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Underground Transmission Construction: Vault and Manhole Design and Current Practices

Underground Transmission Construction: Vault and Manhole Design and Current Practices

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PRODUCT DESCRIPTION

Underground transmission (UT) cable systems are alternatives to overhead transmission lines, especially if the costs in design and construction of the UT cable systems are further reduced. Among the major activities of an underground transmission cable project, vault (manhole) designs and related safety issues need to be addressed. Manhole design and construction account for one of the major costs in a cable project.

This Electric Power Research Institute (EPRI) research project describes a survey of current utility construction practices of UT cable systems. It focuses on designs of manholes for both single and double circuits of extruded dielectric cables at 115/138 kV and on the development of safety guidelines for working in manholes. Gas explosion considerations and heating effects of reinforcing steel in manholes and ducts were discussed, investigated, and tested.

Results and Findings

This report describes EPRI work into the current utility construction practices of UT systems, especially in the areas of manhole designs and safety guidelines for working in them. The report provides details of a survey, manhole designs and safety guides, and results of laboratory tests on the heating effects of reinforcing steels.

Challenges and Objectives

This report is intended for use by utility engineers who are responsible for the design and construction of UT lines. The primary challenges of this project were to evaluate various UT manhole and duct designs, develop manhole designs for single- and double-circuit applications to reduce construction costs, and develop safety guidelines to address concerns associated with working in manholes. This project also investigated heating effects of reinforcing steel in manholes and ducts.

Applications, Value, and Use

One of the most fundamental tasks for underground transmission lines is to determine manhole design and construction in order to control costs and determine safety procedures. This report provides survey results of current industry practices, typical manhole designs, and safety guidelines for utility engineers in design, construction, and operation.

EPRI Perspective

Many EPRI projects have addressed UT design and construction cost issues, including *Underground Cable Installation and System Cost Reduction Phase 1* (TR-109150, 1997) and *Phase 2* (TR-114457, 1999), *Cost Reduction Activities in France for Installing Cable* (1000519, 2001), and *Lower Cost Underground Transmission Cable* (1008719, 2004). Manhole design and construction account for one of the major costs in a cable project. This EPRI report focuses on designs of manholes for both single and double circuits of extruded dielectric cables at 115/138 kV and on the development of safety guidelines for working in manholes. EPRI also conducted research and produced report 1001849 in 2004, *Mechanical Effects on Extruded Dielectric Cables and Joints Installed in Underground Transmission Systems*, describing an application guide for the design of duct-manhole systems and pipe systems. Current EPRI research on the thermomechanical behavior (TMB) of extruded dielectric cables in ducts emphasizes the need for cable offsets to prevent TMB damage and to accommodate differential cable forces in vaults. This research will update the recommendations presented in report 1001849.

Approach

The approach of this project was to survey the UT industry (including utilities, manufacturers, contractors, and consultants) to determine current industry trends in manhole and duct designs and practices. Based on the survey results, the project developed typical straight-through and S-bend (offset joint) manhole designs that can be used to reduce construction costs for both single- and double-circuit configurations. The project then described safety guidelines for working in manholes. Tests were performed at the EPRI Lenox test facility to investigate the heating effects of reinforcing steel in manholes and ducts.

Keywords

Manhole design
Transmission cable
Underground transmission construction
Safety guideline

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INTRODUCTION

Underground transmission (UT) cable systems are alternatives to overhead transmission lines, especially if the costs in design and construction of the UT cable systems are further reduced. The following recent Electric Power Research Institute (EPRI) reports address UT design and construction costs:

- *Underground Cable Installation and System Cost Reduction: Phase 1* (TR-109150)
- *Underground Cable Installation and System Cost Reduction: Phase 2* (TR-114457)
- *Cost Reduction Activities in France for Installing Cable* (1000519)
- *Lower Cost Underground Transmission Cable* (1008719)

These reports describe methods in major cost categories to reduce the installation cost of a transmission cable system by focusing on extruded dielectric transmission cables. The following are highlights of these EPRI reports.

1.1 Permitting

Obtaining permits for a new transmission line is a multiyear process in most parts of the world. The process includes preparing applications and responding to inquiries from governmental and intervener organizations. The process is long and expensive in terms of person-hour costs in the application process and especially in terms of the increased costs to address requirements placed by the approving groups.

Areas to evaluate for permitting include the following:

- Magnetic field levels and limits
- Environmental impacts (such as during construction and operation and in traffic)
- Failure rates and durations
- Burial depth, need for shoring, and joint use with other utilities
- Street opening, time duration, working hours
- Vault or manhole locations and sizes
- Routing and alternative routing evaluation (including utility conflict, ownership, traffic study, underground survey, right-of-way, and access requirements)

Addressing these issues takes resources to evaluate, prepare, and defend responses. Previous EPRI reports indicate that a form of legal brief—different from engineering descriptions and documents and that states utility positions—could save time and money during the permitting process.

1.2 Project Approach

The scope of a cable project includes the following tasks:

- Design systems (for example, planning, design, route selection, and cable specification).
- Obtain bids and select contractors (for example, civil work, material supply, and installation).
- Procure materials.
- Install cables.
- Assume project risk.

Alternative project approaches can be used to reduce project costs. Previous EPRI reports indicate that cost savings can also be achieved if a high-quality technical specification is provided and if the utilities are willing to share some inevitable risk in undertaking a construction project. The reports also recommend that the utilities have the contractor involved in each phase of the project and take advantages of the wealth of experience (for example, in routing, ease of construction, traffic control, and permitting) to benefit the project. Using a cable manufacturer to have overall cable design, material supply, and even overall installation responsibility has become a common practice.

1.3 Cable System Design

Optimization of cable system design can result in cost savings. Cable system design includes the actual cable (conductor, insulation, and shield), conductor sizing, and overall installation configurations adapted to installation configurations and project requirements. Use of standard circuit ratings and cable sizes can simplify the decision-making process and project schedule as well as reduce material cost. The cross-sectional area of the trench significantly affects the excavation costs.

1.4 Installation

Cable system installation—including civil works—is the most costly part of a project, has the greatest risk factor, and has the greatest opportunity for optimization. Previous EPRI reports address issues such as transportation, trench configuration, vault spacing and design, and regulations.

1.5 Accessories

Design and installation of the accessories (such as splices, terminations, and link boxes) are also potential areas for cost reduction.

1.6 Monitoring, Uprating, and Dynamic Rating

Distributed temperature sensing and dynamic thermal circuit rating can be used to allow utilities to increase power transfer for both new and existing cable systems.

1.7 Number of Manholes

Reduction of the number of manholes used can be a source of total cost reduction. The number of manholes is determined by the distance the cable can be pulled or sometimes by standing shield voltage. The maximum distance the cable can be pulled is in turn governed by the allowable pulling tension on the conductor, the sidewall pressure on the cable in traversing a bend, the maximum cable footage on a reel, and access to the manhole. The pulling tension can be calculated by the bend and dip parameters and the coefficient of friction of pulling.

1.8 Manhole Installation

Manholes are installed to pull and splice cable. Both pre-cast and cast-in-place manhole designs are used; the pre-cast manhole design is more commonly used because it requires less time to install. Vaults and manholes should be installed after all other utility locations, especially those crossing the planned cable route perpendicularly near the manhole or vault, are determined. The following issues need to be considered for the manhole installation:

- Type of cable system to be installed
- Equipment and tools to pull and splice cable and install the pre-cast manhole
- Hole excavation and shoring
- Overhead clearances
- Traffic control plans
- Unknown utilities
- Coordination with conduit installation
- Dewatering

1.9 Manhole Design

The physical design of manholes and the related safety issues are important components in the design, construction, and operation of an underground cable system. Manholes are designed for cable pulling, splicing, supporting and racking, and training to control thermomechanical bending movement and forces. Manhole design and construction account for one of the major costs in cable circuit design and construction. Smaller manholes are acceptable at certain installation conditions if the designs can lead to cost reduction. Manhole designs can also be optimized if special splice designs (for example, the length of the splice) and installation procedures (for example, the method to train the cable) are considered. Special designs are also available for two lines in one vault, separated by a safety wall to save costs.

Two different methods are used for cable entrances and racking within a manhole; these are described next.

1.9.1 Method 1: S-Bend/Offset Joint

The conduits enter the manhole close to the center line of the manhole. The cable is trained, bent, and racked over to the sidewall. The cable is clamped immediately adjacent to the joint so that the joint is stationary but remains free throughout the offset bends. Clamps that allow the cable to slip through are placed at the manhole end wall and along the bend to provide vertical support. This allows for cable movement and thermal expansion and contraction of the cable during operation. The manhole must be long and wide enough to accommodate the cable bends during installation and cable movement due to thermal expansion and contraction during operation. This method has additional benefits: cable installation is easier because of conduit location in the vaults, and slack in the cable from the bends can be used to repair a joint failure.

1.9.2 Method 2: Straight-Through

The cable and the splice are placed in a straight line and rigidly clamped within the manhole. This method forces all cable expansion into the duct if the clamping is done properly. Cable expansion into the manhole can create cable buckling or deformation of the stress cone assembly inside the joint casing, which should be avoided if clamping is adequate. This method requires a shorter, narrower manhole but does not provide slack cable to repair a joint failure if needed. Cable pulling is more complex for this method because the conduit openings are not in direct line with the manhole openings.

1.10 Objectives and Organization of the Report

The objective of this project was to evaluate current industry practices in the design and installation of transmission manholes. The work pertains to cables installed in ducts with joints in manholes, as opposed to direct buried cables with joints in manholes. The following design considerations were evaluated:

- Designs shall cover both straight-through and S-bend methods that represent shorter and/or narrower designs.
- Designs shall consider most commonly used splice designs.
- Designs shall consider cable entrance and racking approaches.
- Designs shall consider impact on the duct bank designs.

- Designs shall consider impact on cable pulling.
- Designs shall consider impact on rebuilding splices.
- Designs shall minimize site impact due to installation and repair.
- Designs shall address safety issues while working in the manhole.
- Designs shall address construction cost.
- Designs shall include loading requirement, clamping arrangement, construction material, and other necessary details.
- Designs shall list features, application advantages, and limitations.

This project includes a survey of current utility construction practices of UT cable systems. It also focuses on the designs of manholes for both single and double circuits of extruded dielectric cables at 115/138 kV and on the development of safety procedures for the manholes designed. The voltage of 115/138 kV was used to limit the project scope to the most widely used voltage class. Specific topics are addressed in the report as follows:

- Section 2 provides a summary of the results of the survey performed. Surveys were sent out to utility companies, civil contractors, cable manufacturers, and manhole fabricators.
- Section 3 presents issues associated with the design of single- and double-circuit manholes as it relates to the two types of commonly used racking methods: straight-through and S-bend.
- Section 4 discusses the design considerations for gas explosion.
- Section 5 discusses the heating effect associated with steel rebar installed around the cable at manhole entrances and with the cable trench.
- Section 6 discusses issues associated with duct work.
- Section 7 summarizes the findings of this report.
- Appendix A includes details of the survey results.
- Appendix B includes the single-circuit manhole design drawings.
- Appendix C includes the double-circuit manhole design drawings.

The following publications on the subject provide useful background reading:

- CIGRE Technical Brochure 194, "Construction, Laying, and Installation Techniques for Extruded and Self-Contained Fluid Filled Cable Systems," 2001.
- Section 12, "Installation Design," and Section 13, "Cable System Construction," in *Underground Transmission Systems Reference Book: 2006 Edition.* EPRI, Palo Alto, CA: 2007. 1014840.
- *Mechanical Effects on Extruded Dielectric Cables and Joints Installed in Underground Transmission Systems in North America.* EPRI, Palo Alto, CA: 2004. 1001849.

2
CURRENT INDUSTRY PRACTICES IN MANHOLE DESIGN AND CONSTRUCTION FOR UNDERGROUND TRANSMISSION SYSTEMS: SURVEY SUMMARY

2.1 Introduction

One objective of this project is to investigate manhole design alternatives to improve the cost and safety of these types of installations. To accomplish this objective, a survey of utilities, cable manufacturers, contractors, and manhole fabricators was conducted to determine the current industry practices. This section summarizes the results of the survey; complete survey responses are included in Appendix A.

2.2 Survey Procedure

At the start of the project, it was determined that a survey would be performed to assess the current industry practices for design, cost savings, and safety issues of manholes on UT lines. It was determined that four groups are involved or should be considered in the ultimate design of a particular manhole design:

- **Utility.** Because the utility is the ultimate user of the manhole, care must be taken to ensure a quality and safe product.
- **Cable manufacturer.** Because the manhole is one of the main access points for installing the cable, care must be taken to ensure that no damage will occur during the installation and operation of the cable system.
- **Contractor.** Because the contractor is responsible for installing the manhole and sometimes the cable, consideration should be given to how the manhole is installed.
- **Manhole fabricator.** Because the manhole fabricator is responsible for the final manhole design, consideration must be made to the fabrication process and overall design criteria.

