSI C62.11 Standard for Metal-Oxide Surge Arresters for AC Power Circuits

1.03 SUBMITTALS

- A. Submitted catalog cuts and technical data on surge arrester to be furnished.
- B. Submitted manufacturer's certified test data. Included evidence that the arresters conform to the specified standards.

PART 2 – PRODUCTS

2.01 DC FEEDER ARRESTERS

- A. Provided surge arresters rated for 750 VDC system. Used the arresters, which start clamping at approximately 1,000 Volts and were fully clamped at approximately 1,400 Volts.
- B. Selected bipolar, high energy metal oxide surge arresters with energy discharge capability of at least 2.2 kJ/kV MCOV for 300 amps current or less.
- C. Acceptable arresters: Provided SMC Model 6007-003

2.02 DC NEGATIVE BUSBAR ARRESTERS

- A. Provided surge arresters rated for 750 VDC system. Used the arresters, which start clamping at approximately 1,000 Volts and are fully clamped at approximately 1,400 Volts.

PART 3 – EXECUTION

3.01 ARRESTER INSTALLATION

- A. Provided one DC surge arrester on the load side of each DC feeder circuit breaker external to the substation. Provided DC surge arresters at the first feeder riser pole on each circuit, and at specified feeder riser poles along the wayside for additional protection.
- B. Provided a surge arrester between DC negative busbar and the substation ground bus external to the substation.
- C. Installed DC surge arresters as close as possible to the protected DC circuit and the DC negative busbar, as shown on Contract Drawings.
- D. Used insulated stranded 4/0 copper cable, minimum, for all live connections and connection between surge arresters and ground busbar, and between ground busbar and ground grid.
- E. Installed substation DC surge arresters external to the substation in sealed protective enclosures, as shown on Contract Drawings. Installed feeder riser pole surge arresters at the top of the OCS pole as shown on the Contract Drawings.
- F. Sealed and covered arrester enclosures with a barrier, to prevent escape of ionized gases and debris in case of arrester rupture.
- G. Sealed all cable entrances on enclosure.

END OF SECTION

SECTION 18450

GROUNDING

PART 1 – GENERAL

1.01 SUMMARY

A. Description

1. Designed ground grids, ground rods, ground cables, ground wires, ground lugs and fittings, and exothermic welds.
2. Installation of substation ground grids was performed by Line Section Contractors.
3. Grounded substations and overhead distribution system poles. Line Section Contractors grounded all pullboxes, pole foundations, and fences.

1.02 REFERENCES

A. Comply with applicable provisions of the following references:

1. ASTM B3 Specification for Soft or Annealed Copper Wire
2. ASTM B187 Specification for Copper Busbar, Rod and Shapes
3. NFPA 70 National Fire Protection Association, National Electrical Code (NEC)

1.03 SUBMITTALS

A. Made submittals as specified herein.

B. Submitted product data on the following items:

1. Ground conductors.
2. Connectors, bushings and fittings.
3. Exothermic welding process, materials and molds.

4. Ground rods.
- C. Submitted test reports as specified herein.
 - D. Submitted a sample of each type of mechanical and compression connector proposed, along with a description of its intended use

PART 2 – PRODUCTS

2.01 BASIC GROUNDING MATERIALS

- A. Bare Conductors. Class B stranded, 4/0 AWG minimum, annealed copper conductors, conforming to ASTM B3. Aluminum conductors are prohibited.
- B. Steel Ground Rods. Used rods copper-clad by the molten weld casting process. Used ¾-inch diameter, 20-foot long rods.
- C. Busbars: Busbars conforming to ASTM B187, 98% conductivity copper.
- D. Insulated Conductors. Selected conductors conforming to the requirements for 600 V system grounding. Provided green insulation for conductors No. 2 AWG and smaller, and black insulation with green taped ends for conductors larger than No. 2 AWG.
- E. Accessories:
 1. Lugs. Selected suitable lugs for attaching ground conductors to equipment or metallic surfaces. Used NEMA 2-hole, compression type lugs manufactured of tin or silver plated copper. Installed the lugs with a hydraulic tool.
 2. Used silicon bronze bolts and braided, flexible tin-plated copper jumpers.
 3. Compression connectors for grounding above ground.

2.02 EXOTHERMIC WELDING MATERIALS

- A. Used exothermic welding materials consisting of a system of standard manufactured molds for each type and size of weld. Placed powdered metals in the mold along with the conductors to be welded. Ignited the powder to produce molten copper to weld the conductors to each other or to a surface.

PART 3 – EXECUTION

3.01 GENERAL GROUNDING REQUIREMENTS

- A. Provided all grounding as required by the Contract Drawings
- B. Line Section Contractor welded all underground grounding connections exothermically. Compression or mechanical connections, underground, were prohibited.
 - 1. Used exothermic welding for all underground conductor to conductor splices, tees, and crosses, and for all connections to ground rods.
 - 2. Used exothermic welding for grounding connections to rail, reinforcement steel, and structural steel.
 - 3. Exothermically welded ground grid conductors to concrete reinforcing steel. Prior to welding, removed epoxy coating from reinforcing steel at the location of ground grid conductor connection. Following completion of the weld, reapplied epoxy coating to exposed surfaces of reinforcing steel.
- C. Weld above ground connections in damp or wet locations exothermically.
- D. Make above ground connections or in dry location utilizing compression type terminal lugs. Attached lugs to items being grounded with stainless steel or silicon bronze bolting hardware.
- E. Protect grounding conductors from physical and environmental damage. Wherever possible, enclosed grounding electrodes and bonding conductors in non-metallic raceways. Where conductors were required to be exposed, as in the connection to the main ground busbar, supported grounding conductors by corrosion resistant metallic hardware at 4-foot intervals or less.
- F. Use oxide-inhibiting compound for all mechanical connections where copper to aluminum or copper to steel connections are made. Applied the compound to all copper, aluminum, and steel parts. In addition, abraded all aluminum contact surfaces after application of the inhibiting compound, and before attachment of the bolted connection.
- G. Make all grounding and bonding connection of electrical equipment by continuous, unspliced grounding conductors.

3.02 EXOTHERMIC WELDING

- A. Clean and dry the surfaces to be welded. Wire brush or file the point of contact to a clean bare metal surface.
- B. Use suitable welding cartridges and molds for the type of weld performed. Perform welding in accordance with the manufacturer's recommendations. Discard worn or damaged molds.
- C. After welds were completed and cooled, brushed slag from the weld area and thoroughly cleaned the joint.
- D. Where exothermic grounding connections made between copper wire and steel surfaces were direct-buried, coated the connection with a coal tar epoxy (CTE) coating per before backfilling. Also, coated the entire area of the steel surface disturbed by the exothermic welding.
- E. Where exothermic welds were made to a galvanized surface removed the galvanizing and exposed a clean surface by grinding wheel. After welding, touched up the steel surface with zinc rich primer.
- F. Tested all welds by striking with a two-pound steel hammer. Replaced any defective welds.

3.03 SUBSTATION GROUNDING

- A. Connected the grounding grid "pigtailed" to the structural substation steel, equipment, ground busbars, substation housing, and other associated provisions.

3.04 RACEWAY GROUNDING

- A. Bond all metallic raceways together to provide a continuous electrical ground path. Bonded metallic raceways to other raceway components using insulated grounding bushings. Connected grounding bushings to the grounding system using conductors sized in compliance with NEC.
- B. Install ground conductors in non-metallic raceway systems in accordance with the NEC.

3.05 INSPECTION AND TESTS

- A. Performed grounding tests of the completed ground system as specified herein.

END OF SECTION

SECTION 18950

INSTALLATION VERIFICATION TESTING

PART 1 – GENERAL

1.01 SUMMARY

A. Description

1. The work included the testing requirements for factory tests of individual items of equipment, system installation verification tests, and integrated system tests.
2. Final acceptance of tests to be made by METRO.

1.02 REFERENCES

A. Comply with applicable provisions of the following references:

ANSI C29.1 Test Methods for Electric Power Insulators
IEEE 81 Guide for Measuring Ground Impedance of a Ground System
NETA Standards for Testing

1.03 SUBMITTALS

A. Provide submittals as specified herein.

B. Testing Company. Submit name and qualifications of the testing company to be used for this work. Included the full background data of the proposed testing company, including references of prior work or projects having requirements and/or complexities similar to this Project. Include the names and qualifications of the senior engineering personnel to be performing the tests and management personnel to be responsible for the testing.

C. Test Plans

1. Prepare and submit to METRO a Test Plan for all tests to be performed.
2. Include a detailed schedule of all tests by the Contractor, suppliers and subcontractors to be completed at the plant and on METRO's property.
3. Include the following information for each test:

- a. Title of the test with reference to the appropriate number of this Section and reference the appropriate Section of the Contract Documents.
- b. The name of the organization performing each test.
- c. Test location.
- d. Scheduled starting and completion date.
- e. Test objectives.

D. Test Procedures

1. Prepare and submit to METRO Test Procedure for each test to be performed. No testing will be allowed to occur and no results shall be considered valid until approval of the test procedures by METRO.
2. Include in each test procedure the following information:
 - a. Title of the test with reference to the appropriate Section of the Contract Documents.
 - b. The name of the organization performing the test.
 - c. Test location.
 - d. Schedule starting and completion date.
 - e. Test objectives.
 - f. Applicable procedures specified in ANSI, IEEE, or NEMA standards.
 - g. Test methodology and step-by-step procedure for performing the test, including instrumentation setup, circuit diagrams, and test sequence.
 - h. Require equipment and instrumentation.
 - i. Forms to be used to record and evaluate data.
 - j. Pass/fail criteria and justification for the criteria.
 - k. METRO's personnel requirements.
 - l. Test evaluation procedures.
 - m. Test report format.

E. Test Reports

1. Prepare and submitted to METRO a Test Report for each test performed.
2. Include the test report in the appropriate Substation History Book.
3. Include the following information in each test report:
 - a. Title of the test with reference to the appropriate Section of the Contract Documents.
 - b. The name of the organization performing the test.
 - c. Test location.

- d. Starting and completion date.
- e. Test objectives
- f. Applicable procedures specified in ANSI, IEEE, or NEMA standards.
- g. Test methodology and step-by-step procedure for performing the test, including instrumentation setup, circuit diagrams and test sequence.
- h. List of all equipment and instrumentation used including model number, serial number and calibration date.
- i. Pass/fail criteria and justification for the criteria.
- j. Test evaluation procedures.
- k. Conditions of test, including precipitation, temperature and humidity.
- l. Raw test data.
- m. Reduce test data in tables, curves, photographs and any additional data required to support the test results.
- n. Descriptions of all equipment and material failures and the reasons for the failure.
- o. Descriptions of all modifications to the equipment or wiring performed using the testing and the reasons for the modifications, and the names of individuals approving such modifications.
- p. Conclusions and signature of responsible test supervisors.

1.04 TEST WITNESSING

- A. Notify METRO seven (7) days prior to performing any test.

PART 2 – TEST RESPONSIBILITY

2.01 TESTS INCLUDED

- A. Perform tests under this Contract to verify compliance with all Contract design and performance requirements to the satisfaction of METRO.
- B. Perform all tests specified in the System Specification, and any other tests required in connection with Quality Assurance program. Perform all tests otherwise required to bring the System to revenue service. Include all tests normally performed and tests called for in the ANSI, IEEE and NEMA Standards.
- C. The tests specified under the Contract were not to be considered to be all-inclusive and did not relieve the Contractor from the responsibility of verifying compliance with all Contract design and performance requirements to the satisfaction of METRO

2.02 TEST INSTRUMENTS, PERSONNEL, AND MATERIALS.

- A. Furnish all test instruments and equipment as well as personnel and materials necessary for performing all tests.
- B. Define any support required from METRO or others for tests.

2.03 TEST FAILURE

- A. Replace and/or repaired damaged items due to test failures at no cost to METRO.
- B. Repeat any test showing unsatisfactory results without additional cost to Metro. The original unsatisfactory results, description of corrections, and the new satisfactory results were part of the test report provided to METRO.

PART 3 – EXECUTION

3.01 FACTORY TESTS

- A. Perform design and production tests in the factory prior to shipment of the equipment. Wire, adjust, and test all equipment before shipment to ensure completeness, adequacy and proper functioning of equipment for the application intended.
 - 1. Design Tests
 - a. Perform design tests on one completely finished system component or equipment assembly of each type to establish their characteristics and conformity to the requirements of this Specification or to applicable industry standard if there is not an explicit Specification requirement.
 - b. METRO waived requirements for individual design tests after review and approval of test results and certified documentation of the same or substantially the same equipment as that proposed for this Contract. Such a waiver did not in any way relieve the Contractor from full responsibility regarding the equipment quality, reliability, performance, and safety.
 - 2. Production Tests. Perform production tests on every system component and assembly for the purpose of checking the correctness, quality and uniformity of manufacturing processes.

- B. Refer to the specific sections of the Contract Documents for individual equipment test requirements.

3.02 INSTALLATION VERIFICATION TESTS

A. General

1. Perform field tests verifying that the system has been correctly installed and that there are no equipment incompatibilities.
2. Prior to conducting the field tests, verified that all equipment was installed according to design System Specifications and Shop Drawings and was in operable condition. Included in the work visual inspection, calibration, adjustments and checks of all equipment, including:
 - a. Equipment inspection.
 - b. Calibration and adjustments of protective devices and instruments.
 - c. Connection check of feeders and disconnect switches.
 - d. High potential feeder insulation check.
 - e. Pole, cable, and contact wire attachment check.
 - f. Pole and cantilever position check
 - g. Check of steady arms and their clearance from pantograph path
 - h. Electrical clearance verification
 - i. Conductor installation inspection
 - j. Check for free and smooth movement of counterweights
 - k. Security check of deadends and anchors
3. Coordinated all field tests with METRO.

B. Substation Grounding Resistance Test

1. Measured the substation grounding grid resistances and compare the test results with design calculations. In the event that the measured value of resistance was higher than the design value, METRO directed the Contractor to drive additional ground rods into the earth and connect the rods to the grounding grid to bring down the resistance to the design value.

C. Substation Dielectric Tests

1. Test the power and control wiring exterior to the substations at METRO approved voltages to confirm integrity of insulation.