Because each group has a different design focus, a separate questionnaire was prepared for each group. A distribution list was prepared identifying potential participants in the survey. Table 2-1 summarizes the number of surveys sent and the number returned. A copy of the distribution list and the respondents is included in Appendix A.

Table 2-1
Summary of the Number of Surveys Sent and Returned

Survey Group	Number of Surveys Sent	Number of Surveys Returned	Percent Returned
Utilities	26	10	39%
Cable manufacturers	8	5	63%
Contractors	23	9	39%
Manhole fabricators	5	2	40%

2.3 Survey Results

The questionnaires were designed to determine existing underground construction practices, identify safety issues, and identify potential construction cost savings. The following responses reflect the exact words from the survey questions.

Technologies surveyed included:

- Design of manholes for single and double circuits
- Design of duct banks
- Construction cost savings

The following is a summary of the results as they relate to each of these technologies.

2.3.1 Manhole Design for Single and Double Circuits

The following questions were asked concerning the safety and overall design of different types of manholes:

- Does your company have a policy regarding the use of single-circuit manholes versus double-circuit manholes, when parallel circuits are installed in a common duct bank?
- In a double-circuit transmission manhole, do you allow your workers in the manhole with one circuit energized?
- Do you allow your utility personnel to enter an energized distribution manhole?
- Does your company prefer a pre-cast or cast-in-place manhole installation?
- Does your company have a standard manhole size for 115-/138-kV cables?
- Do your splicing manholes use straight-through or S-bend splicing methods (or both)?
- What method do you use for restraining the cable expansion and contraction while energized?

- Do you have a special grounding requirement for your manholes?
- Do you have a special grounding requirement for your termination structures?
- Does your company have a standard practice for manhole drainage and sump locations?
- Have you applied or are you aware of any innovative installation techniques during the last few years that result in manhole or duct bank installation cost savings and quality and safety improvement? Please describe and provide vendor's name if available.

These questions were designed to assess various safety and design issues such as safety of personnel working in double-circuit and single-circuit manholes as well as the reliability of the cable system.

The following is a summary of the responses received from the groups identified previously and reflects their personal opinions or their company's current standard practices:

- The majority of the utility, contractor, and cable manufacturer respondents expressed concern about the installation of multiple circuits within a single manhole. Here are some of the reasons the respondents gave for their position on double-circuit manholes:
  - "All new circuits shall have individual manholes (no double-circuit manholes). This policy was established for safety reasons. Besides failure concerns, our system does not allow both circuits to be out of service at the same time."
  - "Our present standard since 2001 is to install separate staggered manholes for each circuit. This is for perceived safety of union personnel entering the manhole for any reason. Personnel only enter manhole when the circuit is de-energized."
  - "We do not have a written policy. We take exception to all conditions requiring work in a manhole alongside another energized circuit. We are aware there are certain things that can be done to protect against induced currents, but physical evidence viewed after a splice failure event has convinced us there is no safe way to work in the presence of an energized splice."

  Although many of the utility respondents would enter a manhole with energized distribution circuits, they would not enter a manhole with energized transmission circuits. A few of the utilities indicated that they would enter an energized manhole only for a short time for maintenance and inspection.

  Based on the responses, it appears that none of the respondents has any defined safety procedure for working in an energized transmission manhole, except for the wearing of fire-retardant (FR) rated clothing. Further discussion and recommendations on this issue are presented in Section 3.

- The majority of the respondents preferred pre-cast manholes over cast-in-place manholes. Here are some of the reasons the respondents gave for using pre-cast:
  - "Pre-cast manholes are preferred because of cost savings, short installation times, and savings in dimensions and steel (cast-in-place manholes are assumed to have lower strength concrete and therefore require thicker walls and additional steel)."
  - "In general, pre-cast manholes are used for cost and ease-of-installation reasons. However, if a pre-cast manhole cannot be used due to external factors, we will use a cast-in-place manhole."
- The utilities indicated a wide range of manhole sizes as their standards for 138-/115-kV cable systems. The inside dimensions of the manhole ranged, for the length, from 18 ft (5.5 m) to 20.5 ft (6.3 m); for the width, from 8 ft (2.4 m) to 10 ft (3.1 m); for the height, from 6 ft (1.8 m) to 8 ft (2.4 m).
- The majority of the respondents require an internal ground ring. This ring is connected to ground rods, ground continuity conductors (GCCs), and splice grounding boxes.
- There are currently two methods of routing the cable inside the manhole: the straight-through method and the S-method. Respondents gave contradictory reasons for applying either one of the two methods:
  - "Offset of cables with S-bends will absorb the expansion and contraction of cable."
  - "S-bends allow an indeterminate amount of cable movement and bending and can over-bend cable sheath. On slopes, the cable can accumulate at the S-bend and restrict expansion accommodation."
  - "Straight-through design allows limited expansion of the cable into the manhole in order to reduce mechanical stress on the cable splice."
  - "Splicing of conductors and jointing work is easier."
  - "Straight-through design minimizes cable movement."

2.3.2 Duct Bank Design

The following questions were asked concerning duct bank design:

- Does your company have a standard transmission duct bank design and circuit arrangement?
- Do you require a minimum length of straight duct prior to entering the manhole?
- Do you include a ground continuity conductor in your design?
- What type of duct material do you use?
- What type of duct connections do you use?

These questions were designed to assess the various design issues and requirements. The following is a summary of the responses received from the groups identified previously and reflect their personal opinions or their company's current duct bank design issues:

- **Standard duct bank configuration.** Many of the utility respondents have a standard duct bank configuration for both single-circuit and multiple-circuit installations. None of the contractors and cable manufacturers indicated that they had a standard configuration. The following are some of the reasons utilities have developed a standard trench configuration:
  - "Spare ducts for replacement cable and fiber-optic cable."
  - "The 2 wide by 4 deep configuration is designed for space compactness."
  - "Flexibility (if double-circuit design) and consistency (less confusion in the field)."
- **Ground continuity conductors.** The majority of respondents indicated that they do include a GCC with their trench design. The location of the ground conductor varied. The following are some of the responses:
  - "The GCC is located at the bottom of trench and moved from one side of the trench to the other every 1/3 distance between manholes."
  - "Traditionally the GCC has been at the bottom, but placing it above the ducts is being considered. Install the conductors as a loop to reduce EMF."
  - "For single-bonded systems only, the GCC is positioned between outer phase L1 and middle phase L2 for half the length and between middle phase L2 and outer phase L3 for the other half length. For circuits in trefoil, the GCC is positioned as near as possible to the power cables."
  - "The GCC is positioned preferably close to the middle of the three phases of the circuit."
- **Type of conduit.** The majority of the respondents indicated that their standard duct was the PVC bell and spigot conduit. Many of the respondents are looking into the use of fiberglass conduit. One respondent indicated that their standard duct material was fiberglass, which resulted in a construction cost savings. Here is the response:
  - "Fiberglass reinforced epoxy bell and spigot ducts are our standard. The FRE is very light, resulting in manpower savings. Standard bends are used in the design and can be custom ordered in a matter of days."

Further discussion of design and construction issues is provided in Section 6.

2.3.3 Construction Cost Savings

Questions were asked to determine whether any of the respondents have developed cost savings techniques or methods. The following is a summary of those responses:

- Use various approaches, for example, incentive contracts.
- Use local civil contractors and purchase cable systems separately that include installation.
- Use higher strength concrete and additives to reduce wall sizes along with good engineering.

None of the respondents indicated any specific cost savings associated with the manhole design.

2.4 Conclusions

Based on the results of the survey, the following conclusions were reached:

- There are considerable concerns with entering energized transmission manholes, and there are no procedures or designs that make entering an energized manhole 100% safe. The common practice is to deenergize the line before entering or use separate manholes for double-circuit installations. See Section 5 for information on gas explosions and design recommendations.
- The majority of the respondents prefer the straight-through splice arrangement. See Section 3 for a comparison of each type of splice arrangement and design consideration.
- GCCs are commonly installed, but no specific location is preferred.
- None of the respondents indicated any significant cost savings associated with the installation and design of the manhole or duct bank. For further discussion on cost issues, see Sections 3 and 4 for manholes and Section 6 for duct banks.

3
115-/138-KV SINGLE- AND DOUBLE-CIRCUIT MANHOLE DESIGN

3.1 Introduction

One of the most critical issues in the design of a manhole is the ability of the design to accommodate the expansion and contraction of the cable during normal load cycling without causing any damage to the cable or splice.

Two 115-/138-kV single-circuit manhole designs were developed, considering the safety of personnel and the reliability of the cable system:

- **Straight-through.** At the end walls of the manhole, the duct entry is offset to allow the cable to be aligned inside the manhole without any bends.
- **S-bend.** The duct entry in the manhole is (nearly) centered at the end walls to allow the cable to be configured inside the manhole using two reverse bends, commonly referred to as an S-bend.

Single-circuit manhole design drawings are included in Appendix B; double-circuit manhole design drawings are included in Appendix C. Although typically pre-cast manholes are installed because of their lower cost, a similar cast-in-place manhole design may be used if desired.

3.2 Straight-Through

The duct configuration for the straight-through manhole design is such that the three conduits for each circuit enter the manhole on the same vertical plane and are spaced 2 ft (0.61 m) apart from one another. In the case of a double-circuit manhole, the two circuits are typically on opposite sides of the manhole. In addition, the conduits should enter approximately 1 ft 6 in. (0.46 m) from one of the side walls to facilitate cable pulling in addition to cable racking for support.

Installed using the straight-through method, the cable in the manhole does not have any significant bends. As a result, the extra length due to the cable expanding during load cycling must be accommodated by the cable snaking within the conduit system. Sufficient clamping is needed to force the cable expansion back into the duct. In addition, the ducts need to be of a sufficient size to accommodate the expansion of the cable without damaging the cable.

The typical inside dimensions for a 115-/138-kV single-circuit manhole using the straight-through design is 18 ft (length) × 6 ft (width) × 8 ft (height) (6.1 × 2.4 × 2.4 m). The typical inside dimensions for a double-circuit manhole using the straight-through design is 20 ft (length) × 10 ft (width) × 8 ft (height) (6.1 × 3.1 × 2.4 m). This design allows for a splice joint up to approximately 7 ft (2.1 m) in length.

3.3 S-Bend

The conduits for the S-bend design enter on the same vertical plane for each circuit near the centerline of the manhole. The cables then form two reverse bends to get to the splice locations along the manhole wall. The cable joint is firmly clamped to the manhole wall. The cable is supported vertically and loosely clamped on support racking. With this design, the cable expansion is accommodated by the flexing of the S-bend. It is important that the cable is not allowed to over-bend (having a cable bend radius of <20 times the cable OD), resulting in cable damage.

The typical inside dimensions for a single-circuit manhole using the S-bend design is 25 ft (length) × 8 ft (width) × 8 ft (height) (7.6 × 2.4 × 2.4 m). The typical inside dimensions for a double-circuit manhole using the S-bend design is 25 ft (length) × 10 ft (width) × 8 ft (height) (7.6 × 3.1 × 2.4 m). As with the straight-through design, this approach allows for a splice joint up to approximately 7 ft (2.1 m) in length.

3.4 Comparison of Straight-Through Versus S-Bend Manhole Designs

A comparison between the straight-through and S-bend designs is provided in Table 3-1.

Table 3-1
Comparison of Straight-Through Versus S-Bend for Single-Circuit Designs

	Advantages	Disadvantages
Straight-through	Minimizes length of manhole design Reduced width of manhole	Requires thermomechanical bending to occur outside of the manhole, which may require a larger conduit to absorb the expansion Cable pulling is more difficult because the conduit entrances are offset May result in unacceptable forces on the joint and cable/joint buckling if not properly designed
S-bend	Facilitates cable pulling due to centered cable alignment Allows for thermomechanical bending inside the manhole	Requires longer and wider manhole May limit manhole access May result in cable damage due to excessive cable bending, if not properly designed

3.5 Electrical Safety Considerations

Induced voltages may exist on underground cable, which can present a safety hazard to workers. The induce voltages can be caused by some of the following external events:

- Close proximity to a parallel energized line
- External system fault
- Static charge created during cable installation

Proper grounding is important during cable pulling and splicing operation. Cable manufacturer and current utility grounding practices should be followed. During cable pulling, the following should be grounded:

- Winch truck
- Winch line/pull rope (use a grounded roller)
- Cable reel truck

Regardless of the manhole design—but with particular regard to a double-circuit design–each manhole design should include the ability of providing grounds within the manholes. Surrounding the work zone with grounds will provide an equipotential area within the manhole. An equipotential area can be created by following these safety guidelines:

- Grounds should be located as close as possible to the work being done. Common practice is to install an internal ground loop within the manhole using bare copper wire. This ground loop is then tied to ground stingers embedded in the manhole wall. The ground wire should be sized to accommodate the anticipated system fault current.
- Installing grounding shunts during the splicing process. Before cutting the conductor or shield, a ground shunt should be applied when possible. The shunts will ensure the electric continuity of the metallic loop.
- Installing connections linking all conductive objects in the work zone (for example, scaffolding, ladders, nacelles, winches, tools, and supports).
- Personal protective clothing should be worn; proper gloves and safety equipment should be in use.

One of the primary concerns with entering an energized manhole is the consequence of the splice or cable failing inside the manhole when a person is inside. The manhole design includes the provisions to install blast blankets or a metal barrier in front of the splices. This would provide some level of protection to personnel entering an energized manhole. Proper PPE (air monitoring, manhole ventilating, safety observer, and others following Occupational Safety and Health Administration [OSHA] confined space working requirements) should always be followed and can offer additional safety. It is recommended that all cables in the manhole be deenergized, if possible.

An Insulated Conductors Committee (ICC) Working Group is developing guidelines for working on a cable system in close proximity to another energized circuit. The title of the resulting document is "Guideline for Working Procedures on Underground Transmission Circuits with Induced Voltage."

3.6 Cost Considerations

The most important factor for the cost difference between the straight-through and S-bend manhole designs is the greater size required for the S-bend approach. The additional length and width required is based directly on the minimum bending radius of the cable and movement of the cable allowed for in the system design. The provided manhole designs were based on a minimum bending radius of 8 ft (2.4 m). The larger manhole results in both larger material and civil construction costs for placement of the vault. The larger span may also require internal and/or external supports based on soil conditions and vehicular loading requirements, which could significantly impact the construction cost.

3.7 Waterproofing Issues

Another important design consideration is waterproofing and sealing of manholes. Although having a dry manhole is desirable, it is difficult to achieve. Water can enter the manhole through different areas: the ducts, the lids, the concrete, and the seam if the manhole is pre-cast. Established materials have been used in all of these areas to minimize the water ingress, but the final determinant of whether a manhole is dry is generally the surrounding ground water table. If the water table is low (below the bottom of the manhole), the probability of the manhole being dry is very high. If the water table is high (at the same elevation or above the top of the manhole), the probability of water coming into the manhole is very high. Cable systems are generally designed to operate in a wet environment, so the general reason to attempt to keep water out is not operational, rather, more of a maintenance and construction issue. If the manhole is dry, pumping it out to perform maintenance and construction is not necessary. The following are commonly used methods to attempt to keep water out of manholes:

- **Duct seals.** In many cases, the conduit joints are not watertight, so water can enter the conduit and eventually find its way into the manhole. To prevent water ingress, plastic duct seals have been place in any unused ducts. For ducts that have cable, expanding foam or an inflatable seal has been used. Experience has shown that over time these types of seals have failed. But initially, they provide good results in keeping water from entering through the ducts.
- **Solid lids.** Because there is an opening into the manhole from the surface, surface water has generally found its way into the manhole through these openings. One way to minimize the water is to install a solid lid and use a waterproofing sealant around the edge of the lid. There are two drawbacks to this method. One is that although a solid lid helps to keep the water out, it also retains any gases that might accumulate in the manhole. The general practice has been to vent the lid to allow any gases to escape through it. The other drawback is that each time the lid is opened, the sealant is destroyed and requires replacement.

- **Concrete sealant.** Water can enter the manhole through the concrete. Concrete absorbs water, which can migrate through the concrete into the interior of the manholes. To prevent this, an outer coating can be placed on the outside walls of the manhole. Typically, a coal tar coating has been placed on the outside of the manholes. This coating can be installed on the manholes in the factory or in the field.
- **Joint sealant.** Pre-cast manholes are generally fabricated in multiple sections because of the size requirements. The joints between the manholes are another place where water can enter. A bituminous/butyl material is typically used to seal the joints. Once the manhole is installed, the joints can also be sealed with the coal tar coating on the outside to further seal the manholes. Currently, this is not a common practice.

3.8 Loading Requirements

Another important design consideration is to ensure that the walls of the manholes can withstand the necessary soil loads and anticipated cable pulling loads. Every manhole should be designed to withstand normal traffic loads (Association of State of Highway Transportation Officials [ASHTO] H-20 Loading) while adhering to any applicable American Standard Test Method (ASTM) and Canadian Standards Association (CSA) standards. Final pulling locations should be selected after consultation with the cable installer (each installer has a preferred pulling setup).

3.9 Clamping Requirements

The clamping requirements for a cable system are project dependent. The following factors influence the final clamping arrangement:

- Type of manhole design: straight-through or S-bend
- Length of duct between manholes
- Size of duct
- Size of cable
- Type and strength of clamps
- Elevation changes

Cable manufacturers may use different types of clamps; final clamping designs are usually provided by cable manufacturers.

4
GAS EXPLOSION DESIGN CONSIDERATIONS

4.1 Introduction

Another manhole design issue considered was the ability of a manhole to withstand a gas explosion. This section discusses the impact of a gas explosion on the design of the manhole.

4.2 Design Consideration

A gas explosion can occur when a significant amount of combustible gas accumulates inside a manhole and is ignited due to an electrical arc caused by a cable failure. Although there has been recent history of gas explosions on distribution systems, there has not been a significant incident on a transmission system.

An article that appeared in *T&D World* discusses a test performed to determine the effect of a gas explosion on the manhole.[1] The article states that the utility requires the safety of maintenance crew in the event of a cable or joint failure and permits only one cable circuit per vault at transmission voltage level for the newly installed extruded dielectric cables so that maintenance can be performed on one circuit while the other circuit remains energized. A partitioned underground vault was designed, fabricated, and tested. The vault was designed to provide a partition wall to allow the crew to work on either side of the wall while a cable or joint failure occurs on the other side. Full-scale tests performed within the design limits of the materials were conducted on two vault prototypes. In the test, a high-energy arcing fault was initiated inside one of the vault chambers. The following test parameters were applied: 16 kV single phase, 63 kA rms symmetrical, 60 Hz, and 18 cycles. During the fault test, gas was observed exiting the vault openings. However, no movement or structural damage was observed on the vault structure or soil covering the vault.

During the tests, a 9-psi (62-kPa) pressure rise was observed and is expected as a result of a cable fault in the field. A pressure of 32 psi (221 kPa) was used in the vault design that provides a margin of safety. The tests confirmed that the vaults could provide protection while the crew worked in the adjacent chamber.

[1] Rachel Mosier, Victor Antoniello, and W. Z. Black, "Design and Test 345 kV Vaults," *T&D World*, May 2006.

4.3 Conclusion

The structural designs associated with meeting the H-20 loading and cable pulling requirements have been shown to be sufficient to meet the structural loads applied during a fault.

Certain protection measures should be considered when designing double-circuit manholes. Blast blankets or removable partitions, installed in a double-circuit manhole, should reduce the amount of mechanical damage to the cables and accessories of the other circuit. Blast blankets or removable partitions, depending on the violence created by the fault, may not protect an individual in the manhole.

5
HEATING EFFECT OF STEEL REINFORCING RODS IN MANHOLES AND DUCTS

5.1 Introduction

Some cable manufacturers recommend against placing closed loops of steel reinforcing rods (rebars) around individual transmission cables where they penetrate the end walls of splice vaults, following the general design practices of not surrounding individual power cables with closed loops of ferromagnetic metal. This is because of the concern that induced eddy-current losses and hysteresis losses in the steel rebars may cause overheating of the transmission cable. This restriction sometimes presents problems with the mechanical design of the concrete vault, especially when high cable pulling tensions are anticipated.

To the author's knowledge, the origin of this recommendation is the well-accepted practice of not enclosing power cables with continuous ferromagnetic components. Although this is a legitimate concern, test data were not found that quantify the amount of temperature increase that may be caused by enclosing power cables with steel rebar loops.

Two approaches were considered for determining or estimating the amount of heating that will occur if individual transmission cables are enclosed with steel rebar loops where they pass through splice vault end walls:

- **Numerical modeling.** Numerical modeling of the rebar loops with a commercial finite element analysis (FEA) program (such as FEM Lab) is possible. FEA programs have been used to model both eddy current losses in ferromagnetic materials and thermal field problems. The primary difficulties with the numerical analysis approach are the following:
  - The contact resistance between crossing rebars is unknown. The rust and mill scale that is present on most rebar may effectively reduce or eliminate the induced current heating. Previous full-scale testing [1] to determine rebar losses in cable tunnels showed that there was a significant difference in electrical losses depending on whether the rebar crossings were tied with wires.
  - Most commercial FEA programs model eddy current losses in electrically conducting structures, but they do not model hysteresis losses.
  - The magnetic permeability and electrical resistivity of rebars must be known in order to accurately model eddy current losses with FEA programs.

- The required thermal modeling is a three-dimensional (3-D) problem because the radial heat flow as well as the axial heat flow in the cable conductor must be modeled.

- Although 3-D thermal modeling is possible with FEA programs, it significantly complicates the thermal analysis.

- **Laboratory tests.** High-current laboratory tests can be set up to directly measure the increase in temperature of a power cable surrounded by a steel rebar cage or loop. Laboratory testing can inherently include the effect of rebar crossing resistance and rebar magnetic properties, resulting in higher confidence in test results compared to the numerical modeling approach.

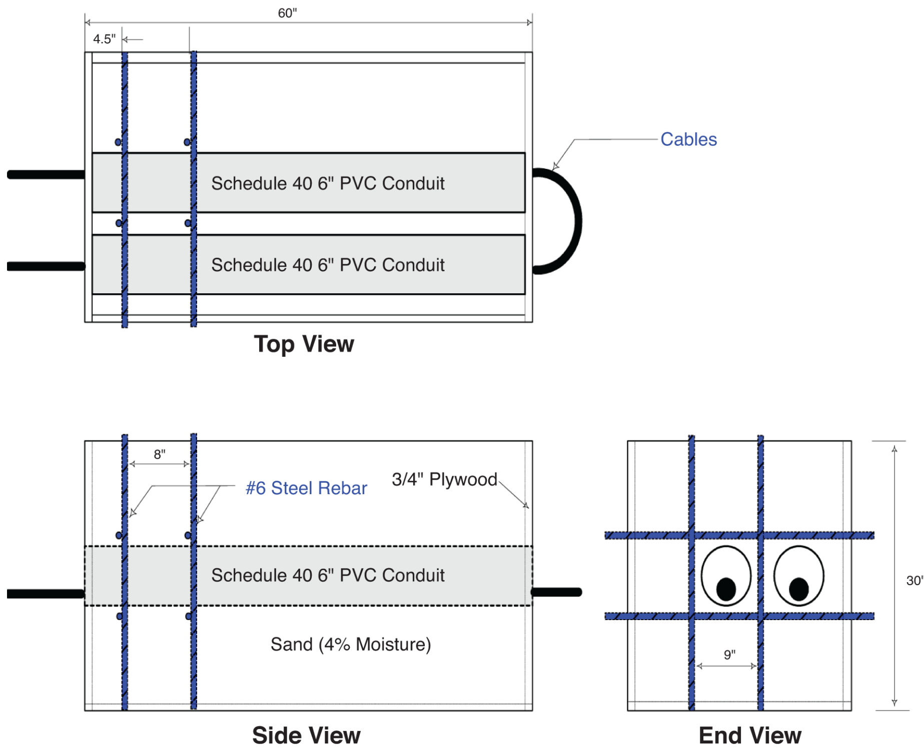
The laboratory tests were performed to determine whether steel reinforcing rod/loop surrounding individual cables in a vault results in significant heating of transmission cables.

5.2 Test Setup and Approach

High-current laboratory tests were set up to measure temperatures of power cables surrounded by steel reinforcing rods or loops. As shown in Figures 6-1 and 6-2, the test fixture was a plywood box with two 6-in. diameter polyvinyl chloride (PVC) conduits and wood supports for steel rebar around one of the two conduits. The plywood box was filled with sand (4% moisture). Four 4/0 American wire gauge (AWG) copper 600-V cables were electrically connected at the ends and bundled together to model a single transmission cable. The model cable was run through both of the PVC conduits and connected to a power current transformer (CT). A closed loop of steel rebar was formed around one of the two PVC conduits. Thermocouples were attached to the outside of the model cable in the vicinity of their exit from the plywood box, the two PVC conduits (with and without rebar), and the steel rebars. The tests were conducted with two test current levels (750 and 1000 A), with and without steel tie wires at the rebar crossings.