D. Substation Functional Tests

1. Perform functional and operational tests to verify that all substation equipment functions in accordance with METRO approved control schematics. After successful testing, each function circuit was so designated on the applicable Shop Drawings.

E. Substation Incoming AC Feeder Test

1. Perform tests or assisted in tests required by the utility prior to energization of the substation incoming feeders.

F. Substation device Coordination and Calibration Tests

1. Perform all necessary tests to demonstrate and confirm satisfactory coordination of all protective devices, including:
 - a. Primary injection tests (high current, low voltage) on all AC and DC switchgear protective devices.
 - b. Short circuit test at the output terminals of the rectifier with all substation breakers closed and the distribution system energized from one adjacent substation to test the AC feeder devices.
 - c. Short circuit on the load side of the DC feeder breakers to test coordination between the DC feeder breaker series overcurrent trip and the AC feeder breaker protection.
 - d. Verify protective device settings of the substations by applying bolted and resistive faults at the substation, midpoint between two adjacent substations and at a remote substation. Provide the same System configuration as for revenue operation with adjacent substations energized and connect to the overhead system.
 - e. Verify operation of the autoreclosing and transfer trip devices.
2. Develop a comprehensive, step-by-step program of short-circuit tests in order to achieve all of the foregoing objectives. Wherever possible, used a single fault test to simultaneously accomplish several requirements.

G. Ground Fault Tests

1. Performed ground fault tests to demonstrate the ability of the protective relaying system to detect and isolate DC system ground faults and determine the magnitude of ground fault currents and voltages under various ground fault conditions.

2. For safety reasons performed the test in secured section of the system.
 - a. Local Ground Fault. Energized three adjacent traction power substations. Applied a low resistance short circuit between the overhead system and ground at trackside. Located the fault no more than one span away from the middle substation. Measured and recorded the following variables.
 - 1) Current in each substation feeder.
 - 2) Current returning via negative return cables to each substation.
 - 3) Voltage between each substation ground busbar and negative return busbar.
 - 4) Voltage between ground and rail at each substation and at points midway between substations.
 - 5) Operation of the of circuit breakers at each substation.
 - b. Remote Ground Fault. Repeated the Local Ground Fault test above with the ground fault located at approximate midpoint between two adjacent substations. If substation feeder breakers clear the ground faults, terminate the test.
3. Remedial Measures. If substation feeder breakers do not clear the ground faults, terminate the test. Analyze the test results, implement any corrective measures and repeat the test. If the circuit beaker still remains closed, then repeat the tests with the rectifier negative busbar grounded. In addition to other required measurements listed above, measure and record the current in the shorting device.
4. Negative Grounding Unit. The results of these tests were used by METRO to determine the need for Negative Grounding Unit, Device 57. When METRO determined that the Negative Grounding Unit was required, installed the Unit at each traction power substation. Following installation of the negative grounding unit, verified its correct operation of the unit by repeating the Local and Remote Ground Fault tests specified above.
5. Carried out the ground fault tests as part of the short-circuit testing and incorporated them in the short-circuit testing program.

H. Substation Audible Sound-Level Tests

1. Performed audible sound-level tests at one substation. Performed the tests for no-load and load conditions.
2. The substation sound level shall not exceed 60 dBA. Measured the sound level outside the substation by microphones, spaced at a

distance of three feet from each other and at a distance of one foot from the substation enclosure.

3. Ambient noise level during the test should not exceed 50 dBA. If the ambient noise level was exceeded, adapted correction procedures in the substation sound level evaluation.

3.03 SYSTEM INTEGRATION TEST

A. Supervisory and Data Acquisition System

1. Following installation and interconnection of the SCADA and fiber optics cable transmission system with the Traction Electrification System, conduct interface tests to:
 - a. Confirm proper operation of all SCADA equipment.
 - b. Confirm proper data communications to and from each PLC.
2. Perform a simulated operational test of the SCADA equipment. Test all combinations of SCADA inputs. Ensure by tests that all appropriate indications are displayed and logged and that all appropriate control actions are granted
3. Perform a pre in-service test. Tested the operation of all equipment and each control and indication point controlled/monitored by the SCADA system. Submitted certified test reports to METRO within fifteen days after completion of each test.
4. Perform SCADA Training Simulator Tests and comply to the general requirements specified herein. Include in the tests, as a minimum, verification of the simulator's capability of emulating all field devices and verification of all commands and the resulting graphic displays and tests.

B. System Pre-Revenue Operation Test

1. Following satisfactory completion of the individual tests specified herein, performed a system pre-revenue operation test.
2. During the test, monitor and operate all systems.
 - a. Monitor and record all substation equipment at three adjacent substations selected by METRO.
 - b. Test all SCADA functions for satisfactory operation, including:
 - 1) All control functions from the Control Console and remotely located PC.
 - 2) All monitoring functions.

3) All measuring functions.

END OF SECTION.

Item 420

Concrete Substructures



1. DESCRIPTION

Construct concrete substructures including footings, columns, caps, abutments, piers, culverts, other bridge substructure elements, and other concrete structures as indicated.

2. MATERIALS

2.1. **Concrete.** Provide concrete in accordance with Item 421, "Hydraulic Cement Concrete." Provide the class of concrete for each type of structure or unit as shown on the plans or in pertinent governing specifications.

2.2. **Grout or Mortar.** Provide grout for dowelling anchors or precast connections in accordance with [DMS-4675](#), "Cementitious Grouts and Mortars for Miscellaneous Applications."

2.3. **Latex Curing Materials.** Provide an acrylic-polymer latex admixture (acrylic resin emulsion per [DMS-4640](#), "Chemical Admixtures for Concrete") suitable for producing polymer-modified concrete or mortar. Do not allow latex to freeze.

2.4. **Reinforcing Steel.** Provide reinforcing steel in accordance with Item 440, "Reinforcement for Concrete."

2.5. **Expansion Joint Material.** Provide materials in accordance with [DMS-6310](#), "Joint Sealants and Fillers."

- Provide preformed fiber expansion joint material that conforms to the dimensions shown on the plans.
- Provide preformed bituminous fiber material unless otherwise specified.
- Provide asphalt board that conforms to dimensions shown on the plans.
- Provide re-bonded neoprene filler that conforms to the dimensions shown on the plans.

2.6. **Waterstop.** Provide rubber or polyvinyl chloride (PVC) waterstops in accordance with [DMS-6160](#), "Water Stops, Nylon Reinforced Neoprene Sheet, and Elastomeric Pads," unless otherwise shown on the plans.

2.7. **Curing Materials.** Provide membrane curing compounds in accordance with [DMS-4650](#), "Hydraulic Cement Concrete Curing Materials and Evaporation Retardants."

Provide cotton mats that consist of a filling material of cotton "bat" or "bats" (at least 12 oz. per square yard) completely covered with unsized cloth (at least 6 oz. per square yard) stitched longitudinally with continuous parallel rows of stitching spaced at less than 4 in., or tuft both longitudinally and transversely at intervals less than 3 in. Provide cotton mats that are free from tears and in good general condition. Provide a flap at least 6 in. wide consisting of 2 thicknesses of the covering and extending along 1 side of the mat.

Provide polyethylene sheeting that is at least 4 mils thick and free from visible defects. Provide only clear or opaque white sheeting when the ambient temperature during curing exceeds 90°F or when applicable to control temperature during mass pours.

Provide burlap-polyethylene mats made from burlap impregnated on 1 side with a film of opaque white pigmented polyethylene, free from visible defects. Provide laminated mats that have at least 1 layer of an impervious material such as polyethylene, vinyl plastic, or other acceptable material (either as a solid sheet or impregnated into another fabric) and are free of visible defects.

Provide burlap material which complies with AASHTO M 182, Class 3 (10 oz. per square yard) with the following additions:

- Manila hemp may also be used to make burlap.
- Do not use burlap fabricated from bags.
- Do not use burlap containing any water soluble ingredient which will retard the setting time of concrete.

Provide used burlap complying with the requirements stated above and that has only been used previously for curing concrete. "Like new" cleanliness is not expected, but contamination with any substance foreign to the concrete curing process, such as grease or oil, will be cause for rejection.

- 2.8. **Epoxy.** Provide epoxy materials in accordance with [DMS-6100](#), "Epoxies and Adhesives," unless otherwise specified.

3. EQUIPMENT

- 3.1. **Transporting and Placing Equipment.** Use appropriate transporting and placing equipment such as buckets, chutes, buggies, belt conveyors, pumps, or other equipment as necessary. Ensure concrete is not transported or conveyed through equipment made of aluminum.

Use tremies to control the fall of concrete or for underwater placement. Use tremies that are watertight and of large enough diameter to allow the placement of the concrete but less than 14 in. in diameter. Construct the tremie so the bottom can be sealed and opened once the tremie has been fully charged with concrete for underwater placements.

Use pumps with lines at least 5 in. inside diameter (I.D.) where Grade 2 or smaller coarse aggregate is used, and at least 8 in. I.D. for Grade 1 coarse aggregate.

- 3.2. **Vibrators.** Use immersion-type vibrators for consolidation of concrete. Provide at least 1 standby vibrator for emergency use. Furnish vibrator head covered by a rubberized or elastomeric cover when used near epoxy coated reinforcing steel.
- 3.3. **Temperature Recording Equipment.** Use strip chart temperature recording devices, recording maturity meters in accordance with [Tex-426-A](#), or other approved devices that are accurate to within $\pm 2^\circ\text{F}$ within the range of 32°F to 212°F for mass concrete operations, cold weather placements, and as otherwise specified.
- 3.4. **Artificial Heating Equipment.** Use artificial heating equipment as necessary for maintaining the concrete temperatures as specified in Section 420.4.7.11., "Placing Concrete in Cold Weather."
- 3.5. **Spraying Equipment.** Use mechanically powered pressure sprayers, either air or airless, with appropriate atomizing nozzles for the application of membrane curing. Use hand-pressurized spray equipment with 2 or 3 fan-spray nozzles if approved. Ensure the spray from each nozzle overlaps the spray from adjacent nozzles by approximately 50%.
- 3.6. **Concrete Testing Equipment.** Provide testing equipment for use by the Engineer in accordance with Section 421.3.3., "Testing Equipment."

4. CONSTRUCTION

Obtain approval for proposed construction methods before starting work. Approval of construction methods and equipment does not relieve the Contractor's responsibility for safety or correctness of methods, adequacy of equipment, or completion of work in full accordance with the Contract.

Unless otherwise shown on the plans, it is the Contractor's option to perform testing on structural concrete (structural classes of concrete are identified in Table 8 of Section 421.4.1., "Classification of Concrete Mix Designs,") to determine the in-situ strength to address the schedule restrictions in Section 420.4.1., "Schedule Restrictions." The Engineer may require the Contractor to perform this testing for concrete placed in cold weather. Make enough test specimens for Contractor-performed testing to ensure strength requirements are met for the operations listed in Section 420.4.1., "Schedule Restrictions." Make at least

1 set of test specimens for each element cast each day. Cure these specimens under the same conditions as the portion of the structure involved for all stages of construction. Ensure safe handling, curing, and storage of all test specimens. Provide testing personnel, and sample and test the hardened concrete in accordance with Section 421.4.8., "Sampling and Testing of Concrete." The maturity method, [Tex-426-A](#), may be used for in-situ strength determination for schedule restrictions if approved. Coring will not be allowed for in-situ strength determination for schedule restrictions. Provide the Engineer the opportunity to witness all testing operations. Report all test results to the Engineer.

If the Contractor does not wish to perform schedule restriction testing, the Engineer's 7-day lab-cured tests, performed in accordance with Article 421.5., "Acceptance of Concrete," will be used for schedule restriction determinations. The Engineer may require additional time for strength gain to account for field curing conditions such as cold weather.

- 4.1. **Schedule Restrictions.** Construct and open completed structures to traffic with the following limitations unless otherwise shown on the plans:
- 4.1.1. **Setting Forms.** Attain at least 2,500 psi compressive strength before erecting forms on concrete footings supported by piling or drilled shafts, or on individual drilled shafts. Erect forms on spread footings and culvert footings after the footing concrete has aged at least 2 curing days as defined in Section 420.4.10., "Curing Concrete." Place concrete only after the forms and reinforcing steel have been inspected by the Engineer.
- Support tie beam or cap forms by falsework on previously placed tie beams only if the tie beam concrete has attained a compressive strength of 2,500 psi and the member is properly supported to eliminate stresses not provided for in the design. Maintain curing as required until completion of the curing period.
- Place superstructure forms or falsework on the substructure only if the substructure concrete has attained a compressive strength of 3,000 psi.
- 4.1.2. **Removal of Forms and Falsework.** Keep in place weight-supporting forms and falsework for bridge components and culvert slabs until the concrete has attained a compressive strength of 2,500 psi in accordance with Section 420.4.11., "Removal of Forms and Falsework." Keep all forms for mass placements in place for 4 days following concrete placement unless otherwise approved based on the outcome of the heat control plan outlined in Section 420.4.7.14., "Mass Placements."
- 4.1.3. **Placement of Superstructure Members.** Erect or place superstructure members or precast substructure members only after the substructure concrete has attained a compressive strength of 3,000 psi.
- 4.1.4. **Opening to Traffic.** Direct traffic culverts may be opened to construction traffic when the design strength specified in Section 421.4.1., "Classification of Concrete Mix Design," has been attained if curing is maintained. Obtain approval before opening direct traffic culverts to the traveling public. Open other noncritical structural and nonstructural concrete for service upon the completion of curing unless otherwise specified or directed.
- 4.1.5. **Post-Tensioned Construction.** Ensure strength requirements on the plans for structural elements designed to be post-tensioned are met for stressing and staged loading of structural elements.
- 4.1.6. **Backfilling.** Backfill in accordance with Section 400.3.3., "Backfill."
- 4.2. **Plans for Falsework and Forms.** Submit plans for falsework and forms for the following items: vertical forms for piers and single column bents; load supporting forms for caps and tie-beams; form attachments for bridges to be widened; and other items as indicated or directed. Provide design calculations when requested. Show all essential details of proposed forms, falsework, and bracing. Have a licensed professional engineer design, seal, and sign these plans. Department approval is not required, except as noted in Table 1 of Item 5, "Control of the Work," when forms or falsework are located such that public safety can be affected, but the Department reserves the right to request modifications to the plans. The Contractor is responsible for the adequacy of these plans. Design job-fabricated formwork assuming a weight of 150 pcf for concrete, and

include a liveload allowance of 50 psf of horizontal surface of the form. Do not exceed 125% of the allowable stresses used by the Department for the design of structures.