Laboratory tests were performed at the EPRI Lenox test facility. John Cooper of Power Delivery Consultants designed the test setup, provided a detailed description of the tests to be performed as well as assistance to Lenox personnel as needed, evaluated the test results, and prepared the written report. EPRI Lenox personnel provided the following test equipment and conducted the tests:

- Material required for the tests
- Test equipment (power CT and voltage regulator)
- Test instrumentation (CT, thermocouples, and data logger)



1 in. = 25.4 mm

Figure 5-1
Test Setup: Fixture and Cable Layout

Figure 5-2
Test Setup: Steel Reinforcing Rods and Temperature Measurements

5.3 Test Results

The tests performed are summarized in Table 6-1. Results of the temperature measurements are shown in Figure 6-3.

Table 5-1
Summary of Test Results

Test Number	Cable Current (A)	Duration (hours)	Test Conditions	Comments
1	750	12.0	Without rebar loop (without wire ties on rebar crossings)	Steady-state (60°C) reached.
2	750	12.0	Without rebar loop (with wire ties on rebar crossings)	Steady-state (60°C) reached.
3	1000	2.67	With rebar loop (with wire ties on rebar crossings)	Test terminated because high cable temperature (80°C) was reached.
4	1000	2.7	With rebar loop (without wire ties on rebar crossings)	Test terminated because high cable temperature (80°C) was reached.
5	1000	2.7	Without rebar loop (without wire ties on rebar crossings)	Test terminated because high cable temperature (80°C) was reached.
6	1000	2.67	Without rebar loop (with wire ties on rebar crossings)	Test terminated because high cable temperature (80°C) was reached.

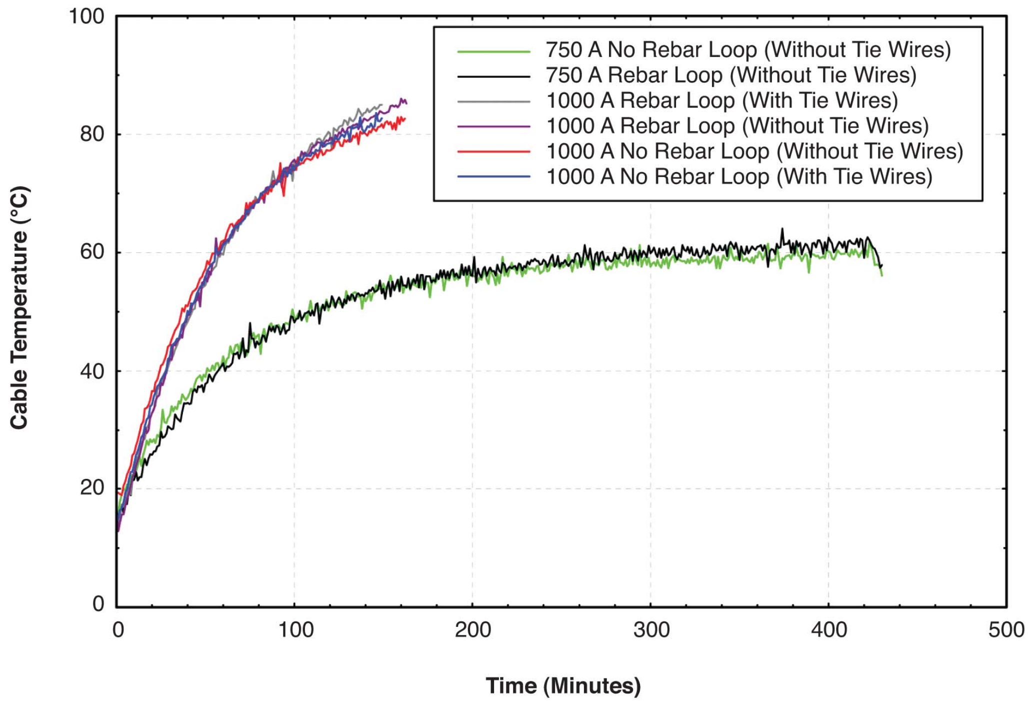


Figure 5-3
Test Results: Temperature Measurements

5.4 Conclusions

The following conclusions were reached during this project:

- Electrical losses in the closed-loop steel reinforcing rods caused less than 2°C temperature rise in cables at 750 A cable current (Test 1 versus Test 2).
- Electrical losses in the steel reinforcing rods caused approximately 4°C temperature rise in cables at 1000 A cable current (Test 3 versus Test 6; Test 4 versus Test 5).
- No circulating current was measured in the closed rebar loops. Rebar heating was a result of eddy current and hysteresis losses.
- Electrical contact resistance between crossing reinforcing rods had a small effect on heating in the reinforcing rods.
- Surrounding individual cables with closed loops of steel reinforcing rods resulted in a relatively small amount of heating in the reinforcing rods.

6
DUCT BANK DESIGN CONSIDERATIONS

6.1 Introduction

In addition to the manhole design, another design consideration is the trench design—specifically, the duct design. This section compares different conduit materials and the use of a ground continuity conductor (GCC).

6.2 Conduit Material Comparison

Most concrete-encased duct bank systems and direct buried conduit systems have used PVC conduit. Other duct materials that have been used for electrical duct systems are high-density polyethylene (HDPE) and fiberglass-reinforced epoxy (FRE). Historically, PVC has been used for open-cut trench application, HDPE for horizontal directional drilled (HDD) application, and fiberglass for bridge installations. The lower installed cost has been the primary reason for installing PVC conduit; Table 6-1 compares the typical properties of the three duct materials.

Table 6-1
Comparison of Typical Properties of Three Duct Materials

	PVC	HDPE	FRE
Tensile strength (psi)	5,000–6,000	2000–4000	11,000
Compressive strength (psi)	9,000	4,570	12,000
Ease of installation	Excellent	Good	Good
UV resistance	Poor	Poor	Good
Type of connection	Bell and spigot coupling	Butt fused coupling	Bell and spigot coupling
Field bending	Good	Excellent	Poor
Coefficient of thermal expansion (10^{-5} in./in.°F)	3.38	13	1.2
Relative cost	0.75	1	1
Temperature range (°F)	-40° to +150°	-40° to +150°	-60° to +250°
Cable fault	May melt/fuse	May melt/fuse	Not affected
Burn through (cable pull)	No	Possibly	Possibly
Water tightness	May leak	No leaks	May leak
Coefficient of friction (unlubricated)	0.40	0.40	0.35

1 psi = 6.89 kPa

ºC = ºF – 32 (5/9)

1 in. = 25.4 mm

As can be seen by this comparison, FRE has superior mechanical and thermal properties compared to the other two conduit materials. However, it is more difficult to bend in the field and has a higher installed cost. Further investigation may be warranted to determine whether FRE can be economically installed in the open trench application. Because of its ability to be pulled in long sections without coming apart, HDPE would still be the preferred conduit material for long HDD application.

6.3 Ground Continuity Conductor

Historically, a GCC has been installed with single-point bonded systems and not with cross-bonded systems. Currently, the ICC is rewriting the IEEE Standard 575, "IEEE Guide for Bonding of High Voltage Single Conductor Power Cables." The new guide indicates that many utilities use a GCC for both single-point and cross-bonded systems. The new guide states the following in regard to the need for the GCC for cross-bonded systems:

> Although a ground continuity conductor is not required for cross-bonded systems since the cable sheaths form an end-to-end path for fault currents, many utilities, especially those in the United States, do install ground continuity conductors to insure a solid end-to-end conductor, and to give a low impedance connection point for grounding the sheath voltage limiters and cable sheaths in manholes. Note that circulating currents may be induced in the ground continuity conductors and the resulting losses should be considered when calculating cable ampacity.

Further study may be warranted to determine the need for a GCC with cross-bonded systems.

Another issue is the placement of the GCC conductor in reference to the cable. The IEEE bonding guide states: "The spacing of this conductor from the cable circuit should be sufficiently close to limit the voltage rise of the sheath to an acceptable level during a single-phase fault." Ideally, if the cables are placed flat, the GCC should be placed between two of the phases and then transposed midway to the other side of the trench between the phases. For cables arranged in a triangular or trefoil configuration, the ideal location is in the middle of the phases.

Further study may be warranted to determine the optimum location for the GCC for various circuit configurations.

7 SUMMARY AND RECOMMENDATIONS

7.1 Summary

This report investigates the current trends in the underground industry as they relate to the design of transmission manholes. Among the respondents who returned the survey, there were considerable concerns with entering energized transmission manholes, and there were no procedures or designs that made entering an energized manhole 100% safe. The common practice was to deenergize the line before entering or to use separate manholes for double-circuit installations. The majority of the respondents preferred the straight-through splice arrangement. None of the respondents indicated any significant cost savings associated with the installation and design of the manhole or duct bank.

Typical manhole details are provided for both single- and double-circuit manhole designs. These are generic drawings that provide a good starting point in the design of manholes. Although these designs might work for most projects, each design should be evaluated to determine its suitability for an actual project in which it is to be installed. The selected cable manufacturer should be consulted before the final manhole designs are completed.

This report provides general information for grounding of the cable system during installation and cable repair. An ICC Working Group is developing guidelines for working on a cable system in close proximity to another energized circuit ("Guideline for Working Procedures on Underground Transmission Circuits with Induced Voltage"). Each utility must establish its own operational procedures for personnel entering an energized manhole (if allowed by the utility) and a grounding procedure for working on or repairing a cable in a manhole.

Based on the previous testing, it can be concluded that the structural designs associated with meeting the H-20 loading and cable pulling requirements are sufficient to meet the structural loads applied during a fault.

Laboratory tests were performed to determine whether steel reinforcing rods or loops surrounding individual cables in a vault results in significant heating of transmission cables. The test results indicated that electrical losses in the closed-loop steel reinforcing rods caused less than 2ºC temperature rise in cables at 750-A cable current and 4ºC temperature rise in cables at 1000-A cable current. No circulating current was measured in the closed rebar loops, and rebar heating was a result of eddy current and hysteresis losses.

7.2 Recommendations for Future Research

Cable supports within vaults are a challenging issue. EPRI will soon release research results that include the EPRI NSPAN software, test results from a test facility being planned in an EPRI laboratory, discussions on associated principles and fundamentals, and guidelines for practical designs.

Grounding is also an important topic. In 2010, EPRI will begin a project on safety in underground transmission construction, installation, operation, and maintenance. Grounding and associated safety issues are the primary topics to be addressed in the project, including fundamental and practical aspects of grounding within and outside vaults and along cable circuits. In response to the survey conducted in this project, several utilities required an internal grounding ring. The safety, electrical, cost, material, or design aspects of this requirement can be studied in the future project.

Manhole design and construction account for one of the major costs in a cable project. EPRI research in underground transmission cable system installation and construction will continue this endeavor to reduce the costs of a cable project, particularly in vault design, construction, and installation.

8
REFERENCE

1. T. Ueno, H. Takagi, *et al.*, "Iron Losses in Cable Supports and Members of Tunnels Adjacent to Large Power Transmission Cables," IEEE Transaction Paper 86 SM 392-5, 1986.

A
SURVEY RESULTS

A.1 Introduction

The answers to the survey questionnaire that was sent to utilities, cable manufacturers, contractors, and manhole fabricators are listed in this appendix. The answers have not been modified from the original response. The name of each survey participant has been removed in the report. At the end of the appendix, a list of survey recipients and respondents is included.

A.2 Utility Questionnaire

Question 1

Does your company have a policy regarding the use of single circuit manholes versus double circuit manholes, when parallel circuits are installed in a common duct bank?

- Yes – 6 participants
- No – 3 participants

If a policy exists, please provide. What are the reasons for your policy?

- For HPFF systems, generally, there is not a requirement for multiple manholes for paralleled circuits. For extruded dielectric cable circuits, we are tending to install one manhole per circuit.
- To reduce employee risk.
- All new feeders shall have individual manholes (no double circuit manholes). This policy was established for safety reasons. Besides failure concerns, our system does not allow both feeders to be out at the same time.
- There is no written policy on this subject but the past practices have been followed.
- We attempt to maintain a minimum of 8-feet between electric transmission circuits due to mutual heating effect (F-factor). In light of this we always install single circuit manholes. We do have a few common HPFF-PTC manholes, but this is not our standard.
- For transmission circuits, all manholes are based on 6 cable design (whether single circuit or double circuit). No maintenance access is allowed inside the manhole unless all 6 cables are de-energized.

- There is no policy in existence, but in case of XLPE cables, we do not put the two circuits in common splicing chambers (manholes). There is no such restriction for the pipe type cables.
- Our present standard since 2001 is to install separate staggered manholes for each circuit. This is for perceived safety of union personnel entering the manhole for any reason. Personnel only enter manholes when the circuit is de-energized.

2 circuits, separate breakers?

- Haven't had this situation, but would likely provide separate manholes.
- Preference is for separate breakers but there are several older configurations using one common breaker.
- We have used double circuit manholes for pipe type cables (two circuits in a common manhole) and single circuit manholes for self contained fluid filled and extruded dielectric cables.
- Yes - we use sectionalizing.
- Have never had the need to address this. Probably would require separate manholes for each circuit.
- For transmission circuits, all manholes are based on 6 cable design (whether single circuit or double circuit). No maintenance access is allowed inside the manhole unless all 6 cables are de-energized.
- Cables are not allowed in a common splicing chamber if the circuits are controlled by separate breakers.
- Separate manholes.

1 circuit, multiple cables per phase?

- Where there are multiple cables per phase, one manhole is provided per circuit, except for 345 kV where isolation capability would be provided between multiple cable sets. Individual manholes would be provided for each set of cables within the same circuit.
- Feeders with two legs are operated to a common bus position in a breaker and a half scheme. The terminations are connected directly to the bus. There are breakers on either side of the tie point.
- We have one self contained fluid filled circuit that has parallel conductors per phase. The cables are installed in separate manholes, but this installation was originally two separate circuits prior to paralleling the cables together to create one circuit.
- Not on HPFF-PTC circuits.
- We would allow two cables per circuit in the same manhole.

- For transmission circuits, all manholes are based on 6 cable design (whether single circuit or double circuit). No maintenance access is allowed inside manhole unless all 6 cables are de-energized.
- Acceptable in one splicing chamber.
- We place the two sets of cables in a common manhole that is 10 ft wide and 22 ft long. Cables are separated by a blast blanket and has 4 access holes.

Question 2

In a double circuit transmission manhole, do you allow your workers in the manhole with one circuit energized?

- Yes – 4 participants
- No – 3 participants

If yes, what measures do you take to protect the workers?

- Blast Blankets – 0 participants
- Grounding – 2 participants
- Other
    - We use contracted labor for all field work. Practices vary somewhat depending on the region and the contractor. All multiple circuit manholes are HPFF, which have a natural barrier via pipe/splice housing.
    - Fire/Flame retardant clothing.
    - Access for a quick visual inspection of extruded dielectric feeders is permitted. Otherwise, the feeder must be taken out of service for any work or extended inspection is needed. Work on double circuit pipe type feeders is allowed.
    - The only situation where this could occur in our service territory is for pipe-type cable circuits.
    - We allow accessing manholes for maintenance and inspections. When a circuit is out for work, we ground the conductors at the station grounds. All HFFP-PTC circuits are protected using I/SPs.

If no, why?

- Too scary. Arc flash requirements.
- Compliance with State Public Utilities Commission General Order regarding restricted work in areas exceeding 25 volts induced voltage. General company safety concerns.
- Safety reasons.

Question 3

Do you allow your utility personnel to enter an energized distribution manhole?

- Yes – 7 participants

If yes, what measures do you take to protect the workers?

- Blast Blankets – 3 participants
- Grounding – 3 participants
- Insulating Mats – 2 participants
- Other
    - FR Clothing.
    - Access is determined by classification of known conditions. Depending upon the seriousness of the condition, feeder outages to install blast blankets and other protective measures are taken.
    - Besides the normal PPE (hard hat, safety glasses, etc.) all workers entering the vault must be wearing fire retardant clothing and body harnesses with attached lanyards and tethers to a manhole rescue device on the surface.
    - It is not required, but crews sometimes install insulating blankets over splices and cables.

Question 4

Does your company have a standard transmission duct bank design and circuit arrangement?

- Yes – 6 participants
- No – 3 participants

Single circuit?

- Yes – 6 participants

Multiple circuit?

- Yes – 6 participants

If so, what do you feel are the benefits of your design?

- Spare ducts for replacement cable and fiber.
- The 2 wide by 4 deep configuration is designed for space compactness.
- We use only HFFP and HPGF-PTC circuits. We space parallel circuits apart to minimize the mutual heating effects. This improves the rating.
- Ability to increase capacity by pulling in additional cables.
- Flexibility (if double-circuit design), consistency (less confusion in field).
- Safety, working space, two accesses centered in middle of vault and cables racked on one side.

Do you include a ground continuity conductor in your design?

- Yes – 6 participants

If yes, where do you place it in the trench?

- Direct buried is installed in trench. Duct system in 2" conduit. Recently in duct design, are considering putting in top corners to reduce EMF.
- In the middle of the 3 x 3 duct bank.
- The GCC is placed in the middle of the duct bank.
- Traditionally it has been at the bottom, but considering placing it above the ducts. We may install two conductors. This could help to reduce EMF.
- Bottom of trench and repositioned every 1/3 distance between manholes.
- Usually at the lower corner in the concrete and transpose as necessary.

Do you have any methods that provide construction cost savings?

- Yes – 4 participants
- No – 4 participants

If so, what methods have you used?

- Various, incentive contracts, etc.
- Fiberglass reinforced epoxy bell and spigot ducts are our standard. The FRE is very light resulting in manpower savings. Standard bends are used in the design and can be custom ordered in a matter of days.
- Competitive bidding for new installations.
- Use local civil contractors and purchase cable system separately that includes installation.

What type of duct connections do you use?

- Bell and Spigot – 8 participants
- Long Couplings – 4 participants
- Glued – 7 participants
- Fused – 2 participants
- Other
  - Bell and Spigot with a gasket.

What type of duct material do you use?

- PVC – 8 participants
- HDPE – 4 participants
- Other
  - Considering using fiberglass duct.
  - Currently investigating fiberglass.
  - Fiberglass Reinforced Epoxy.
  - Fiberglass reinforced epoxy (FRE).
  - Carbon Steel ASTM-523 latest revision. Also Nitronic 33 for risers.
  - Fiberglass pipes for certain bridge attachments.

Question 5

Do you require a minimum length of straight duct prior to entering the manhole?

- Yes – 5 participants
- No – 5 participants

If so, what is the length, and why?

- 10 ft, so as not to damage the cable.
- Company standard requires ten feet of straight duct to preclude the cable from riding on a duct edge during pulling operations.
- We specify at least 25-feet of straight pipe prior to manhole access. This is specified by the Cable Engineer.
- 40 ft. length to establish straight cable length into splice joints.
- We use one PVC length, 20 ft. The matchup is then made with a coupling one length away. During pulling this ensures we don't have any sharp bends out of the manhole and the conduits seats well into the vault bushing.

Question 6

Does your company prefer a pre-cast or cast-in-place manhole installation?

- Pre-cast – 7 participants
- Both – 3 participants

Why?

- Pre-cast
  - Very easy to assemble.
  - Use cast-in-place where a new manhole is required in an existing cable system or for special situations.
  - In general, pre-cast manholes are used for cost and ease of installation reasons. However if a pre-cast manhole can not be used due to external factors then we will use a cast-in-place manhole.
  - Easier.

    - Less time to install, less environmental concerns, more product consistency.
    - Due to traffic constraints it will take longer and harder to do cast-in-place work.
    - Easier to set and lower cost. Quicker installation so street can be reopened.
- Both
    - It depends on the type of cable installation, new or reconductoring.
    - Pre-cast manholes are preferred because of cost savings, short installation times and savings in dimensions and steel (cast-in-place manholes are assumed to have lower strength concrete and therefore require thicker walls and additional steel).
    - Transmission manhole installations are at the discretion of the Contractor. In order to bid competitively, Contractors select the most cost effective manhole installation method available for each individual application.

Do you have any specific requirements for each type of manhole installation?

- Yes – 6 participants
- No – 4 participants

If so, please describe.

- Specific drawings for steel rebar for traffic rating.
- Ground rods at corners, ground ring, stainless steel rack.
- Cast-in-place manholes are used if pre-cast manholes cannot be dropped into a sheeted excavation. Cast-in-place manholes are often custom designed depending upon available subsurface space.
- Our standard transmission manholes are 6' x 20' x 6.5' ID and have two 36-inch frames and covers. They are designed to HS-20 specifications or as per the property owners requirements (RR usually require HS-80). Our Trifurcator Manholes are 6' x 7' x 6.5' single frame and cover.
- Traffic bearing, Single access for 69 kV and 138 kV / Double access for 230 kV, various concrete and rebar specs. Watertight. No rebar loops around individual phases.
- Like to keep three feet of cover over the vault. On the chimneys, we require the last two spacers be each 3" thick to facilitate street resurfacing.

What techniques and construction equipment are utilized?

- Boom Truck or Crane.
- Multiple part pre-cast manholes, floor walls and separate roof slab, are generally used. In special low clearance sites, three part manholes requiring smaller cranes have been used.
- Open excavation with standard equipment and the manhole (pre-cast) is set using a crane.
- Excavation, framing and pouring either new or around an existing pipe.
- Nothing special.
- Standard.
- Large track hoe and 100 ton crane to set each of two vault sections.

Question 7

What are the waterproofing features employed for manhole installation?

- Sealer is used between manhole sections.
- Bituminous waterproofer.
- Sealing the outside with a waterproof paint and injecting water ceiling compounds.
- Asphalt is used to bond multiple layers of fiberglass matting and seal the seam between frames and roof and between roof and walls.
- Pre-cast manholes are filled with a field applied asphalt (or equivalent) based product between the two halves (construction joint).
- Our manholes are poured in place concrete or two piece pre-fab. Pre-fab manholes are installed using the key method for the two halves and the application of mastic to seal the seams. We are not concerned with water in our transmission manholes. We do like to see the pipe either covered totally or not at all with water for CP reasons.
- Grout around PVC.
- Exterior surface coating. Sealing compound between pre-cast sections. Interior coated with Thoroseal.
- Bitumastic coating and proprietor sealers are used to waterproof the splicing chambers.
- Conceal in the lap joint and chimney rings. Exterior and risers coated with bituminous coating for damp proofing.

What method is used to seal the area where the ducts are brought in?

- Ducts come into pre-existing duct terminators installed in manhole nose.
- Grout and bituminous waterproofer. Sometimes a cast in place coupling/bell-end.
- Cast-in-place duct terminator.
- Ducts are grouted.
- In general, conduits are sealed into the manhole wall with concrete or hydraulic cement. Pipe type cables utilize a "link seal."
- The pipes enter the manhole though Linkseal sleeves and are centered and fixed in place using Linkseals.
- Grout.
- Bitumastic coating and proprietor sealers are used to waterproof the splicing chambers.
- Duct terminator from Bowco Industries. The insert is in the vault wall and allow conduit to be glued to insert.

Do you feel water ingress is an issue?

- Yes – 4 participants
- No – 6 participants

Please comment.

- N - We have floor drains in places where water will migrate. Some manholes do fill up with water anyway.
- Y - Also provide sump pits. Generally not a permanent pump.
- Y - Apparent leakage from incoming ducts.
- Y - Affects cable and splice designs and life expectancy. Maintenance is impeded in disposal of water for access (i.e., storm water discharge concerns, contaminated water concerns).
- N - The concern is making sure the sheath link boxes are water proof. We presently don't have any vaults that are under water but do get one to two feet above the floor.

Question 8

Does your company have a standard manhole size for 115/138 kV cables?

- Yes – 5 participants
- No – 5 participants

If so, what is it?

- 10 ft x 22 ft.
- Internal dimensions: 19'-6" long by 6'-4" wide by 6'-6" high.
- There is no standard manhole size, but recent projects have used a manhole with dimensions of 7' x 20'6" x 6'8" for solid dielectric cables.
- Our manhole standard is 6' wide x 20' long x 6.5' high and uses two 36" frames and covers.
- No standard, but 10' x 20' or 8' x 18' is probably what we would use. 8' x 18' is what we last installed, for a single, three-conductor circuit.
- 8' x 20' x 9.5'.
- 21' ODL x 7' ODW x 8' ODH. 20' IDL x 6' IDW x 7' IDH.

What factors determine that size?

- Provisions for 2 sets of cable and/or multiple circuits are large manholes.
- Cable size, splicing methods.
- These dimensions are historically based upon our high pressure pipe type manholes and the joints and casings used.
- The size was chosen based on a consultant's recommendation after reviewing several recent (2001) installations.
- Splicing requirements.
- 8' x 18' is a pre-cast that is readily available.
- Safe working area for (6) splices and associated racking.
- As recommended by the cable vendor (XLPE Cables).
- Working space, space to install/rack splices.

Question 9

Do your splicing manholes utilize straight-through or S-bend splicing methods (or both)?

- Straight-through – 6 participants
- Both – 4 participants

Why?

- Straight-through
  - No need to bend the cables.
  - Reduces overall size of manhole.
  - Preferred to minimize cable movement.
  - It is easier to run the pipe through the manholes and cut out the section not needed, then weld on the reducers. This insures we have a good pipe alignment through the manhole.
  - Clamping system of cable at vault walls and clamping system for splices keep cable from moving in vault, I think.
- Both
  - Design is based upon cable system vendor requirements.
  - Historically we have used both a single offset and a double offset on our self contained fluid filled cables. Our solid dielectric cable installations are set up for straight-through splicing.
  - Manufacturer dependent. All 69 kV and 138 kV are straight-through design, and 230 kV are all S-bend.
  - Based on the cable manufacturer's recommendations.

Question 10

What method do you use for restraining the cable expansion and contraction while energized?