- 4.3. **Falsework.** Design and construct falsework to safely carry the maximum anticipated loads, including wind loads, and to provide the necessary rigidity. Consult AASHTO's *Guide Design Specifications for Bridge Temporary Works* and *Construction Handbook for Bridge Temporary Works* for falsework and shoring information not indicated below. Submit details in accordance with Section 420.4.2., "Plans for Falsework and Forms."

Design job-fabricated falsework assuming a weight of 150 pcf for concrete, and include a minimum liveload allowance of 50 psf of horizontal surface of the form. Do not exceed 125% of the allowable stresses used by the Department for the design of structures.

Do not exceed the manufacturer's maximum allowable working loads for moment and shear or end reaction for commercially produced structural units used in falsework. Include a minimum liveload allowance of 35 psf of horizontal form surface in determining the maximum allowable working load for commercially produced structural units.

Provide timber that is sound, in good condition, and free from defects that would impair its strength. Provide timber that meets or exceeds the species, size, and grade requirements in the submitted falsework plans.

Provide wedges made of hardwood or metal in pairs to adjust falsework to desired elevations to ensure even bearing. Do not use wedges to compensate for incorrectly cut bearing surfaces.

Use sills or grillages large enough to support the superimposed load without settlement. Take precautions to prevent settling of the supporting material unless the sills or grillages are founded on solid rock, shale, or other hard materials.

Place falsework that cannot be founded on a satisfactory spread footing on piling or drilled shafts with enough bearing capacity to support the superimposed load without settlement. Drive falsework piling to the required resistance determined by the applicable formula in Item 404, "Driving Piling." Design drilled shafts for falsework to carry the superimposed load using both skin friction and point bearing.

Weld in conformance with Item 448, "Structural Field Welding." Securely brace each falsework bent to provide the stiffness required, and securely fasten the bracing to each pile or column it crosses.

Remove falsework when it is no longer required or as indicated on the submitted falsework plan. Pull or cut off foundations for falsework at least 2 ft. below finished ground level. Completely remove falsework, piling, or drilled shafts in a stream, lake, or bay to the approved limits to prevent obstruction to the waterway.

- 4.4. **Forms.** Submit formwork plans in accordance with Section 420.4.2., "Plans for Falsework and Forms."

- 4.4.1. **General.** Provide forms of either timber or metal except where otherwise specified or permitted.

Design forms for the pressure exerted by a liquid weighing 150 pcf. Take the rate of concrete placement into consideration in determining the depth of the equivalent liquid. Include a minimum liveload allowance of 50 psf of horizontal surface for job-fabricated forms. Do not exceed 125% of the Department's allowable stresses for the design of structures.

Do not exceed the manufacturer's maximum allowable working loads for moment and shear or end reaction for commercially produced structural units used for forms. Include a minimum liveload allowance of 35 psf of horizontal form surface in determining the maximum allowable working load for commercially produced structural units.

Provide steel forms for round columns unless otherwise approved. Refer to Item 427, "Surface Finishes for Concrete," for additional requirements for off-the-form finishes.

Provide commercial form liners for imprinting a pattern or texture on the concrete surface as shown on the plans and specified in Section 427.4.3.5., "Form Liner Finish."

Provide forming systems that are practically mortar-tight, rigidly braced, and strong enough to prevent bulging between supports, and maintain them to the proper line and grade during concrete placement. Maintain forms in a manner that prevents warping and shrinkage. Do not allow offsets at form joints to exceed 1/16 in.

Use only material that is inert, non-biodegradable, and nonabsorptive for forms to be left in place.

Construct all forms to permit their removal without marring or damaging the concrete. Clean all forms and footing areas of any extraneous matter before placing concrete. Provide openings in forms if needed for the removal of laitance or foreign matter.

Treat the facing of all forms with bond-breaking coating of composition that will not discolor or injuriously affect the concrete surface. Take care to prevent coating of the reinforcing steel.

Complete all preparatory work before requesting permission to place concrete.

Cease placement if the forms show signs of bulging or sagging at any stage of the placement, and remove the portion of the concrete causing this condition immediately as directed. Reset the forms and securely brace them against further movement before continuing the placement.

4.4.2.

Timber Forms. Provide properly seasoned, good-quality lumber that is free from imperfections that would affect its strength or impair the finished surface of the concrete. Provide timber or lumber that meets or exceeds the requirements for species and grade in the submitted formwork plans.

Maintain forms or form lumber that will be reused so it stays clean and in good condition. Do not use any lumber that is split, warped, bulged, or marred, or that has defects in any way that will produce inferior work. Promptly remove such lumber from the work.

Provide form lining for all formed surfaces except:

- the inside of culvert barrels, inlets, manholes, and box girders;
- surfaces that are subsequently covered by backfill material or are completely enclosed; and
- any surface formed by a single finished board or by plywood.

Provide form lining of an approved type such as masonite or plywood. Do not provide thin membrane sheeting such as polyethylene sheets for form lining.

Use plywood at least 3/4 in. thick. Place the grain of the face plies on plywood forms parallel to the span between the supporting studs or joists unless otherwise indicated on the submitted form drawings.

Use plywood for forming surfaces that remain exposed that meets the requirements for B-B Plyform Class I or Class II Exterior of the U.S. Department of Commerce Voluntary Product Standard PS 1.

Space studs and joists so the facing form material remains in true alignment under the imposed loads.

Space wales closely enough to hold forms securely to the designated lines, scabbed at least 4 ft. on each side of joints to provide continuity. Place a row of wales near the bottom of each placement.

Place facing material with parallel and square joints, securely fastened to supporting studs.

Place forms with the form panels symmetrical (long dimensions set in the same direction) for surfaces exposed to view and receiving only an ordinary surface finish as defined in Section 420.4.13., "Ordinary Surface Finish." Make horizontal joints continuous.

Make molding for chamfer strips or other uses of materials of a grade that will not split when nailed and can be maintained to a true line without warping. Dress wood molding on all faces. Fill forms at all sharp corners and edges with triangular chamfer strips measuring 3/4 in. on the sides unless otherwise shown on the plans.

Use metal form ties of an approved type or a satisfactory substitute of a type that permits ease of removal of the metal to hold forms in place. Cut back wire ties at least 1/2 in. from the face of the concrete.

Use devices to hold metal ties in place that are able to develop the strength of the tie and adjust to allow for proper alignment.

Entirely remove metal and wooden spreaders that separate the forms as the concrete is being placed.

Provide adequate clean-out openings for narrow walls and other locations where access to the bottom of the forms is not readily attainable.

- 4.4.3. **Metal Forms.** Requirements for timber forms regarding design, mortar-tightness, filleted corners, beveled projections, bracing, alignment, removal, reuse, and wetting also apply to metal forms except metal forms do not require lining unless specifically noted on the plans.

Use form metal thick enough to maintain the true shape without warping or bulging. Countersink all bolt and rivet heads on the facing sides. Design clamps, pins, or other connecting devices to hold the forms rigidly together and to allow removal without damage to the concrete. Use metal forms that present a smooth surface and line up properly. Keep metal free from rust, grease, and other foreign materials.

- 4.5. **Drains.** Install and construct weep holes and roadway drains as shown on the plans.

- 4.6. **Placing Reinforcement and Post-Tensioning.** Place reinforcement as provided in Item 440, "Reinforcement for Concrete." Do not weld reinforcing steel supports to other reinforcing steel except where shown on the plans.

Place post-tensioning ducts, anchorages, and other hardware in accordance with the approved prestressing details and Item 426, "Post-Tensioning." Keep ducts free of obstructions until all post-tensioning operations are complete.

- 4.7. **Placing Concrete.** Give the Engineer sufficient advance notice before placing concrete in any unit of the structure to permit the inspection of forms, reinforcing steel placement, and other preparations.

Do not place concrete when impending weather conditions would impair the quality of the finished work. Place concrete in early morning or at night or adjust the placement schedule for more favorable weather when conditions of wind, humidity, and temperature are such that concrete cannot be placed without the potential for weather-related distress.

Adequately illuminate the entire placement site as approved when mixing, placing, and finishing concrete in non-daylight hours.

Furnish adequate shelter to protect the concrete against damage from rainfall or freezing temperatures as outlined in this Item if changes in weather conditions require protective measures after work starts. Continue operations during rainfall only if approved. Use protective coverings for the material stockpiles. Cover aggregate stockpiles only to the extent necessary to control the moisture conditions in the aggregates.

Allow at least 1 curing day after the concrete has achieved initial set before placing strain on projecting reinforcement to prevent damage to the concrete.

- 4.7.1. **Placing Temperature.** Place concrete according to the following temperature limits for the classes of concrete defined in Section 421.4.1., "Classification of Concrete Mix Designs."

- Place Class C, F, H, K, or SS concrete only when its temperature at time of placement is between 50°F and 95°F. Increase the minimum placement temperature to 60°F if slag cement is used in the concrete.
- Place Class S concrete, used in this Item only as indicated for culvert top slabs, only when its temperature is between 50°F and 85°F. Increase the minimum placement temperature to 60°F if slag cement is used in the concrete.
- Place Class A, B, and D concrete only when its temperature at the time of placement is greater than 50°F.
- Place mass concrete in accordance with Section 420.4.7.14., “Mass Placements,” only when its temperature at the time of placement is between 50°F and 75°F.

4.7.2. **Transporting Time.** Begin the discharge of concrete delivered in truck mixers within the times listed in Table 14 of Item 421, “Hydraulic Cement Concrete.”

4.7.3. **Workability of Concrete.** Place concrete with a slump as specified in Section 421.4.2.5., “Slump.” Water may be added to the concrete before discharging any concrete from the truck to adjust for low slump provided that the maximum mix design water–cement ratio is not exceeded. Mix concrete in accordance with Section 421.4.6., “Mixing and Delivering Concrete,” after introduction of any additional water or chemical admixtures. Do not add water or chemical admixtures after any concrete has been discharged.

4.7.4. **Transporting Concrete.** Transport concrete by buckets, chutes, buggies, belt conveyors, pumps, or other methods.

Protect concrete transported by conveyors from sun and wind to prevent loss of slump and workability. Shade or wrap with wet burlap pipes through which concrete is pumped as necessary to prevent loss of slump and workability.

Arrange and use chutes, troughs, conveyors, or pipes so the concrete ingredients will not be separated. Terminate such equipment in vertical downspouts when necessary to prevent segregation. Extend open troughs and chutes, if necessary, down inside the forms or through holes left in the forms.

Keep all transporting equipment clean and free from hardened concrete coatings. Discharge water used for cleaning clear of the concrete.

4.7.5. **Preparation of Surfaces.** Thoroughly wet all forms and hardened concrete on which concrete is to be placed before placing concrete on them. Remove any remaining puddles of excess water before placing concrete. Provide surfaces that are in a moist, saturated surface-dry condition when concrete is placed on them.

Ensure the subgrade or foundation is moist before placing concrete on grade. Lightly sprinkle the subgrade if dry.

4.7.6. **Expansion Joints.** Construct joints and devices to provide for expansion and contraction in accordance with plan details.

Use light wire or nails to anchor any preformed fiber joint material to the concrete on 1 side of the joint.

Ensure finished joints conform to the plan details with the concrete sections completely separated by the specified opening or joint material.

Remove all concrete within the joint opening soon after form removal and again where necessary after surface finishing to ensure full effectiveness of the joint.

4.7.7. **Construction Joints.** A construction joint is the joint formed by placing plastic concrete in direct contact with concrete that has attained its initial set. Monolithic placement means the manner and sequence of concrete placing does not create a construction joint.

Make construction joints of the type and at the locations shown on the plans. Additional joints in other members are not permitted without approval. Place authorized additional joints using details equivalent to those shown on the plans for joints in similar locations.

Make construction joints square and normal to the forms unless otherwise required. Use bulkheads in the forms for all vertical joints.

Thoroughly roughen the top surface of a concrete placement terminating at a horizontal construction joint as soon as practical after initial set is attained.

Thoroughly clean the hardened concrete surface of all loose material, laitance, dirt, and foreign matter, and saturate it with water. Remove all free water and moisten the surface before concrete or bonding grout is placed against it. Ensure the surface of the existing concrete is in a saturated surface-dry condition (SSD) just before placing subsequent concrete. Wet the existing concrete by ponding water on the surface for 24 hr. before placing subsequent concrete. Use high-pressure water blasting if ponding is not possible to achieve SSD conditions 15 to 30 min. before placing the concrete. An SSD condition is achieved when the surface remains damp when exposed to sunlight for 15 min.

Draw forms tight against the existing concrete to avoid mortar loss and offsets at joints.

Bonding agents are not required unless indicated otherwise. Coat the joint surface with bonding mortar, grout, epoxy, or other material if a bonding agent is required as indicated on the plans. Provide Type V epoxy per [DMS-6100](#), "Epoxies and Adhesives," for bonding fresh concrete to hardened concrete. Place the bonding epoxy on a clean, dry surface, and place the fresh concrete while the epoxy is still tacky. Place bonding mortar or grout on a surface that is SSD, and place the concrete before the bonding mortar or grout dries. Place other bonding agents in accordance with the manufacturer's recommendations.

- 4.7.8. **Handling and Placing.** Minimize segregation of the concrete and displacement of the reinforcement when handling and placing concrete. Produce a uniform, dense compact mass.

Ensure concrete free-falls no more than 5 ft. except in the case of drilled shafts, thin walls such as in culverts, or as allowed by other items. Remove any hardened concrete splatter ahead of the plastic concrete.

Fill each part of the forms by depositing concrete as near its final position as possible. Do not deposit large quantities of concrete at 1 point and run or move the concrete along to fill the forms.

Deposit concrete in the forms in layers of suitable depth but no more than 36 in. deep unless otherwise permitted.

Avoid cold joints in a monolithic placement. Sequence successive layers or adjacent portions of concrete so they can be vibrated into a homogeneous mass with the previously placed concrete before it sets. Allow no more than 1 hr. to elapse between adjacent or successive placements of concrete when re-vibration of the concrete is shown on the plans except as otherwise allowed by an approved placing procedure. This time limit may be extended by 1/2 hr. if the concrete contains at least the minimum recommended dosage of a Type B or D admixture.