- At manholes:
  - We typically do not restrain distribution cables.
  - Cable clamps for solid dielectric.
  - Use of clamps.
  - The clamping design is determined by the cable system vendor and includes racks, stanchions and clamps.

  - Cable clamps.
  - Double sets of clamps on each side of splice.
  - Standard anchor/cleat system as recommended by the cable manufacturer.
  - Clamping system of cable at vault walls and clamping system for splices keep cable from moving in vault.
- At terminations:
  - Terminations are held in place by cable brackets on termination mounting bracket.
  - Cable clamps for solid dielectric.
  - Use of clamps.
  - Various designs have been supplied depending upon the length of unsupported cable. Typically an additional cross member is added to support clamps.
  - Cable clamps located approximately every three feet along the exposed cable.
  - The terminator design accounts for anchoring at the Semi-Stop by the termination of the Skid Wires. Also, the ferrule is pressed on the conductor and then held in place by the top or cap nut and its bolts.
  - Clamps.
  - Standard anchor/cleat system as recommended by the cable manufacturer.
  - None specifically as most of the terminations are level for 100' or more. We have one location where we have installed two sets of Sagem clamps in series to hold the cables at the top of the hill.

Question 11

Do you have a special grounding requirement for your manholes?

- Yes – 8 participants
- No – 2 participants

If yes, what is the requirement?

- 4/0 AWG copper bond wire that runs through each manhole and the conduit system.
- Grounding loop inside manhole with driven grounding rod adjacent to manhole, all tied together with the continuity conductor, if appropriate. HPFF pipe is normally isolated at manholes. Solid DE cables are cross or single point bonded depending on cable length.
- The ground continuity conductor is brought into the manhole and tied to station ground at either end. Connections are made via a link box and with pressed connectors.

- The internal rebar is all grounded.
- 10 ohm.
- Provide groundings using proper sized grounding cable, grounding rods and grounding lugs for connection to the cable sheath or cable bonding system through the link boxes.
- We install two 8' copper clad grounds, one at each corner, and run the ground in the vault from the conduit system in a loop. We do not tie the rebar in the vault to the ground system.

Question 12

Do you have a special grounding requirement for your termination structures?

- Yes – 4 participants
- No – 4 participants

If yes, what is the requirement?

- For solid dielectric, we use a link box or sheath voltage limiter (SVL), depending on the cable length and related type of cable grounding. For HPFF, we use solid state Isolator/Surge Protector (ISP).
- Link boxes, structural ground.
- Terminal ground leads are brought into a link box and from there to station ground.
- Grounding of the terminators at the stations is though as I/SP attached to the riser pipe.
- 10 ohm.
- A termination structure at a substation is tied to the substation ground grid. At a riser pole location, we install two buried 4/0 copper ground rings around the riser pole with ground rods and tie the express ground down the pole into the ground system at two locations.

Question 13

Does your company have a standard practice for manhole drainage and sump locations?

- Yes – 6 participants
- No – 2 participants

If so, what is it?

- Drain crock in manholes that can be pumped out.
- Provide sump pits in the manhole floor, but generally not a permanent pump.
- Because of environmental concerns, including foreign deposits, our manholes are sealed. We used to sump locations for the event that the manhole is not level.
- Sump locations are located directly underneath one of the manhole openings. Manhole floors have a 1 inch pitch so all sides to drain into the sump location.
- Every manhole is constructed with a sump hole located near the end wall. Manhole floors are sloped toward the sump hole.
- We use sump pump arrangement in order to drain the water accumulated inside the splicing chambers.
- We provide a sealed sump point at one corner of the vault. The vault floor has a 1% slope.

Question 14

Have you applied or are you aware of any innovative installation techniques during the last few years that result in manhole or duct bank installation cost savings, and quality and safety improvement? Please describe and provide vendor's name if available.

- TT Technologies - Trenchless installation and/or duct expansion. www.tttechnologies.com
- Sealing manholes for water leaks. Duct bank leakage is still a problem.
- We have not been involved. However, our primary pre-cast supplier, A.C. Miller Concrete Products, has been involved.
- We have removed the 20,000# pulling irons from the vault end walls. These pulling irons are rigged at numerous side angles and have failed (sheared) at 7-9K#. We use a 6" diameter A500 Grade B galvanized pipe in the bottom of each vault.

A.3 Cable Manufacturer Questionnaire

Question 1

Does your company have a policy regarding the use of single circuit manholes versus double circuit manholes, when parallel circuits are installed in a common duct bank?

- Yes – 2 participants
- No – 3 participants

If a policy exists, please provide it. What are the reasons for your policy?

- If engineering is done by us, we recommend separation walls or installation on opposite sides of the joint bays. Reason is to protect the second circuit in case of a failure on the first circuit.
- We do not have a written policy. We take exception to all conditions requiring work in a manhole alongside another energized circuit.

Question 2

In a double circuit transmission manhole, do you allow your workers in the manhole with one circuit energized?

- Yes – 1 participants
- No – 3 participants

If yes, what measures do you take to protect the workers?

- Blast Blankets – 1 participants
- Grounding – 0 participants
- Insulating Mats – 0 participant
- Other
  - Cable pulling: Energized circuit must be shut down or protected with wall panels.
  - Jointing: If energized circuit is less than 1/2 years in service, circuit has to be shut down.

If no, why?

- Safety concerns. If the safety concerns can be properly mitigated, then we would be willing to change our policy.
- For safety reasons.
- We do not have a written policy. We take exception to all conditions requiring work in a manhole alongside another energized circuit. We are aware there are certain things that can be done to protect against induced currents but physical evidence viewed after a splice failure event has convinced us there is no safe way to work in the presence of an energized splice.
- Work at site is out of our scope. If our engineer is requested to work in a manhole as a technical advisor, we allow him in a manhole with one circuit energized. Suitable protection measure shall be taken by the client.

Question 3

Do you utilize pulling irons/eyes for cable pulling?

- Yes – 4 participants
- No – 1 participant

If so, what are the preferred locations of the pulling hardware in the manhole?

- Back wall and/or the floor of the manhole.
- Cable winch outside the manhole.
- On end walls and sidewalls approx. 36" from the corners and approx. 9" above the floor. On the floor at the 4 corners approx. 36" from the end wall and 9" from the sidewall. We do not utilize pulling irons on the manhole roof or above the cables on the end wall.

What are the strength requirements?

- Depends on cross-section: greater than 60 N/mm^2 for Cu, greater than 40 N/mm^2 for Al.
- Up to 25,000 pounds.
- > 5 kg/mm^2.
- Strength requirements vary according to size and material of the conductor and the expected setup for pulling. Because of the variables, each case should be evaluated on its own requirements.

Question 4

Does your company have a standard transmission duct bank design and circuit arrangement?

- No – 5 participants

Do you include a ground continuity conductor in your design?

- Yes – 3 participants

If yes, where do you place it in the trench?

- For single bonded systems only. Position between outer phase L1 and middle phase L2 for half the length and between middle phase L2 and outer phase L3 for the other half length. For circuit in trefoil as near as possible to power cable.
- Preferably close to the middle of the three phases of the circuit.
- Ground continuity conductors are not required if metal sheaths of the cables are cross-bonded. Otherwise we would recommend placing it between the HV cables.
- Most of the time a ground continuity conductor is included in the duct bank design. It can either be placed in the bottom of the trench near a corner, on top of the duct spacers or laid on top of the concrete or FTB after it is poured.

Do you have any methods that provide construction cost savings?

- Yes – 1 participants
- No – 2 participants

If so, what methods have you used?

- Direct burying with trenching equipment

What type of duct connections do you use?

- Bell and Spigot – 2 participants
- Long Couplings – 2 participants
- Glued – 3 participants
- Fused – 1 participants
- Other
    - We like to use a slip coupling at the manhole to duct bank interface to improve constructability. This is about the only place we would recommend using couplings.

What type of duct material do you recommend?

- PVC – 3 participants
- HDPE – 2 participants
- Other
    - Fusible PVC

Question 5

Do you require a minimum length of straight duct prior to entering the manhole?

- Yes – 1 participants
- No – 3 participants

If so, what is the length, and why?

- Approximately 4-6 m. Small sections of cable have to be pushed back in conduit. Joint arrangement has to be perfectly in line.
- Although we don't require it, we recommend it to establish an alignment orientation parallel with the side wall of the manhole. Minimum length should be 36".

Question 6

Does your company prefer a pre-cast or cast-in-place manhole installation?

- Pre-cast – 1 participants
- Both – 2 participants

Why?

- Pre-cast
    - Believe pre-cast is the simplest solution. Construction takes place in a controlled environment. Installation is quick, eliminating the need for an excavation that is open for weeks before backfill operations are completed.

Do you have any specific requirements for each type of installation?

- Yes – 2 participants
- No – 1 participants

If so, please describe.

- Anchor clamps on both sides of joint.
- All joints watertight. Design roof and walls for H20 loading. Design walls to resist pulling iron forces. Set manhole in the excavation with end walls perpendicular for entering/leaving ducts. Set manhole on a bed of crushed stone. Provide a sump with cover.

Question 7

What are the waterproofing features employed for manhole installation?

- Waterproofing measures outside the concrete walls.
- This is the responsibility of civil engineering.
- Location of manhole should be considered from a drainage point of view (don't locate in depressions, ditches, etc.), slope ground away from manhole entry to enhance cleanliness. Provide a joint sealer such as CETCO RX-101 in the manhole sections and the riser ring sections.

What method is used to seal the area where the ducts are brought in?

- Conduits seals or mastic compound.
- This is generally done by the pre-cast manufacturer and sometimes not very well. A waterstop product such as CETCO RX-102 might be applicable. Ducts with the CETCO or other waterstop product should be cast into the wall. We do not like to work with knockouts.

Do you feel water ingress is an issue?

- Yes – 3 participants
- No – 1 participants

Please comment.

- Y - Temporary flooding no issue but permanent water level above joints.
- Y - We generally supply land cables. Submarine is another issue. Earthing boxes may not be submersed continuously.
- Y - Ground rods should be external to the manhole to eliminate another water entry source. Location of manhole should be considered from a drainage point of view, slope ground away from manhole entry. If ground rods are inside the manhole, the annular space between the hole in the floor and the ground rod needs to be sealed.

Question 8

Are there any features that could be added to the manhole design that would save on pulling costs?

- Yes – 3 participants

If so, what are the features?

- Anchor plates on both sides of manhole.
- Maybe, but we don't know what those might be.
- A separate entry facility of the pulling rope/cable and outlet of the rope.
- Ground rods should be external to the manhole to eliminate another water entry source. Also, believe that the duct bank contractor can install the ground rods.

Question 9

Do your splicing manholes utilize straight-through or S-bend splicing methods (or both)?

- Straight-through – 1 participants
- S-bend – 2 participants
- Both – 2 participants

Why?

- Straight-through
  - For the use of standard supporting materials and techniques.
- S-bend
  - To allow limited expansion of the cable into the manhole to reduce mechanical stress on the cable. Splicing of conductors and jointing work result to be easier.
- Both
  - Depending on dimensions of joint bay and arrangement.

Question 10

What method do you use for restraining the cable expansion and contraction while energized?

- At manholes:
  - Anchor clamps on both sides of joint
  - Clamps in two locations prior to and after the splice
  - Double clamping either side at entrance to manhole.
  - We clamp the cable rigidly at the entering/leaving end walls.
  - Off-set arrangement of cables is proposed.
- At terminations:
  - Clamp below termination.
  - Clamping in at least three locations for substation termination structures. More for riser pole termination depending on the height of the structure.
  - Repeated clamping below terminations.
  - We require 2 rigid clamps located approximately 24" below the termination mounting plate. Below these clamps, other clamps should be spaced at 60" center-to-center.
  - Free R-Bending is proposed.

Question 11

Does your company have a standard practice for manhole drainage and sump locations?

- Yes – 2 participants
- No – 2 participants

If so, what is it?

- Sump should be 12" x 12" x 4" deep and should be located in center of manhole floor. The floor should be sloped to drain to the sump. The manhole should be set level.

Question 12

Have you applied or are you aware of any innovative installation techniques during the last few years that result in manhole or duct bank installation cost savings, and quality and safety improvement? Please describe and provide vendor's name if available.

- Some overall comments: Recommend 6" duct for cable diameter <= 4.4" and 8" duct for all other cable diameters to minimize pulling tensions and sidewall pressures. Curve radii should be as large as practical (generally >60') to minimize cable damage and increase pulling speeds and to be able to deflect the duct material, thus eliminating use of offsets to form the curves. When offsets are necessary, use 5 degrees whenever possible and nothing greater than 11 degrees. Do not stack offsets back-to-back, use a minimum 5' straight section between 5 degree offsets and 10' straight section between 11 degree offsets. It is possible to form a 90 degree curve with a 63' radius using 5 degree offsets and 5' straight lengths between the offsets. An exception to the curve rule is at riser poles and substation structures. Use factory made 90 degree elbows with 72" or 96" radius. This elbow should be encased in concrete to anchor and stabilize the elbow and to reduce burn-through.

A.4 Contractor Questionnaire

Question 1

Does your company have a policy regarding the use of single circuit manholes versus double circuit manholes, when parallel circuits are installed in a common duct bank?

- Yes – 3 participants
- No – 3 participants

If a policy exists, please provide it. What are the reasons for your policy?

- No common manhole will be allowed for two circuits. One manhole per circuit (3 or 6 cables) and two manholes for two circuits. We do allow six cables per manhole, if it includes 2 cables per phase.
- Each circuit is in a separate manhole. Multiple cables per phase circuits are allowed in a simple manhole.
- Most clients specify independent manholes.
- Pipe type cable, two joints may be installed in a single manhole. For XLPE circuits, separate manholes are required for separate circuits.

Question 2

In a double circuit transmission manhole, do you allow your workers in the manhole with one circuit energized?

- Yes – 2 participants
- No – 2 participants

If yes, what measures do you take to protect the worker?

- Blast Blankets – 0 participants
- Grounding – 1 participants
- Insulating Mats – 1 participant
- Other
  - Check temperature and monitor on splices if exposed.

If no, why?

- Safety concerns, especially during fault situation while workers are working in the manhole.

Question 3

Do you utilize pulling irons/eyes for cable pulling?

- Yes – 6 participants

If so, what are the preferred locations of the pulling hardware in the manhole?

- Floors and the end walls.
- End wall near ducts and in the floor under the manhole chimney.
- Per engineers design or preference.
- Walls on opposite end of pull.
- Depends on position of chimney and duct entrances. After rigging try to maintain angle from duct to winch < 3°.
- Roof and floor opposite the conduit entrances.

What are the strength requirements?

- Maximum pulling tension x safety factor of 2.
- 30-60,000 lbs.
- 10,000 lbs. minimum.
- Depends on cable construction. Should be 50% greater than max allowable tension; should match requirement for cable winch.
- 40,000 minimum.

Question 4

Does your company have a standard transmission duct bank design and circuit arrangement?

- No – 6 participants

Single circuit?

- No – 3 participants

Multiple circuit?

- No – 3 participants

If so, what do you feel are the benefits of your design?

- Spacing and burial depth are subject to local soil conditions.

Do you include a ground continuity conductor in your design?

- Yes – 4 participants
- No – 1 participant

If yes, where do you place it in the trench?

- It varies based on the project/situation. The preferred location is an individual 2" conduit.
- Depends upon the circuit but typically above the cable ducts.
- Depends on conduit spacer used.

- In conduit in the duct bank. It is permissible to install in the bottom of the duct bank if no conduit is available.
- Bottom of trench and repositioned every 1/3 distance between manholes.
- Usually at the lower corner in the concrete and transpose as necessary.

Do you have any methods that provide construction cost savings?

- Yes – 4 participants

If so, what methods have you used?

- Optimized duct bank design, and cable system design, balancing the cable cost vs. civil duct bank cost.
- Flow fill instead of compacted backfill, pre-cast manholes, HDD instead of HOBAS PIPE for short bores, worked with municipalities to save on restoration costs.
- Installation practices and methods.
- Modifying trench and duct spacing depending on soil thermal properties.

What type of duct connections do you use?

- Bell and Spigot – 6 participants
- Long Couplings – 4 participants
- Glued – 5 participants
- Fused – 5 participants
- Other
  - PVC x Steel / PVC x HDPE
  - HDPE x Steel / Steel

What type of duct material do you use?

- PVC – 8 participants
- HDPE – 5 participants
- Other
  - Fiberglass reinforced epoxy (FRE)
  - Steel
  - Some fiberglass

Question 5

Do you require a minimum length of straight duct prior to entering the manhole?

- Yes – 4 participants
- No – 3 participants

If so, what is the length, and why?

- A minimum of 10 to 20 feet, depends on the situation.
- Approximately 10' to ensure the cable is straight entering a joint.
- 20 to 40 feet depending on cable and depth of conduit installation.
- Would be best if approximately 20' straight to minimize roll of cable entering MH for TMB reduction.
- Most of our customers require 10' entering and exiting each manhole - flat + level.

Question 6

Does your company prefer a pre-cast or cast-in-place manhole installation?

- Pre-cast – 5 participants
- Both – 4 participants

Why?

- Pre-cast
    - Less cost. More time efficient to install. Cast-in-place only used where pre-cast cannot be installed, i.e., interfering utilities.
    - Easier to install.
    - Minimize construction time.
- Both
    - We have no preference one way or the other. The driver is the cost. It is cheaper for pre-case in US. However, it is cheaper for cast-in-place type manhole in some countries. We used both in previous jobs.
    - Location due to overhead lines, location due to traffic control.
    - MH depends on location. Whether should be built to match drawings and be watertight. No unsealed penetrations.
    - Depending on existing utilities.

Do you have any specific requirements for each type of installation?

- Yes – 4 participants
- No – 3 participants

If so, please describe.

- We have a detailed installation specification for each type of installation, and cannot provide for this survey purpose.
- Differing site conditions for shoring and depth.
- Cart-in-place where pre-cast is not feasible.
- Concrete strength suitable for roadway traffic.

What techniques and construction equipment are utilized?

- We have a detailed installation specification for each type of installation, and cannot provide for this survey purpose.
- Typically excavator with shoring box.
- Cranes/different shoring applications, excavation methods.

Question 7

What are the waterproofing features employed for manhole installation?

- Waterproof sealant is required at manhole joint and manhole ring joint locations.
- Waterproof coating is added. Joints for pre-cast vaults have gaskets.
- Water stops/waterproofing outside and pre-cast joints.

What method is used to seal the area where the ducts are brought in?

- Waterproof sealant.
- End bell is cast in the end wall.
- Terminations/2-link seal.
- Grouting.

Do you feel water ingress is an issue?

- Yes – 2 participants
- No – 5 participants

Please comment.

- N - Cable system needs to be designed watertight.
- N - Most mandates will leak eventually due to cracking or pre-cast joints / manhole cover and necks.
- Y - Causes significant problems and costs during construction.

Question 8

Are there any features that could be added to the manhole design that would save on pulling costs?

- Yes – 2 participants
- No – 2 participants

If so, what are the features?

- It varies. Our manhole design will be optimized for each project, based on local situation.
- Make sure if possible for two entrances.
- Properly arranging irons and chimney and duct to reduce rigging. Maybe feed-in chute could be employed to optimize.

Question 9

Do your splicing manholes utilize straight-through or S-bend splicing methods (or both)?

- Straight-through – 3 participants
- Both – 3 participants

Why?

- Straight-through
  - S-bends allow an indeterminate amount of cable movement and bending and can over bend cable sheath. On slopes, cable can accumulate at S-bend and restrict expansion accommodation.
  - Simplifies installation.

- Both
    - Either way works, as long as the thermal mechanical bend forces have been considered and no forces are applied to joint and termination.
    - Typically straight-through but have used S-bend if it is cable vendor's standard design.
    - Manufacturer's specs.

Question 10

What method do you use for restraining the cable expansion and contraction while energized?

- At manholes:
    - Straight-through clamping and/or S-bend.
    - Clamps to vault wall.
    - Structured steel supports and spring loaded clamps.
    - Clamps on cables on each side of the joint.
- At terminations:
    - Straight-through clamping and/or S-bend.
    - Clamps to termination structure.
    - Clamps.
    - Clamp at the riser base and clamp below termination.
    - Cable clamps located approximately every three feet along the exposed cable.
    - The terminator design accounts for anchoring at the Semi-Stop by the termination of the Skid Wires. Also, the ferrule is pressed on the conductor and then held in place by the top or cap nut and its bolts.
    - Clamps.
    - Standard anchor/cleat system as recommended by the cable manufacturer.
    - None specifically as most of the terminations are level for 100' or more. We have one location where we have installed two sets of Sagem clamps in series to hold the cables at the top of the hill.

Question 11

Does your company have a standard practice for manhole drainage and sump locations?

- Yes – 3 participants
- No – 3 participants

If so, what is it?

- Sloped floor to one corner under the manhole chimney.
- Install as close as possible to man way on low side of surface drainage.
- Corner of manhole, normally sloped to the lowest point.

Question 12

Have you applied or are you aware of any innovative installation techniques during the last few years that result in manhole or duct bank installation cost savings, and quality and safety improvement? Please describe and provide vendor's name if available.

- Controlled density fill is commonly used for backfill around manholes and above duct bank. Although it is more expensive it ensures compaction.
- Spacer assemblies.
- Yes. We routinely work with our customers to optimize MH for installation, operation, and maintenance.

A.5 Manhole Fabricator Questionnaire

Question 1

For your transmission manholes, what are the design limitations on end wall strengths?

- As required per job. Wall sizes and reinforcing are determined by design criteria:
    - H2O / HS25 / E80 / 100,000 lb wheel load, etc.
    - Earth cover
    - Water table
    - Soil weight
    - Utility standards: PSE&G, PECO, Con Edison, Delmarva, Verizon, BG&E, PP&L, Dominion, Atlantic Electric, etc.

- It is more traditional for the design firm to tell us what they need and we will make our structure to accommodate the design. We build standard size structures from 2' x 2' to 16' x 30' and configure them to accommodate the design requirements. We often see equivalent fluid pressures from 35 pcf to 62.4 pcf and use M-20 and M-25 loadings. Buoyancy is often an issue as well.

Question 2

Do you cast pulling irons/eyes in the manhole for cable pulling?

- Yes – 2 participants

If yes, what are the pulling strength limitations?

- As required. Normally 12,000 PSI - to Con Edison 50,000#.
- Varies. 10,000 lbs.-20,000 lbs. but you must know loading. Also now using a restrained pipe system which is good for 25000 lbs any direction. There are many things available. Need to know what you need. These values have the required safety factor.

Question 3

Does your company have any manhole fabrication methods that provide cost savings?

- Yes – 2 participants

If so, what are the methods?

- IPC bases up to 7'-0" HR w/ flat tops.
- Adjustable forming.
- Re-design from original field cast drawings.
- But we need to know what you are looking for as far as size and layout.

Question 4

Does your company employ waterproofing features to the manhole for installation?

- Yes – 2 participants

If so, what are the features?

- Steel faucets and exterior coatings as specified. (C4SP - Coopers 760 Bitumastic - 775 2 coat epoxy, etc.).
- Low water to cement ratios, wet cast products. Have used Xypex. Have used many Bituminous coatings. Have provided Coaltar Epoxy coatings.

Do you feel water ingress is an issue? Please comment.

- Y - Sewer and water
- N - Elect/tele/comm - frame and covers are not watertight and water enters through ducts.
- Y - If manhole is watertight you will normally have moisture from condensation in conduit and conduit infiltration as well.

Question 5

Are there any aspects of a typical manhole design that could be modified to save on manufacturing costs?

- Yes – 1 participant

If so, what are the aspects?

- Higher strength concrete and additives to reduce wall sizes along with good engineering

Question 6

Does your company have a standard practice for manhole drainage and sump locations?

- Yes – 1 participant
- No – 1 participant

If so, what is it?

- ACM standard - 12" dia x 4" deep ctr line. However we build as per approved design drawings and specs - through sumps, sump boxes, steel and plastic lids, etc.
- Sumps below access with a grate which can be hooked and pulled from the access openings are most prevalent.

Question 7

Have you applied or are you aware of any innovative installation techniques during the last few years that result in manhole or duct bank installation cost savings, and quality and safety improvement? Please describe and provide vendor's name if available.

- Many - most of them done by ourselves: special forming, joints, inbeds, etc. Would be happy to discuss.
- Not directly - we work very hard to provide superior coordination to make it all go well.

A.6 List of Survey Participants

Utilities

Participants	Responded	Participants	Responded
AEP		National Grid	Y
Alabama Power		New York Power Authority	
Ameren	Y	NSTAR	
American Transmission Company	Y	Progress Energy	
Arizona Public Service		Public Service Electric & Gas	Y
Baltimore Gas & Electric	Y	Oncor	
Consolidated Edison	Y	PEPCO	
Commonwealth Edison		Northeast Utilities	
Dominion		Puget Sound Energy	Y
E.ON U.S. LLC		Sacramento Municipal Utility District	
EPCOR		San Diego Gas and Electric	Y
Florida Power & Light		South Caroline Electric & Gas	
ITC		United Illuminating	Y
JEA		Xcel	Y

Contractors

Participants	Responded	Participants	Responded
ARB Underground		Henkels & McCoy, Inc.	
Black & Veatch	Y	Larrett, Inc	Y
Bond Brothers	Y	Lawrence Lynch Corp	
Burns and McDonnell	Y	New River Electrical Corporation	
Cianbro		Power Delivery Consultants	Y
ECI		Prysmian	Y
EHV Power		Sargent & Lundy	Y
Gabes Construction Company	Y	UTEC Constructors Corporation	
Ground Hog Utilities		Underground Constructors	Y
InterCon		W.A. Chester	
Hawkeye		Wilson	

Manufacturers

Participants	Responded	Participants	Responded
Brugg Cables	Y	Prysmian Power Cables	
Fujikura America, Inc.		Southwire	Y
General Cable	Y	Sumotomo	Y
Nexans	Y	Taihan Electric	

Manhole Vendors

Participants	Responded	Participants	Responded
AC Miller	Y	Pre-Cast Specialties, Inc.	
Oldcastle Pre-cast		Vaughn Concrete Products, Inc	Y
Rotondo Pre-cast			

B
SINGLE-CIRCUIT MANHOLE DESIGN DRAWINGS

The following drawings provide a typical manhole design for two types of single-circuit manhole designs.