- 4.7.9. **Consolidation.** Carefully consolidate concrete and flush mortar to the form surfaces with immersion type vibrators. Do not use vibrators that operate by attachment to forms or reinforcement except where approved on steel forms.

Vibrate the concrete immediately after deposit. Systematically space points of vibration to ensure complete consolidation and thorough working of the concrete around the reinforcement, embedded fixtures, and into the corners and angles of the forms. Insert the vibrators vertically where possible. Vibrate the entire depth of each lift, allowing the vibrator to penetrate several inches into the preceding lift. Do not use the vibrator to move the concrete to other locations in the forms. Do not drag the vibrator through the concrete. Thoroughly consolidate concrete along construction joints by operating the vibrator along and close to but not against the joint surface. Continue the vibration until the concrete surrounding reinforcements and fixtures is completely

consolidated. Hand-spade or rod the concrete if necessary to ensure flushing of mortar to the surface of all forms.

- 4.7.10. **Installation of Dowels and Anchor Bolts.** Install dowels and anchor bolts by casting them in-place or by grouting with grout, epoxy, or epoxy mortar unless noted otherwise. Form or drill holes for grouting. Follow the manufacturer's recommended installation procedures for pre-packaged grout or epoxy anchor systems. Test anchors if required on the plans or by other items.

Drill holes for anchor bolts to accommodate the bolt embedment required by the plans. Make holes for dowels at least 12 in. deep unless otherwise shown on the plans. Make the hole diameter at least twice the dowel or bolt diameter, but not exceeding the dowel or bolt diameter plus 1-1/2 in. when using cementitious grout or epoxy mortar. Make the hole diameter 1/16 to 1/4 in. greater than the dowel or bolt diameter when using neat epoxy unless indicated otherwise by the epoxy manufacturer.

Thoroughly clean holes of all loose material, oil, grease, or other bond-breaking substance, and blow them clean with filtered compressed air. Use a wire brush followed by oil-free compressed air to remove all loose material from the holes, repeating as necessary until no more material is removed. Ensure holes are in a surface-dry condition when epoxy type materials are used and in a surface-moist condition when cementitious grout is used. Develop and demonstrate for approval a procedure for cleaning and preparing the holes for installation of the dowels and anchor bolts. Completely fill the void between the hole and dowel or bolt with grouting material. Follow exactly the requirements for cleaning outlined in the product specifications for pre-packaged systems.

Provide hydraulic cement grout for cast-in-place or grouted systems in accordance with [DMS-4675](#), "Cementitious Grouts and Mortars for Miscellaneous Applications." Provide a Type III epoxy per [DMS-6100](#), "Epoxyes and Adhesives," when neat epoxy is used for anchor bolts or dowels. Provide Type VIII epoxy per [DMS-6100](#), "Epoxyes and Adhesives," when an epoxy grout is used. Provide grout, epoxy, or epoxy mortar as the binding agent unless otherwise indicated on the plans.

Provide other anchor systems as required on the plans.

- 4.7.11. **Placing Concrete in Cold Weather.** Protect concrete placed under weather conditions where weather may adversely affect results. Permission given by the Engineer for placing during cold weather does not relieve the Contractor of responsibility for producing concrete equal in quality to that placed under normal conditions. Remove and replace concrete as directed at the Contractor's expense if it is determined unsatisfactory due to poor conditions.

Do not place concrete in contact with any material coated with frost or with a temperature of 32°F or lower. Do not place concrete when the ambient temperature in the shade is below 40°F and falling unless approved. Place concrete when the ambient temperature in the shade is at least 35°F and rising or above 40°F.

Provide and install recording thermometers, maturity meters, or other suitable temperature measuring devices to verify all concrete is effectively protected as follows:

- Maintain the temperature at all surfaces of concrete in bents, piers, culvert walls, retaining walls, parapets, wingwalls, top slabs of non-direct traffic culverts, and other similar formed concrete at or above 40°F for 72 hr. from the time of placement.
- Maintain the temperature of all other concrete, including the bottom slabs (footings) of culverts, placed on or in the ground above 32°F for 72 hr. from the time of placement.

Use additional covering, insulated forms, or other means and, if necessary, supplement the covering with artificial heating. Avoid applying heat directly to concrete surfaces. Cure as specified in Section 420.4.10., "Curing Concrete," during this period until all requirements for curing have been satisfied.

Have all necessary heating and covering material ready for use before permission is granted to begin placement when impending weather conditions indicate the possible need for temperature protection.

- 4.7.12. **Placing Concrete in Hot Weather.** Keep the concrete at or below the maximum temperature at time of placement as specified in Section 420.4.7.1., "Placing Temperature." Sprinkle and shade aggregate stockpiles or use ice, liquid nitrogen systems, or other approved methods as necessary to control the concrete temperature.
- 4.7.13. **Placing Concrete in Water.** Deposit concrete in water only when shown on the plans or with approval. Make forms or cofferdams tight enough to prevent any water current passing through the space in which the concrete is being deposited. Do not pump water during the concrete placing or until the concrete has set for at least 36 hr.

Place the concrete with a tremie or pump, or use another approved method, and do not allow it to fall freely through the water or disturb it after it is placed. Keep the concrete surface level during placement.

Support the tremie or operate the pump so it can be easily moved horizontally to cover all the work area and vertically to control the concrete flow. Submerge the lower end of the tremie or pump hose in the concrete at all times. Use continuous placing operations until the work is complete.

Design the concrete mix in accordance with Item 421, "Hydraulic Cement Concrete," with a minimum cement content of 650 lb. per cubic yard for concrete to be placed under water. Include an anti-washout admixture in the mix design as necessary to produce a satisfactory finished product.

- 4.7.14. **Mass Placements.** Develop and obtain approval for a heat control plan for monolithic placements designated on the plans as mass concrete to ensure the following during the heat dissipation period:
- the temperature differential between the central core of the placement and the exposed concrete surface does not exceed 35°F and
 - the temperature at the central core of the placement does not exceed 160°F.

Use the ConcreteWorks© software available from the Department, or another approved method based on the guidelines in ACI 207, "Mass Concrete," to develop the heat control plan. The Department will make available technical assistance on the use of ConcreteWorks©. Develop the heat control plan using historical temperature ranges for the anticipated time of the mass placement. Re-create the plan if the work schedule shifts by more than one month.

The heat control plan may include a combination of the following elements:

- selection of concrete ingredients including aggregates, gradation, and cement types, to minimize heat of hydration;
- use of ice or other concrete cooling ingredients;
- use of liquid nitrogen dosing systems;
- controlling rate or time of concrete placement;
- use of insulation or supplemental external heat to control heat loss;
- use of supplementary cementing materials;
- use of a cooling system to control the core temperature; or
- vary the duration formwork remains in place.

Furnish and install 2 pairs of temperature recording devices, maturity meters, or other approved equivalent devices. Install devices to measure the surface temperature no more than 3 in. from the surface. Install devices to measure the core temperature a distance of half the least dimension from the nearest surface near the point of maximum predicted heat. Use these devices to simultaneously measure the temperature of the concrete at the core and the surface. Maintain temperature control methods for 4 days unless otherwise approved based on the submitted heat control plan. Do not use maturity meters to predict strength of mass concrete. Revise the heat control plan as necessary to maintain the temperature limitations shown above.

If the core temperature exceeds 160°F, the mass concrete element will be subject to review and acceptance by the Engineer using forensic analyses to determine its potential reduction in service life or performance. Proceed with subsequent construction on the affected element only when notified regarding acceptance.

Repair any resulting cracking if the temperature differential between the central core of the placement and the nearest concrete surface exceeds 35°F at no expense to the Department and revise the heat control plan as necessary to prevent further occurrences.

- 4.7.15. **Placing Concrete in Foundation and Substructure.** Do not place concrete in footings until the depth and character of the foundation has been inspected and permission has been given to proceed.

Place concrete footings upon seal concrete after the cofferdams are free from water and the seal concrete is cleaned. Perform any necessary pumping or bailing during the concreting from a suitable sump located outside the forms.

Construct or adjust all temporary wales or braces inside cofferdams as the work proceeds to prevent unauthorized construction joints.

Omit forms when footings can be placed in a dry excavation without the use of cofferdams, if approved, and fill the entire excavation with concrete to the elevation of the top of footing.

Place concrete in columns monolithically between construction joints unless otherwise directed. Columns and caps or tie beams supported on them may be placed in the same operation or separately. Allow for settlement and shrinkage of the column concrete, if placed in the same operation, by placing it to the lower level of the cap or tie beam, and delay placement between 1 and 2 hr. before proceeding with the cap or tie beam placement.

- 4.7.16. **Placing Concrete in Box Culverts.** Allow between 1 and 2 hr. to elapse where the top slab and walls are placed monolithically in culverts more than 4 ft. in clear height before placing the top slab to allow for settlement and shrinkage in the wall concrete.

Accurately finish the footing slab at the proper time to provide a smooth uniform surface. Finish top slabs that carry direct traffic as specified in Item 422, "Concrete Superstructures." Give top slabs of fill type culverts a float finish.

- 4.8. **Extending Existing Substructures.** Verify pertinent dimensions and elevations of the existing structure before ordering any required materials.

- 4.8.1. **Removal.** Remove portions of the existing structure to the lines and dimensions shown on the plans or as directed. Dispose of these materials as shown on the plans or as directed. Repair any portion of the remaining structure damaged as a result of the construction.

Do not use explosives to remove portions of the existing structure unless approved in writing. Do not use a demolition ball, other swinging weight, or impact equipment unless shown on the plans. Use pneumatic or hydraulic tools for final removal of concrete at the "break" line. Use removal equipment, as approved that will not damage the remaining concrete.

- 4.8.2. **Reuse of Removed Portions of Structure.** Detach and remove all portions of the old structure that are to be incorporated into the extended structure to the lines and details as specified on the plans or as directed. Move the unit to be reused to the new location specified using approved methods. Place the reinforcement and extension concrete according to the plan details.

- 4.8.3. **Splicing Reinforcing Steel.** Splice new reinforcing bars to exposed bars in the existing structure using lap splices in accordance with Item 440, "Reinforcement for Concrete," unless otherwise shown on the plans. The new reinforcing steel does not need to be tied to the existing steel where spacing or elevation does not match that of the existing steel provided the lap length is attained. Weld in accordance with Item 448, "Structural Field Welding," when welded splices are permitted. Install any required dowels in accordance with Section 420.4.7.10., "Installation of Dowels and Anchor Bolts."

- 4.8.4. **Concrete Preparation.** Roughen and clean concrete surfaces that are in contact with new construction before placing forms. Prepare these construction joint surfaces in accordance with Section 420.4.7.7., "Construction Joints."

- 4.9. **Treatment and Finishing of Horizontal Surfaces.** Strike off to grade and finish all unformed upper surfaces. Do not use mortar topping for surfaces constructed under this Section.

Float the surface with a suitable float after the concrete has been struck off.

Slope the tops of caps and piers between bearing areas from the center slightly toward the edge, and slope the tops of abutment and transition bent caps from the backwall to the edge, as directed, so water drains from the surface. Give the concrete a smooth trowel finish. Construct bearing areas for steel units in accordance with Section 441.3.11.6., "Bearing and Anchorage Devices." Give the bearing area under the expansion ends of concrete slabs and slab and girder spans a steel-trowel finish to the exact grades required. Give bearing areas under elastomeric bearing pads or nonreinforced bearing seat buildups a textured, wood float finish. Do not allow the bearing area to vary from a level plane more than 1/16 in. in all directions.

Cast bearing seat buildups or pedestals for concrete units integrally with the cap or a construction joint. Provide a latex-based mortar, an epoxy mortar, or an approved proprietary bearing mortar for bearing seat buildups cast with a construction joint. Mix mortars in accordance with the manufacturer's recommendations. Construct pedestals of Class C concrete, reinforced as shown on the plans or as indicated in Figure 1 and Figure 2. The Engineer of Record will design pedestals higher than 12 in.

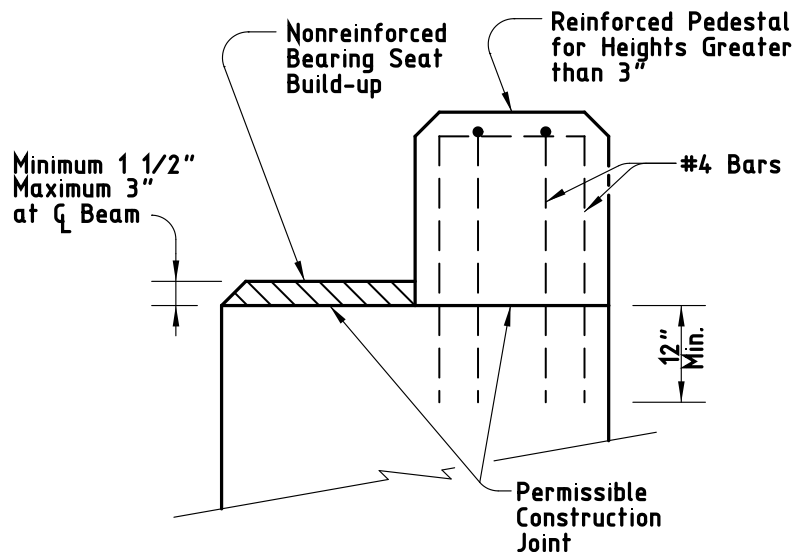


Figure 1
Section through Bearing Seat Buildups

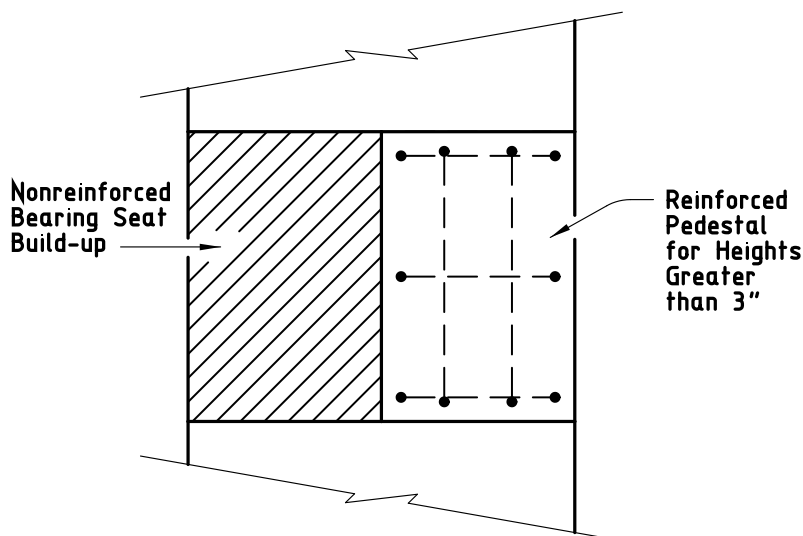


Figure 2
Plan View of Bearing Seat Buildups

- 4.10. **Curing Concrete.** Obtain approval of the proposed curing methods, equipment, and materials before placing concrete. The Engineer may require the same curing methods for like portions of a single structure. Inadequate curing or facilities may delay all concrete placements on the job until remedial action is taken.

A curing day is a calendar day when the temperature, taken in the shade away from artificial heat, is above 50°F for at least 19 hr. or, on colder days if the temperature of all surfaces of the concrete is maintained above 40°F, for the entire 24 hr. The required curing period begins when all concrete has attained its initial set unless indicated otherwise. [Tex-440-A](#) may be used to determine when the concrete has attained its initial set.

Cure all concrete for 4 consecutive days except as allowed for the curing options listed below. Use form or membrane curing for vertical surfaces unless otherwise approved. Use only water curing for horizontal surfaces of HPC or mass concrete. Use water or membrane curing for horizontal or unformed surfaces for all other concrete.

Use one of the following curing options for vertical surfaces, unless indicated otherwise.

- Form cure for 48 hr. after placement.
- Form cure for 12 hr. after placement followed by membrane curing.
- For HPC Concrete, form cure for 48 hr. after placement followed by membrane curing.
- For mass concrete, form cure as required by the heat control plan followed by membrane curing if forms are removed before 4 days.

Apply membrane curing, if used, within 2 hr. of form removal.

Use only water curing in accordance with this Section for the top surface of any concrete unit upon which concrete is to be placed and bonded at a later interval (stub walls, caps with backwalls, risers, etc.).

Cure all other concrete as specified in the pertinent Items. Use the following methods for curing concrete, subject to the requirements of this Item.

- 4.10.1. **Form Curing.** When forms are left in intimate contact with the concrete, other curing methods are not required except for exposed surfaces and for cold weather protection. Use another approved curing method if forms are removed before the 4-day required curing period.

- 4.10.2. **Water Curing.** Keep all exposed surfaces of the concrete wet continuously for the required curing time. Use water curing in accordance with concrete mixing water in Section 421.2.5., "Water." Do not use seawater or water that stains or leaves an unsightly residue.
- 4.10.2.1. **Blankets.** Keep the concrete continuously wet by maintaining wet cotton or burlap mats in direct contact with the concrete for the required curing time. Weight the mats adequately to provide continuous contact with all concrete. Cover surfaces that cannot be cured by direct contact with mats, forming an enclosure well anchored to the forms or ground so outside air cannot enter the enclosure. Provide sufficient moisture inside the enclosure to keep all surfaces of the concrete wet.
- 4.10.2.2. **Water Spray.** Overlap sprays or sprinklers to keep all unformed surfaces continuously wet.
- 4.10.2.3. **Ponding.** Cover the surfaces with at least 2 in. of clean granular material, kept wet at all times, or at least 1 in. deep water. Use a dam to retain the water or saturated granular material.
- 4.10.3. **Membrane Curing.** Choose either Type 1-D or Type 2 membrane-curing compound unless otherwise shown on the plans. Use the same type of curing compound on an individual member.

Apply membrane curing just after free moisture has disappeared at a rate of approximately 180 sq. ft. per gallon. Do not spray curing compound on projecting reinforcing steel or concrete that will later form a construction joint. Do not apply membrane curing to dry surfaces. Dampen formed surfaces and surfaces that have been given a first rub so they are moist at the time of application of the membrane.

Leave the film unbroken for the minimum curing period specified when membrane is used for complete curing. Correct damaged membrane immediately by reapplication of membrane. Polyethylene sheeting, burlap-polyethylene mats, or laminated mats in close contact with the concrete surfaces are equivalent to membrane curing.

- 4.11. **Removal of Forms and Falsework.** Remove forms for vertical surfaces after the concrete has aged a minimum of 12 hr. after initial set provided the removal can be done without damage to the concrete unless otherwise directed. Keep forms for mass placements in place for 4 days following concrete placement unless otherwise approved based on the outcome of the heat control plan outlined in Section 420.4.7.14., "Mass Placements."

Leave in place weight-supporting forms and falsework spanning more than 1 ft. for all bridge components and culvert slabs except as directed otherwise until the concrete has attained a compressive strength of 2,500 psi. Remove forms for other structural components as necessary.

Remove inside forms (walls and top slabs) for box culverts and sewers after concrete has attained a compressive strength of 1,800 psi if an approved overhead support system is used to transfer the weight of the top slab to the walls of the box culvert or sewer before removal of the support provided by the forms.

Forms or parts of forms may be removed only if constructed to permit removal without disturbing forms or falsework required to be left in place for a longer period on other portions of the structure.

Remove all metal appliances used inside forms for alignment to a depth of at least 1/2 in. from the concrete surface. Make the appliances so metal may be removed without undue chipping or spalling of the concrete, and so it leaves a smooth opening in the concrete surface when removed. Do not burn off rods, bolts, or ties.

Remove all forms and falsework unless otherwise directed.

- 4.12. **Defective Work.** Repair defective work as soon as possible. Remove and replace at the expense of the Contractor any defect that cannot be repaired to the satisfaction of the Engineer.
- 4.13. **Ordinary Surface Finish.** Apply an ordinary surface finish to all concrete surfaces. Provide flat or textured surfaces as specified with uniform appearance. Address defects and surface irregularities not consistent with the intent of the expected finish by the following:

- Chip away all loose or broken material to sound concrete where porous, spalled, or honeycombed areas are visible after form removal.
- Repair spalls in accordance with the procedures outlined in the *Concrete Repair Manual* available on the Department's website.
- Clean and fill holes or spalls caused by the removal of form ties, etc., with latex grout, cement grout, or epoxy grout as approved. Fill only the holes. Do not blend the patch with the surrounding concrete. On surfaces to receive a rub finish in accordance with Item 427, "Surface Finishes for Concrete," chip out exposed parts of metal chairs to a depth of 1/2 in. and repair the surface.
- Remove all fins, rust staining, runs, drips, or mortar from surfaces that will be exposed. Smooth all form marks and chamfer edges by grinding or dry-rubbing.
- Ensure all repairs are dense, well-bonded, and properly cured. Finish exposed large repairs to blend with the surrounding concrete where a higher class of finish is not specified.

Apply an ordinary surface finish as the final finish to the following exposed surfaces unless noted otherwise:

- inside and top of inlets,
- inside and top of manholes,
- inside of sewer appurtenances, and
- inside of culvert barrels.

Form marks and chamfer edges do not need to be smoothed for the inside of culvert barrels.

5. MEASUREMENT

This Item will be measured by the cubic yard, square yard, foot, square foot, or by each structure.

- 5.1. **General.** Concrete quantities will be based on the dimensions shown on the plans or those established in writing by the Engineer.

In determining quantities, no deductions will be made for chamfers less than 2 in. or for embedded portions of steel or prestressed concrete beams, piling, anchor bolts, reinforcing steel, drains, weep holes, junction boxes, electrical or telephone conduit, ducts and voids for prestressed tendons, or embedded portions of light fixtures.

Variation in concrete headwall quantity incurred when an alternate bid for pipe is permitted will not be cause for payment adjustment.

Quantities revised by a change in design, measured as specified, will be increased or decreased and included for payment.

- 5.2. **Plans Quantity.** Structure elements designated in Table 1 and measured by the cubic yard are plans quantity measurement items. The quantity to be paid for plans quantity items is the quantity shown in the proposal unless modified by Article 9.2., "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

No adjustment will be made for footings or other in-ground elements where the Contractor has been allowed to place concrete in an excavation without forms.

Table 1
Plans Quantity Payment
(Cubic Yard Measurement Only)

Culverts and culvert wing walls	Abutments
Headwalls for pipe	Footings
Retaining walls	Pile bent caps
Inlets and manholes	Post-tensioned elements

Note—Other elements, including pier and bent concrete, may be paid for as “plans quantity” when shown on the plans.

5.3. **Measured in Place.** Items not paid for as “plans quantity” will be measured in place.

6. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit price bid for the class of concrete and element identified and by the special designation when appropriate. This price is full compensation for furnishing, hauling, and mixing concrete materials; furnishing, bending, fabricating, splicing, welding and placing the required reinforcement; clips, blocks, metal spacers, ties, wire, or other materials used for fastening reinforcement in place; furnishing, placing, and stressing post-tensioning system; placing, finishing, and curing concrete; mass placement controls; applying ordinary surface finish; furnishing and placing drains, metal flashing strips, and expansion-joint material; excavation, subgrade preparation; and forms and falsework, equipment, labor, tools, and incidentals.

Price will be adjusted in accordance with Article 421.6., “Measurement and Payment” when required to address non-compliance of project acceptance testing.

Design and installation of foundations for falsework is at the Contractor’s expense.

In addition to the work described above, for extending structures the unit prices bid for the various classifications of concrete shown are full compensation for removing and disposing of, if necessary, the designated portion of the existing structure; removing, stockpiling if necessary, and replacing headwall units for reuse; cleaning, bending, and cutting of exposed reinforcing steel; splicing of new reinforcing steel to existing reinforcing steel; installation of dowels; and cleaning and preparing existing concrete surfaces.

Item 441

Steel Structures



1. DESCRIPTION

Fabricate and erect structural steel and other metals used for steel structures or for steel portions of structures.

2. MATERIALS

2.1. **Base Metal.** Use metal that meets Item 442, “Metal for Structures.”

2.2. **Approved Electrodes and Flux-Electrode Combinations.** Use only electrodes and flux-electrode combinations found on the Department’s MPL. To request a product be added to this list or to renew an expired approval, electronically submit a current Certificate of Conformance containing all tests required by the applicable AWS A5 specification according to the applicable welding code (for most construction, AASHTO/AWS D1.5, *Bridge Welding Code*, or AWS D1.1, *Structural Welding Code—Steel*) to the Construction Division.

2.3. **High-Strength Bolts.** Use fasteners that meet Item 447, “Structural Bolting.” Use galvanized fasteners on field connections of bridge members when ASTM A325 bolts are specified and steel is painted.

2.4. **Paint Systems.** Provide the paint system (surface preparation, primer, intermediate, and appearance coats as required) shown on the plans. Provide System IV if no system is specified.

2.4.1. **Standard Paint Systems.** Standard paint systems for painting new steel include the following:

2.4.1.1. **System III-B.** Provide paint in accordance with [DMS-8101](#), “Structural Steel Paints-Performance.” Provide inorganic zinc (IOZ) prime coat, epoxy intermediate coat, and urethane appearance coat for all outer surfaces except those to be in contact with concrete. Provide epoxy zinc prime coat for touchup of IOZ.

2.4.1.2. **System IV.** Provide paint in accordance with [DMS-8101](#), “Structural Steel Paints-Performance.” Provide IOZ prime coat and acrylic latex appearance coat for all outer surfaces except those to be in contact with concrete. Provide epoxy zinc prime coat for touchup of IOZ.

2.4.2. **Paint Inside Tub Girders and Closed Boxes.** Provide a white polyamide cured epoxy for all interior surfaces, including splice plate but excluding the faying surfaces, unless otherwise shown on the plans. Provide IOZ primer meeting the requirements of [DMS-8101](#), “Structural Steel Paints—Performance,” to all interior faying surfaces and splice plates.

2.4.3. **Special Protection System.** Provide the type of paint system shown on the plans or in special provisions to this Item. Special Protection Systems must have completed NTPEP Structural Steel Coatings (SSC) testing regimen as a complete system, with full data available through NTPEP.

2.4.4. **Galvanizing.** Provide galvanizing, as required, in accordance with Item 445, “Galvanizing.”

2.4.5. **Paint over Galvanizing.** Paint over galvanized surfaces, when required, in accordance with Item 445, “Galvanizing.”

2.4.6. **Field Painting.** Provide field paint, as required, in accordance with Item 446, “Field Cleaning and Painting Steel.”

3. CONSTRUCTION

3.1. General Requirements.

- 3.1.1. **Applicable Codes.** Perform all fabrication of bridge members in accordance with AASHTO/NSBA Steel Bridge Collaboration S2.1. Follow all applicable provisions of the appropriate AWS code (D1.5 or D1.1) except as otherwise noted on the plans or in this Item. Weld sheet steel (thinner than 1/8 in.) in accordance with ANSI/AWS D1.3, Structural Welding Code—Sheet Steel. Unless otherwise stated, requirements of this Item are in addition to the requirements of S2.1 for bridge members. Follow the more stringent requirement in case of a conflict between this Item and S2.1. Perform all bolting in accordance with Item 447, “Structural Bolting.”

Fabricate railroad underpass structures in accordance with the latest AREMA *Manual for Railway Engineering* and this Item. In the case of a conflict between this Item and the AREMA manual, the more stringent requirements apply.

- 3.1.2. **Notice of Fabrication.** Give adequate notice before commencing fabrication work as specified in Table 1. Include a schedule for all major fabrication processes and dates when inspections are to occur.

Table 1
Notice of Beginning Work

Plant Location	Notice Required
In Texas	7 days
In the contiguous United States	21 days
Outside the contiguous United States	60 days

Perform no Department work in the plant before the Engineer authorizes fabrication. The Contractor must bear all Department travel costs when changes to their fabrication or inspection schedules are not adequately conveyed to the Department.

When any structural steel is fabricated outside of the contiguous 48 states, the additional cost of inspection will be in accordance with Article 6.4., “Sampling, Testing, and Inspection.”

- 3.1.3. **Bridge Members.** Primary bridge members include:

- web and flanges of plate, tub, and box girders;
- rolled beams and cover plates;
- floor beam webs and flanges;
- arch ribs and arch tie beams or girders;
- truss members;
- diaphragm members for curved plate girders or beams;
- pier diaphragm members for tub girders;
- splice plates for primary members; and
- any other member designated as “primary” or “main” on the plans.

Secondary bridge members include:

- bracing (diaphragms, cross frames, and lateral bracing); and
- all other miscellaneous bridge items not considered primary bridge members.

- 3.1.4. **Responsibility.** The Contractor is responsible for the correctness and completeness of shop drawings and for the fit of shop and field connections.

3.1.5. **Qualification of Plants and Personnel.**

- 3.1.5.1. **Plants.** Fabrication plants that produce bridge members must be approved in accordance with [DMS-7370](#), "Steel Bridge Member Fabrication Plant Qualification." The Department's MPL has a list of approved bridge member fabrication plants.

Fabrication plants that produce non-bridge steel members listed below must be approved in accordance with [DMS-7380](#), "Steel Non-Bridge Member Fabrication Plant Qualification." The Construction Division maintains a list of approved non-bridge fabrication plants for the following items:

- Roadway Illumination Poles,
- High Mast Illumination Poles,
- High Mast Rings and Support Assemblies,
- Overhead Sign Support Structures,
- Traffic Signal Poles, and
- Intelligent Transportation System (ITS) Poles

The Department will evaluate non-bridge member fabrication plants for competence of the plant, equipment, organization, experience, knowledge, and personnel to produce acceptable work.

- 3.1.5.2. **Personnel.** Provide a QC staff qualified in accordance with the applicable AWS code. Provide an adequate number of qualified QC personnel for each specific production operation. QC must be on-site and independent of production personnel, as the Engineer determines. QC personnel must be proficient in utilizing the applicable plans, specifications, and test methods, and in verifying compliance with the plant QC and production procedures. Welding inspectors must be current AWS Certified Welding Inspectors for bridge member plants, and for non-bridge member plants requiring Department approval per [DMS-7380](#), "Steel Non-Bridge Member Fabrication Plant Qualification." The QC staff must provide inspection of all materials and workmanship before the Department's inspection. Provide the Department inspector with adequate personnel and equipment needed to move material for inspection access. QC is solely the Contractor's responsibility.

- 3.1.5.3. **Nondestructive Testing (NDT).** Personnel performing NDT must be qualified in accordance with the applicable AWS code and the employer's Written Practice. Level III personnel who qualify AS Level I and Level II inspectors must be certified by ASNT for which the NDT Level III is qualified. Testing agencies and individual third-party contractors must also successfully complete periodic audits for compliance, performed by the Department. In addition, ultrasound technicians must pass a hands-on test the Construction Division administers. This will remain current provided they continue to perform testing on Department materials as evidenced by test reports requiring their signature. A technician who fails the hands-on test must wait 6 months before taking the test again. Qualification to perform ultrasonic testing will be revoked when the technician's employment is terminated or when the technician goes 6 months without performing a test on a Department project. The technician must pass a new hands-on test to be re-certified.

- 3.1.5.4. **Welding Procedure Specifications Qualification Testing.** For bridge member fabrication, laboratories performing welding procedure specifications (WPSs) qualified by testing must be approved in accordance with [DMS-7360](#), "Qualification Procedure for Laboratories Performing Welding Procedure Qualification Testing." The Department's MPL has a list of laboratories approved to perform WPS qualification testing.

3.1.6. **Drawings.**

- 3.1.6.1. **Erection Drawings.** Submit erection drawings prepared by a licensed professional engineer, including calculations, for approval in accordance with Item 5, "Control of the Work," at least 4 weeks before erecting any portion of field-spliced (welded or bolted) girders, railroad underpasses, trusses, arches, or other members for which erection drawings are required on the plans. Include drawings and calculations for any temporary structures used to support partially erected members. Erection drawings are not required for rolled I-beam units unless otherwise noted on the plans.

Prepare erection drawings following the procedures outlined in Section 2.2 of the AASHTO/NSBA Steel Bridge Collaboration S10.1. As a minimum, include:

- plan of work area showing structure location relative to supports and all obstructions;
- equipment to be used including allowable load information;
- erection sequence for all pieces;
- member weights and center of gravity location of pieces to be lifted;
- locations of cranes, holding cranes, and temporary supports (falsework), including when to release load from temporary supports and holding cranes;
- details of falsework including specific bracing requirements with maximum allowable design wind speed clearly indicated;
- girder lifting points;
- diaphragm and bracing requirements; and
- minimum connection requirements when more than the standard requirements.

Perform girder erection analyses using UT-Lift and UT-Bridge software available on the Department's website or other suitable commercial software. Ensure temporary stresses in members being erected will not cause permanent damage and that stability is maintained throughout the erection operations. Provide actual input files and output results from UT-Lift and UT-Bridge, or graphical and hard copy results from commercial software programs.

Do not proceed if site conditions differing from those depicted on the approved erection drawings could affect temporary support stresses, erected girders, or public safety in any manner. Revise erection drawings and resubmit to the Engineer for approval before proceeding if site conditions could affect these things.

- 3.1.6.2. **Shop Drawings.** Prepare and electronically submit shop drawings before fabrication for each detail of the general plans requiring the use of structural steel, forgings, wrought iron, or castings as documented in the *Guide to Electronic Shop Drawing Submittal* available on the Bridge Division website and as directed for other items the standard specifications require.

Indicate joint details on shop drawings for all welds. Provide a title block on each sheet in the lower right corner that includes:

- project identification data including federal and state project numbers,
- sheet numbering for the shop drawings,
- name of the structure or stream for bridge structures,
- name of owner or developer,
- name of the fabricator or supplier, and
- name of the Contractor.

Provide one set of 11 × 17-in. approved shop drawings in hardcopy to the Department for the inspector at the fabrication plant.

- 3.1.6.2.1. **Bridge Members.** Prepare drawings in accordance with AASHTO/NSBA Steel Bridge Collaboration G1.3, "Shop Detail Drawing Presentation" unless otherwise approved. Print a bill of material on each sheet, including the Charpy V-Notch (CVN) and fracture-critical requirements, if any, for each piece. Indicate fracture-critical areas of members.

- 3.1.6.2.2. **Non-Bridge Members.** Furnish shop drawings for non-bridge members when required by the plans or pertinent items.

- 3.1.7. **Welding Procedure Specifications (WPSs).** Submit WPSs and test reports in accordance with the applicable AWS code to the Construction Division before fabrication begins, and notify the Engineer which procedures will be used for each joint or joint type. Do not begin fabrication until the Engineer approves WPSs.

Post the approved WPSs for the welding being performed on each welding machine, or use another approved method of ensuring the welder has access to the procedure information at all times.

- 3.1.8. **Documentation.** Before beginning fabrication, provide a completed Material Statement Form 1818 (a.k.a. D-9-USA-1) with supporting documentation (such as mill test reports (MTRs)) that the producing mill issues and qualified personnel verifies. Ensure the documentation legibly reflects all information the applicable ASTM specifications require. Supply documents electronically to the Department.

Provide a copy of the shipping or storage invoice, as material is shipped or placed in approved storage that reflects:

- member piece mark identification and calculated weight per piece from the contract drawings,
- number of pieces shipped or in storage,
- total calculated weight for each invoice per bid item, and
- the unique identification number of the shipping or storage invoice.

The inspector's acceptance of material or finished members will not prohibit subsequent rejection if the material or members are found to be damaged or defective. Replace rejected material promptly.

- 3.1.9. **Material Identification.** Assembly-mark individual pieces and issue cutting instructions to the shop using a system that will maintain identity of the original piece.

Identify structural steel by standard and grade of steel. Also differentiate between material toughness requirements (CVN, fracture-critical) as well as any other special physical requirements. In addition, identify structural steel for primary members by mill identification numbers (heat numbers). Use an approved identification system. Use either paint or low-stress stencils to make identification markings on the metal. Mark the material as soon as it enters the shop and carry the markings on all pieces through final fabrication. Transfer the markings before cutting steel for primary members of bridge structures into smaller pieces. Loss of identification marking on any piece, with no other positive identification, or loss of heat number identification on any primary member piece will render the piece unacceptable for use. Unidentifiable material may be approved for use after testing to establish acceptability to the satisfaction of the Engineer. Have an approved testing facility perform testing and a licensed professional engineer sign and seal the results.

3.2. **Welding.**

3.2.1. **Details.**

- 3.2.1.1. **Rolled Edges.** Trim plates with rolled edges used for webs by thermal cutting.

- 3.2.1.2. **Weld Tabs.** Use weld tabs at least 2 in. long for manual and semi-automatic processes, at least 3 in. long for automatic processes, and in all cases at least as long as the thickness of the material being welded. Use longer weld tabs as required for satisfactory work.

- 3.2.1.3. **Weld Termination.** Terminate fillet welds approximately 1/4 in. from the end of the attachment except for galvanized structures and flange-to-web welds, for which the fillet weld must run the full length of the attachment, unless otherwise shown on the plans.

- 3.2.1.4. **No-Paint Areas at Field-Welded Connections.** Keep surfaces within 4 in. of groove welds or within 2 in. of fillet welds free from shop paint.

- 3.2.1.5. **Galvanized Assemblies.** Completely seal all edges of tightly contacting surfaces by welding before galvanizing.

- 3.2.1.6. **Submerged-Arc Welding (SAW).** Do not use hand-held semiautomatic SAW for welding bridge members unless altered to provide automatic guidance or otherwise approved.

- 3.2.1.7. **Tubular Stiffeners for Bridge Members.** Weld in accordance with AWS D1.5, using WPSs qualified based on tests on ASTM A709 Gr. 50W or Gr. 50 steel for non-weathering applications and ASTM A709 Gr. 50W steel for weathering applications.
- 3.2.1.8. **Non-Bridge Member Weathering Steel Welds.** Provide weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal for weathering steel structures fabricated per AWS D1.1.
- 3.2.2. **Shop Splices.**
- 3.2.2.1. **Shop Splice Locations.** Keep at least 6 in. between shop splices and stiffeners or cross-frames. Obtain approval for shop splices added after shop drawings are approved.
- 3.2.2.2. **Grinding Splice Welds.** Grind shop groove welds in flange plates smooth and flush with the base metal on all surfaces whether the joined parts are of equal or unequal thickness. Grind so the finished grinding marks run in the direction of stress, and keep the metal below the blue brittle range (below 350°F). Groove welds in web plates, except at locations of intersecting welds, need not be ground unless shown on the plans except as required to meet AWS welding code requirements.
- 3.2.3. **Joint Restraint.** Never restrain a joint on both sides when welding.
- 3.2.4. **Stiffener Installation.**
- 3.2.4.1. **Flange Tilt.** Members must meet combined tilt and warpage tolerances before the installation of stiffeners. Cut stiffeners to fit acceptable flange tilt and cupping. Minor jacking or hammering that does not permanently deform the material will be permitted.
- 3.2.4.2. **Stiffeners Near Field Splices.** Tack weld intermediate stiffeners within 12 in. of a welded field splice point in the shop. Weld the stiffeners in the field in accordance with Item 448, "Structural Field Welding," after the splice is made.
- 3.2.5. **Nondestructive Testing (NDT).** Perform magnetic particle testing (MT), radiographic testing (RT), or ultrasonic testing (UT) at the Contractor's expense as specified in D1.5 for bridge structures. The Engineer will periodically witness, examine, verify, and interpret NDT. Additional welds may be designated for NDT on the plans. Retest repaired groove welds per the applicable AWS code after repairs are made and have cooled to ambient temperature. Complete NDT and repairs before assembly of parts into a member, but after any heat-correction of weld distortion.
- 3.2.5.1. **Radiographic Testing.** Radiographs must have a density of at least 2.5 and no more than 3.5, as a radiographer confirms. The density in any single radiograph showing a continuous area of constant thickness must not vary in this area by more than 0.5. Use only ASTM System Class I radiographic film as described in ASTM E1815. Use low-stress stencils to make radiograph location identification marks on the steel.
- 3.2.5.2. **Ultrasonic Testing.** Have UT equipment calibrated yearly by an authorized representative of the equipment manufacturer or by an approved testing laboratory.
- 3.2.5.3. **Magnetic Particle Testing.** Use half-wave rectified DC when using the yoke method unless otherwise approved. Welds may be further evaluated with prod method for detecting centerline cracking.
- 3.2.6. **Testing of Galvanized Weldments.** If problems develop during galvanizing of welded material, the Engineer may require a test of the compatibility of the combined galvanizing and welding procedures in accordance with this Section and may require modification of one or both of the galvanizing and welding procedures.

Prepare a test specimen with a minimum length of 12 in. using the same base material, with the same joint configuration, and using the welding procedure proposed for production work if testing is required. Clean and galvanize this test specimen using the same conditions and procedure that will be applied to the production galvanizing.

Examine the test specimen after galvanizing. There must be no evidence of excessive buildup of zinc coating over the weld area. Excessive zinc coating buildup will require modification of the galvanizing procedure.

Remove the zinc from the weld area of the test specimen and visually examine the surface. There must be no evidence of loss of weld metal or any deterioration of the base metal due to the galvanizing or welding procedure. Modify the galvanizing or welding procedure as required if there is evidence of deterioration or loss of weld metal, and run a satisfactory retest on the modified procedures before production work. Report procedures and results on the galvanized weldment worksheet provided by the Department.

- 3.3. **Bolt Holes.** Detail holes on shop drawings 1/16 in. larger in diameter than the nominal bolt size shown on the plans unless another hole size is shown on the plans.

Thoroughly clean the contact surfaces of connection parts in accordance with Item 447, "Structural Bolting," before assembling them for hole fabrication. Make holes in primary members full-size (by reaming from a subsize hole, drilling full-size, or punching full-size where permissible) only in assembly unless otherwise approved.

Ream and drill with twist drills guided by mechanical means unless otherwise approved. If subpunching holes, punch them at least 3/16 in. smaller than the nominal bolt size. Submit the proposed procedures for approval to accomplish the work from initial drilling or punching through check assembly when numerically controlled (N/C) equipment is used. Use thermal cutting for holes only with permission of the Engineer. Permission for thermal cutting is not required for making slotted holes, when slotted holes are shown on the plans, by drilling or punching 2 holes and then thermally cutting the straight portion between them. Perform all thermal cutting in accordance with Section 441.3.5.1., "Thermal Cutting."

Slightly conical holes that naturally result from punching operations are acceptable provided they do not exceed the tolerances of S2.1. The tolerance for anchor bolt hole diameter for bridge bearing assemblies is +1/8 in., -0.

- 3.4. **Dimensional Tolerances.** Meet tolerances of the applicable AWS specifications and S2.1 except as modified in this Section.

- 3.4.1. **Rolled Sections.** Use ASTM A6 mill tolerances for rolled sections, except D1.5 camber tolerances apply to rolled sections with a specified camber.

- 3.4.2. **Flange Straightness.** Ensure flanges of completed girders are free of kinks, short bends, and waviness that depart from straightness or the specified camber by more than 1/8 in. in any 10 ft. along the flange. Rolled material must meet this straightness requirement before being laid out or worked. Plates must meet this requirement before assembly into a member. Inspect the surface of the metal for evidence of fracture after straightening a bend or buckle. The Engineer may require nondestructive testing.

- 3.4.3. **Alignment of Deep Webs in Welded Field Connections.** For girders 48 in. deep or deeper, the webs may be slightly restrained while checking compliance with tolerances of S2.1 for lateral alignment at field-welded connections. In the unrestrained condition, webs 48 in. deep or deeper must meet the tolerances of Table 2. Girders under 48 in. deep must meet the alignment tolerances of S2.1.

Table 2
Web Alignment Tolerances for Deep Girders

Web Depth (in.)	Maximum Web Misalignment (in.)
48	1/16
60	1/8
72	1/4
84	5/16
96	5/16
108	3/8
120	7/16
132	7/16
144	1/2

3.4.4. **Bearings.** Correct bearing areas of shoes, beams, and girders using heat, external pressure, or both. Grind or mill only if the actual thickness of the member is not reduced by more than 1/16 in. below the required thickness.

3.4.4.1. **I-Beams, Plate Girders, and Tub Girders.** The plane of the bearing area of beams and girders must be perpendicular to the vertical axis of the member within 1/16 in. in any 24 in.

3.4.4.2. **Closed Box Girders.** Meet these tolerances:

- The plane of the bearing areas of the box girder is perpendicular to the vertical axis of the girder within 1/16 in. across any horizontal dimension of the bearing.
- The planes of the beam supports on the box girder are true to the vertical axis of the supported beams or girders to 1/16 in. in any 24 in.

In the shop, verify the plane of all bearing areas with the box placed on its bearings to field grade, using an approved process for verification.

3.4.4.3. **Shoes.** Meet these tolerances:

- The top bolster has the center 75% of the long dimension (transverse to the girder) true to 1/32 in., with the remainder true to 1/16 in., and is true to 1/32 in. across its entire width in the short dimension (longitudinal to the girder).
- The bottom bolster is true to 1/16 in. across its diagonals.
- For a pin and rocker type expansion shoe, the axis of rotation coincides with the central axis of the pin.
- When the shoe is completely assembled, as the top bolster travels through its full anticipated range, no point in the top bolster plane changes elevation by more than 1/16 in. and the top bolster does not change inclination by more than 1 degree, for the full possible travel.

3.4.4.4. **Beam supports.** Fabricate beam support planes true to the box girder bearing to 1/16 in. in the short direction and true to the vertical axis of the nesting girders to 1/16 in.

3.4.5. **End Connection Angles.** For floor beams and girders with end connection angles, the tolerance for the length back to back of connection angles is $\pm 1/32$ in. Do not reduce the finished thickness of the angles below that shown on the shop drawings if end connections are faced.

3.5. **Other Fabrication Processes.**

3.5.1. **Thermal Cutting.** Use a mechanical guide to obtain a true profile. Hand-cut only where approved. Hand-cutting of radii for beam copes, weld access holes, and width transitions is permitted if acceptable profile and finish are produced by grinding. Provide a surface finish on thermal-cut surfaces, including holes, in accordance with D1.5 requirements for base metal preparation. Obtain approval before using other cutting processes.

- 3.5.2. **Oxygen-Gouging.** Do not oxygen-gouge quenched and tempered (Q&T), normalized, or thermo-mechanically controlled processed (TMCP) steel.
- 3.5.3. **Annealing and Normalizing.** Complete all annealing or normalizing (as defined in ASTM A941) before finished machining, boring, and straightening. Maintain the temperature uniformly throughout the furnace during heating and cooling so the range of temperatures at all points on the member is no more than 100°F.
- 3.5.4. **Machining.** Machine the surfaces of expansion bearings so the travel direction of the tool is in the direction of expansion.
- 3.5.5. **Camber.** Complete cambering in accordance with S2.1 before any heat-curving.
- 3.5.6. **Heat Curving.** Heat-curve in accordance with S2.1. The methods in the AASHTO bridge construction specifications are recommended. Attach cover plates to rolled beams before heat-curving only if the total thickness of one flange and cover plate is less than 2-1/2 in. and the radius of curvature is greater than 1,000 ft. Attach cover plates for other rolled beams only after heat-curving is completed. Locate and attach connection plates, diaphragm stiffeners, and bearing stiffeners after curving, unless girder shrinkage is accounted for.
- 3.5.7. **Bending of Quenched and Tempered Steels.** The cold-bending radius limitations for HPS 70W in S2.1 apply to all Q&T steels.
- 3.6. **Nonconformance Reports (NCRs).** Submit an NCR to the Engineer for approval when the requirements of this Item are not met. Submit NCRs in accordance with the Construction Division's NCR guidelines document. Have readily available access to the services of a licensed professional engineer experienced in steel structures design and fabrication. This licensed professional engineer may be responsible for reviewing potentially structurally deficient members in accordance with the NCR guidelines document. Receive Department approval before beginning repairs. Perform all repair work in strict compliance with the approved NCR and repair procedure.
- 3.7. **Shop Assembly.**
- 3.7.1. **General Shop Assembly.** Shop-assemble field connections of primary members of trusses, arches, continuous beam spans, bents, towers (each face), plate girders, field connections of floor beams and stringers (including for railroad structures), field-bolted diaphragms for curved plate girders and railroad underpasses, and rigid frames. Field-bolted cross-frames and rolled-section diaphragms do not require shop assembly. Complete fabrication, welding (except for shear studs), and field splice preparation before members are removed from shop assembly. Obtain approval for any deviation from this procedure. The Contractor is responsible for accurate geometry.
- Use a method and details of preassembly consistent with the erection procedure shown on the erection plans and camber diagrams. The sequence of assembly may start from any location in the structure and proceed in one or both directions. An approved method of sequential geometry control is required unless the full length of the structure is assembled.
- Verify by shop assembly the fit of all bolted and welded field connections between bent cap girders and plate girders or between plate girders and floor beams.
- Do not measure horizontal curvature and vertical camber for final acceptance until all welding and heating operations are completed and the steel has cooled to a uniform temperature. Check horizontal curvature and vertical camber in a no-load condition.
- 3.7.2. **Bolted Field Connections.** Each shop assembly, including camber, alignment, accuracy of holes, and fit of milled joints, must be approved before the assembly is dismantled.

Assemble with milled ends of compression members in full bearing. Assemble non-bearing connections to the specified gap. Ream all subsize holes to the specified size while the connections are assembled, or drill

full size while the connections are assembled. Notify the Engineer before shipping if fill plates or shims are added. Adding or increasing the thickness of shims or fill plates in bearing connections requires approval. Use drift pins and snug-tight bolts during the drilling process to ensure all planes of the connection (webs and flanges) can be assembled simultaneously. Do not use tack welds to secure plates while drilling.

Secure parts not completely bolted in the shop with temporary bolts to prevent damage in shipment and handling. Never use tack welds in place of temporary bolts.

Match-mark connecting parts in field connections using low-stress stencils in accordance with the diagram in the erection drawings.

- 3.7.3. **Welded Field Connections.** Mill or grind bevels for groove welds. Do not cut into the web when cutting the flange bevel adjacent to the web. End preparation, backing, and tolerances for girder splices must be in accordance with Item 448, "Structural Field Welding." Details for all other field-welds must conform to the applicable AWS code unless otherwise shown on the plans.

In the shop, prepare ends of beams or girders to be field-welded taking into account their relative positions in the finished structure due to grade, camber, and curvature. Completely shop-assemble and check each splice. Match-mark the splice while it is assembled with low-stress stencils in accordance with the diagram in the erection drawings.

3.8. **Finish and Painting.**

- 3.8.1. **Shop Painting.** Perform shop painting of bridge members as required in [DMS-8104](#), "Paint, Shop Application for Steel Bridge Members." Grind corners on new steel items to be painted (except for the coatings on box and tub girder interiors) that are sharp or form essentially 90° angles to an approximately 1/16 in. flat surface before blast cleaning. (A corner is the intersection of 2 plane faces.) This requirement does not apply to punched or drilled holes. Do not omit shop paint to preserve original markings.

Ensure painted faying surfaces meet the required slip and creep coefficients for bolted connections as outlined in [DMS-8104](#), "Paint, Shop Application for Steel Bridge Members."

Use a Class A slip (minimum slip coefficient of 0.33) if no slip coefficient or corresponding surface condition is specified. Perform all required testing at no expense to the Department.

Surface preparation and painting the interiors of Tub Girders and Closed Boxes is in accordance with [DMS-8104](#), "Paint, Shop Application for Steel Bridge Members."

- 3.8.2. **Weathering Steel.** Provide an SSPC-SP 6 blast in the shop to all fascia surfaces of unpainted weathering steel beams. Fascia surfaces include:

- exterior sides of outermost webs and undersides of bottom flanges of plate girders and rolled beams,
- all outer surfaces of tub girders and box girders,
- all surfaces of truss members,
- webs and undersides of bottom flanges of plate diaphragms,
- bottom surfaces of floor beams, and
- any other surfaces designated as "fascia" on the plans.

Do not mark fascia surfaces. Use one of the following methods as soon as possible to remove any markings or any other foreign material that adheres to the steel during fabrication and could inhibit the formation of oxide film:

- SSPC-SP 1, "Solvent Cleaning,"
- SSPC-SP 2, "Hand Tool Cleaning,"
- SSPC-SP 3, "Power Tool Cleaning," and
- SSPC-SP 7, "Brush-off Blast Cleaning."

Do not use acids to remove stains or scales. Feather out touched-up areas over several feet.

- 3.8.3. **Machined Surfaces.** Clean and coat machine-finished surfaces that are in sliding contact, particularly pins and pinholes, with a non-drying, water-repellent grease-type material containing rust-inhibitive compounds. Ensure the coating material contains no ingredients that might damage the steel. Protect machined surfaces from abrasive blasting.
- 3.9. **Handling and Storage of Materials.** Prevent damage when storing or handling girders or other materials. Remove or repair material damaged by handling devices or improper storage by acceptable means in accordance with ASTM A6 and the applicable AWS code.
- Place stored materials on skids or acceptable dunnage above the ground. Keep materials clean. Shore girders and beams to keep them upright and free of standing water. Place support skids close enough to prevent excessive deflection in long members such as columns. Do not stack completed girders or beams at the jobsite.
- Protect structural steel from salt water or other corrosive environments during storage and transit.
- 3.10. **Marking and Shipping.** Mark all structural members in accordance with the erection drawings. If a surface is painted, make the marks over the paint. Do not use impact-applied stencils to mark painted surfaces.
- Mark the weight directly on all members weighing more than 3 tons.
- Keep material clean and free from injury during loading, transportation, unloading, and storage. Pack bolts of each length and diameter, and loose nuts or washers of each size, separately and ship them in boxes, crates, kegs, or barrels. Plainly mark a list and description of the contents on the outside of each package.
- 3.11. **Field Erection.** Do not lift and place any steel member, including girders and diaphragms, over an open highway or other open travel way unless otherwise approved. Do not allow traffic to travel under erected members until sufficiently stable as shown on approved erection drawings.
- 3.11.1. **Pre-Erection Conference.** Schedule and attend a pre-erection conference with the Engineer at least 7 days before commencing steel erection operations. Do not install falsework or perform any erection operations before the meeting.
- 3.11.2. **Methods and Equipment.** Do not tack-weld parts instead of using erection bolts. Do not tack-weld parts to hold them in place for bolting. Provide falsework, tools, machinery, and appliances, including drift pins and erection bolts. Provide enough drift pins, 1/32 in. larger than the connection bolts, to fill at least 1/4 of the bolt holes for primary connections. Use erection bolts of the same diameter as the connection bolts.
- Securely tie, brace, or shore steel beams or girders immediately after erection as shown on the erection drawings. Maintain bracing or shoring until the diaphragms are in place and as specified in the erection drawings. Protect railroad, roadway, and marine traffic underneath previously erected girders or beams from falling objects associated with other construction activities.
- Only welders certified or working directly under the supervision of a foreman certified in accordance with Item 448, "Structural Field Welding," may handle torches when applying heat to permanent structural steel members.
- 3.11.3. **Falsework.** Construct falsework in accordance with the erection plan. Construct foundations for shore towers as shown on erection drawings. Do not use timber mats with deteriorated timbers or soil to construct shore tower foundations. Notify the Engineer of completed falsework to obtain approval before opening roadway to traffic or starting girder erection activities. Ensure falsework is protected from potential vehicle impact. Inspect and maintain falsework daily. Use screw jacks or other approved methods to control vertical adjustment of falsework to minimize the use of shims.

- 3.11.4. **Handling and Assembly.** Accurately assemble all parts as shown on the plans and the approved shop drawings. Verify match-marks. Handle parts carefully to prevent bending or other damage. Do not hammer if doing so damages or distorts members. Do not weld any member for transportation or erection unless noted on the plans or approved by the Engineer.
- 3.11.4.1. **Welded Connections.** Weld flange splices to 50% of their thickness and meet the minimum erection bracing and support requirements before releasing the erection cranes, as shown on the plans and on the approved erection plans. Field-weld in accordance with Item 448, "Structural Field Welding."
- 3.11.4.2. **Bolted Connections.** Before releasing the erection cranes:
- install 50% of the bolts in the top and bottom flanges and the web with all nuts finger-tight,
 - meet the minimum erection bracing and support requirements shown on the plans and on the approved erection plans, and
 - install top lateral bracing across the connection for tub girders, and fully tension the bolts connecting the bracing to the top flanges.
- Install high-strength bolts, including erection bolts, in accordance with Item 447, "Structural Bolting." Clean bearing and faying surfaces for bolted connections in accordance with Item 447, "Structural Bolting." Clean the areas of the outside ply under washers, nuts, and bolt heads before bolt installation. Ensure the required faying surface condition is present at the time of bolting.
- 3.11.5. **Misfits.** Correct minor misfits. Ream no more than 10% of the holes in a plate connection (flange or web), and ensure no single hole is more than 1/8 in. larger than the nominal bolt diameter. Submit proposed correction methods for members with defects that exceed these limits or prevent the proper assembly of parts. Straighten structural members in accordance with S2.1. Make all corrections in the presence of the Engineer at no expense to the Department. Do not remove and reweld gusset plates without approval.
- 3.11.6. **Bearing and Anchorage Devices.** Place all bearing devices such as elastomeric pads, castings, bearing plates, or shoes on properly finished bearing areas with full and even bearing on the concrete. Place metallic bearing devices on 1/4 in.-thick preformed fabric pads manufactured in accordance with [DMS-6160](#), "Water Stops, Nylon-Reinforced Neoprene Sheet, and Elastomeric Pads," to the dimensions shown on the plans. Provide holes in the pad that are no more than 1/4 in. larger than the bolt diameter.
- Build the concrete bearing area up to the correct elevation once it has been placed below grade using mortar that meets Item 420, "Concrete Substructures," and provide adequate curing. Use only mortar for build-ups between 1/8 in. and 3/8 in. thick. Use galvanized steel shims or other approved shim materials in conjunction with mortar if the bearing area must be raised more than 3/8 in.
- Provide at least 75% contact of flange to shoe with no separation greater than 1/32 in. for beams and girders. Make corrections using heat or pressure in accordance with S2.1, or with galvanized shims. Correct small irregularities by grinding.
- Provide at least 85% contact between the rocker plate and the base plate. Adjust the location of slotted holes in expansion bearings for the prevailing temperature. Adjust the nuts on the anchor bolts at the expansion ends of spans to permit free movement of the span. Provide lock nuts or burr the threads.
- Remove all foreign matter from sliding or machine-finished surfaces before placing them in the structure.
- Restore distorted bearing pads or expansion bearings to an equivalent 70°F position after completion of all welded or bolted splices, using an approved method of relieving the load on the bearing devices.
- 3.11.7. **Erecting Forms.** Do not erect forms until all welding or bolting is complete and the unit is positioned and properly set on the bearings unless otherwise noted on the plans.
- 3.11.8. **Field Finish.** Paint in accordance with Item 446, "Field Cleaning and Painting Steel." Restore weathering steel that will remain unpainted to a uniform appearance by solvent cleaning, hand cleaning, power brush, or

blast cleaning after all welding and slab concrete placement has been completed. Remove from all unpainted weathering steel fascia surfaces (see Section 441.3.8.2., "Weathering Steel,") any foreign material, including markings, that adheres to the steel and could inhibit formation of oxide film as soon as possible. Feather out touched-up areas over several feet. Do not use acids to remove stains or scales.

4. MEASUREMENT AND PAYMENT

The work performed, materials furnished, equipment, labor, tools, and incidentals will not be measured or paid for directly but will be subsidiary to pertinent Items.

Item 442

Metal for Structures



1. DESCRIPTION

Provide structural steel, high-strength bolts, forgings, steel castings, iron castings, wrought iron, steel pipe and tubing, aluminum castings and tubing, or other metals used in structures, except reinforcing steel and metal culvert pipe.

2. MATERIALS

Furnish mill test reports (MTRs), supplemental test documentation, and certifications required by this and other pertinent Items.

2.1. **Structural Steel.** The Engineer may sample and test steel in accordance with ASTM A370.

2.1.1. **Bridge Structures.** Provide the grade of ASTM A709 steel shown on the plans. Grade 50W, 50S, or HPS 50W may be substituted for Grade 50 at no additional cost to the Department. Use Zone 1 if no AASHTO temperature zone is shown on the plans.

2.1.2. **Non-Bridge Structures.**

2.1.2.1. **Steel Classifications.** Provide the types and grades of steel listed in this Section unless otherwise shown on the plans.

2.1.2.1.1. **Carbon Steel.** Meet ASTM A36.

2.1.2.1.2. **Low-Alloy Steel.** Meet the requirements of one of the following standards:

- ASTM A529 Grade 50;
- ASTM A572 Grade 50 or 55;
- ASTM A588;
- ASTM A709 Grade 50, 50S, 50W, or HPS 50W; or
- ASTM A992.

Specify ASTM A6 supplemental requirement S18, "Maximum Tensile Strength," for material used for sign, signal, and luminaire supports.

2.1.2.2. **Impact Testing.** Tension members and components of the following structure types, if more than 1/2 in. thick. Other members designated on the plans must meet the Charpy V-notch (CVN) requirements of Table 1:

- base plates for roadway illumination assemblies, traffic signal pole assemblies, high mast illumination poles, camera poles, and overhead sign supports;
- pole mounting plates, arm mounting plates, and clamp-on plates for traffic signal pole assemblies;
- arm stiffeners, pole gussets, and stiffeners for traffic signal pole long mast arm assemblies (50 ft. to 65 ft.);
- pole shafts, ground sleeves, and handhole frames for high mast illumination poles;
- W-columns, tower pipes, multiple-sided shafts, tower pipe and multiple-sided shaft connection plates, chord angles, chord splice plates or angles, and truss bearing angles for truss type overhead sign supports; and

- pipe posts, pipe arms, post and arm flange plates, and handhole frames for monotube overhead sign supports.

Table 1
CVN Requirements for Non-Bridge Steel

Material	Thickness	Minimum CVN Toughness
ASTM A36, A53, A242, A500, A501, A709 Gr. 36, any other steel with minimum specified yield point below 40 ksi	up to 4"	15 ft.-lb. at 70°F
ASTM A572, ¹ A588, ¹ A633, ¹ any other steel with minimum specified yield point between 40 and 65 ksi, inclusive	up to 2"	15 ft.-lb. at 70°F
	over 2" to 4", mechanically fastened	15 ft.-lb. at 70°F
	over 2" to 4", welded	20 ft.-lb. at 70°F
Any steel with minimum specified yield point over 65 ksi and under 90 ksi ²	up to 2-1/2"	20 ft.-lb. at 50°F
	over 2-1/2" to 4", mechanically fastened	20 ft.-lb. at 50°F
	over 2-1/2" to 4", welded	25 ft.-lb. at 50°F

1. Reduce the testing temperature by 15°F for each 10-ksi increment or fraction thereof above 65 ksi if the yield point of the material given on the MTR exceeds 65 ksi.
2. Reduce the testing temperature by 15°F for each 10-ksi increment or fraction thereof above 85 ksi if the yield point of the material given on the MTR exceeds 85 ksi.

Use the (H) frequency of testing for material with minimum specified yield point up to 50 ksi. Use the (P) frequency of testing for material with minimum specified yield point over 50 ksi. Ensure steel is sampled and tested in accordance with ASTM A673.

2.1.3. Other Components.

2.1.3.1. **Miscellaneous Bridge Components.** Provide steel that meets ASTM A36, A709 Grade 36, or A500 Grade B for members such as steel bearing components not bid under other items, steel diaphragms for use with concrete bridges, and armor and finger joints, unless otherwise shown on the plans.

2.1.3.2. **Shear Connectors and Anchors.** Provide cold-drawn bars for stud shear connectors, slab anchors, and anchors on armor and finger joints that meet the requirements of ASTM A108, Grade 1010, 1015, 1018, or 1020, either semi-killed or killed, and have the tensile properties given in Table 2 after drawing or finishing. Determine tensile properties in accordance with ASTM A370.

Table 2
Minimum Tensile Properties for Bar Stock

Tensile strength	60 ksi
Yield strength	50 ksi
Elongation	20% (2")
Reduction of area	50%

Provide certification from the manufacturer that the studs or anchors as delivered have the required material properties.

2.1.3.3. **Fasteners.** Provide high-strength bolts that meet ASTM A325 or A490 as shown on the plans. The Department may sample high-strength bolts, nuts, and washers for structural connections in accordance with [Tex-719-I](#).

Follow the requirements of Item 447, "Structural Bolting," for tests, test reports, and supplemental requirements for high-strength bolts, nuts, and washers.

Use bolts that meet ASTM A307 and nuts that meet ASTM A563 when ASTM A325 or A490 bolts are not shown on the plans.

2.1.3.4. **Slip-Resistant Deck Plates.** Furnish steel for deck plates that meets ASTM A786 and one of A242, A588, or A709 Gr. 50W. State the type and trade name of material to be used on the shop drawings.

- 2.1.3.5. **Rail Posts.** Provide material for rail posts that meets ASTM A36 or ASTM A709 Grade 36 unless otherwise shown on the plans.
- 2.2. **Steel Forgings.** Provide steel forgings for pins, rollers, trunnions, or other forged parts that meet ASTM A668, Class C, D, F, or G, as shown on the plans. For pins 4 in. or smaller in diameter for non-railroad structures, material that meets ASTM A108, Grades 1016 to 1030, with a minimum yield strength of 36 ksi, may be used instead.
- 2.3. **Steel Castings.** Provide steel castings that meet ASTM A27, Grade 70-36.
- 2.4. **Iron Castings.** Provide iron castings that are true to pattern in form and dimensions; free from pouring faults, sponginess, cracks, blow holes, and other defects in positions affecting their strength and value for the service intended; and meet the standards shown in Table 3.

Table 3
Standards for Iron Castings

Casting Material	ASTM Standard	Grade or Class
Gray iron	A48	35B
Malleable iron	A47	32510
Ductile iron	A536	70-50-05

- 2.5. **Steel Tubing.** Provide steel tubing that meets ASTM A500, Grade B unless otherwise shown on the plans. Tubing that meets API Standard 5L, Grade X52 may be used if produced by a mill listed in the standard API specifications as authorized to produce pipe with the API monogram. Hydrostatic tests are not required for API 5L steel, and instead of an MTR, the manufacturer may furnish a certificate for each lot or shipment certifying the tubing meets the requirements of this Section.
- 2.6. **Pipe Rail.** "Pipe" includes special extruded and bent shapes. Provide pipe that is rolled, extruded, or cold-pressed from a round pipe or flat plate, and of the section shown on the plans.

Ensure the design of the cold press and dies results in a pipe of uniform section-free from die marks. Cut the pipe to the lengths required once it has been formed to the required section. Make the end cuts and notches at the angles to the axis of the pipe required to produce vertical end faces and plumb posts when required by the plans. Provide a neat and workmanlike finish when cutting and notching pipe.

- 2.7. **Aluminum.** Provide aluminum materials that meet the standards shown in Table 4 unless otherwise shown on the plans.

Table 4
Aluminum Standards

Material	ASTM Standard	Alloy-Temper
Castings	B108	A444.0-T4
Extrusions	B221	6061-T6
Sheet or plate	B209	6061-T6

When testing is required, cut test specimens from castings from the lower 14 in. of the tension flange, but not at the junction of the rib or base. Flatten the curved surfaces before machining. Provide standard test specimens in conformance with ASTM E8.

3. CONSTRUCTION

- 3.1. **Fabrication, Erection, and Painting.** Fabricate, weld, and erect structural metal in accordance with Item 441, "Steel Structures," Item 447, "Structural Bolting," Item 448, "Structural Field Welding," and the applicable AWS welding code. Paint in accordance with Item 446, "Field Cleaning and Painting Steel." Aluminum or galvanized steel members do not require painting unless otherwise shown on the plans.
- 3.2. **Galvanizing.** Galvanize fabricated steel items, steel castings, bolts, nuts, screws, washers, and other miscellaneous hardware in accordance with Item 445, "Galvanizing." Galvanizing is not required unless specified.

4. MEASUREMENT

This Item will be measured by the pound of structural metal furnished and placed in a complete structure not including the weight of erection bolts, paint, or weld metal.

This is a plans quantity measurement Item. The quantity to be paid is the quantity shown in the proposal unless modified by Article 9.2., "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

The maximum percent variance from the plans quantity will be as given in Table 5.

Table 5
Percent Variance

Quantity	Variance
Over 1,000,000 lb.	1/2%
100,000 through 1,000,000 lb.	1%
Under 100,000 lb.	1-1/2%

If the requests for increases in sizes or weights of members are approved, measurement will be made on the sizes or weights shown on the plans.

Castings, bearing plates, anchor bolts, drains, deck plates, armor and finger joints, and other metal for which no separate measurement is specified will be included in the total quantity of structural steel.

The weights of rolled materials (such as structural shapes and plate) will be computed on the basis of nominal weights and dimensions using measurements shown on the plans. Deductions will not be made for material that is removed for copes, clips, planing, or weld preparation. The weight of castings will be computed from the dimensions shown on the approved shop drawings. Shoes will be measured by the weights shown on the plans.

Weight of high-strength fasteners will be based on Table 6. Weight of other metal will be based on Table 7.

Splices will be measured as follows:

- No additional weight will be allowed for weld metal in a welded splice.
- Where a bolted splice is permitted as an alternate for a welded splice, measurement will be made on the basis of a welded splice.
- Where a bolted splice is required, the weight of the splice material, bolt heads, washers, and nuts will be measured with no deduction for holes.

Table 6
Pay Weight for High-Strength Fasteners, Pounds per Hundred Units

Diameter	Item		
	Bolt heads	Nuts	Washers
3/4"	15	19	4.8
7/8"	23	30	7.0
1"	32	43	9.4
1-1/8"	45	59	11
1-1/4"	64	79	14

Table 7
Pay Weight for Metals

Material	Weight (lb./cu. in.)
Steel	0.2836
Cast iron	0.2604
Wrought iron	0.2777

5. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Structural Steel" of the type (Rolled Beam, Plate Girder, Tub Girder, Box Girder, Railroad Through-Girder, Railroad Deck-Girder, Miscellaneous Bridge, Miscellaneous Non-Bridge) specified. This price is full compensation for materials, fabrication, transportation, erection, paint, painting, galvanizing, equipment, tools, labor, and incidentals.