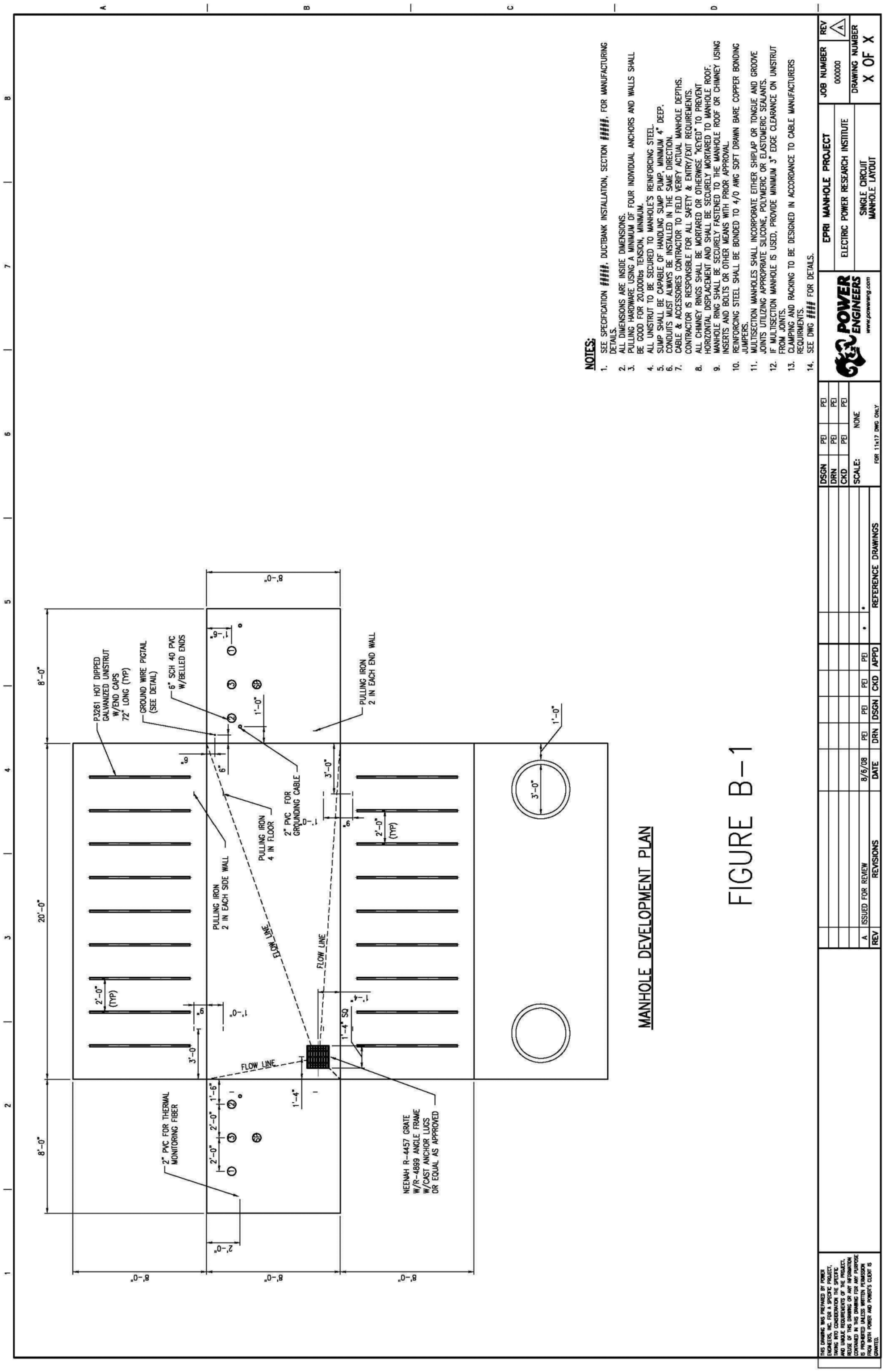


Figure B-1
Typical Single-Circuit Manhole Layout

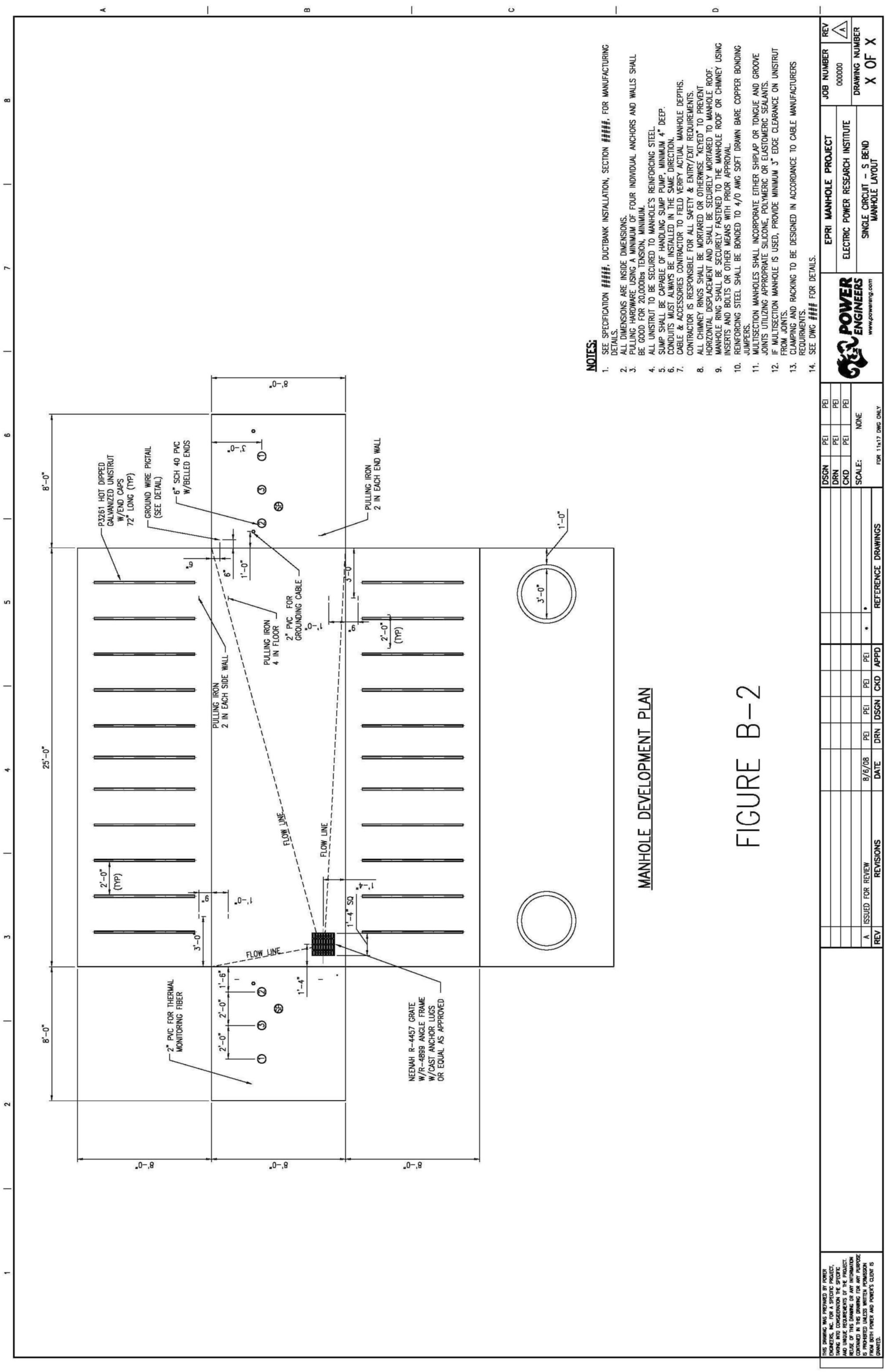


Figure B-2
Typical Single-Circuit S-Bend Manhole Layout

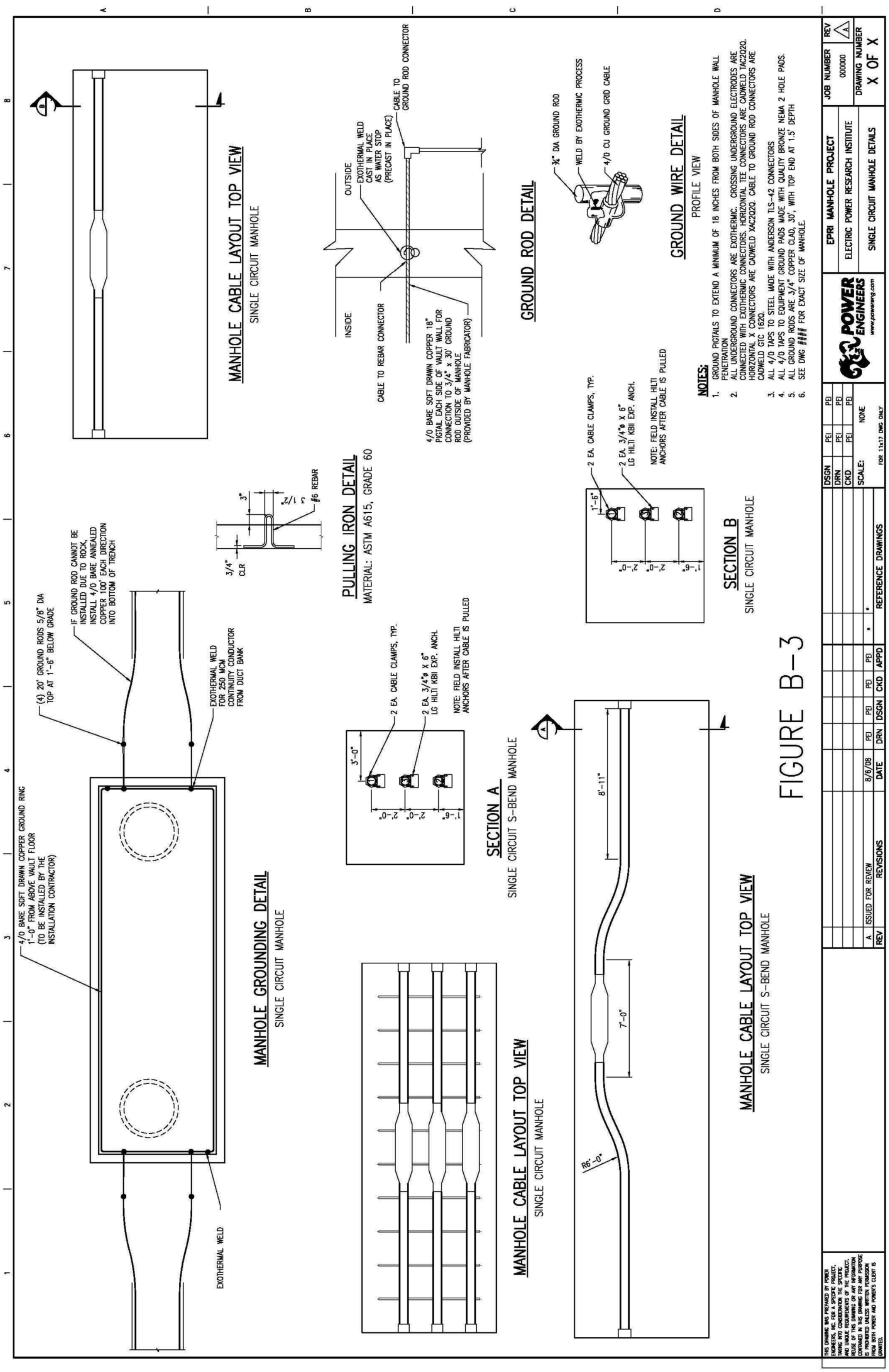


Figure B-3
Typical Manhole Details

C
DOUBLE-CIRCUIT MANHOLE DESIGN DRAWINGS

The following drawings provide a typical manhole design for two types of double-circuit manhole designs.

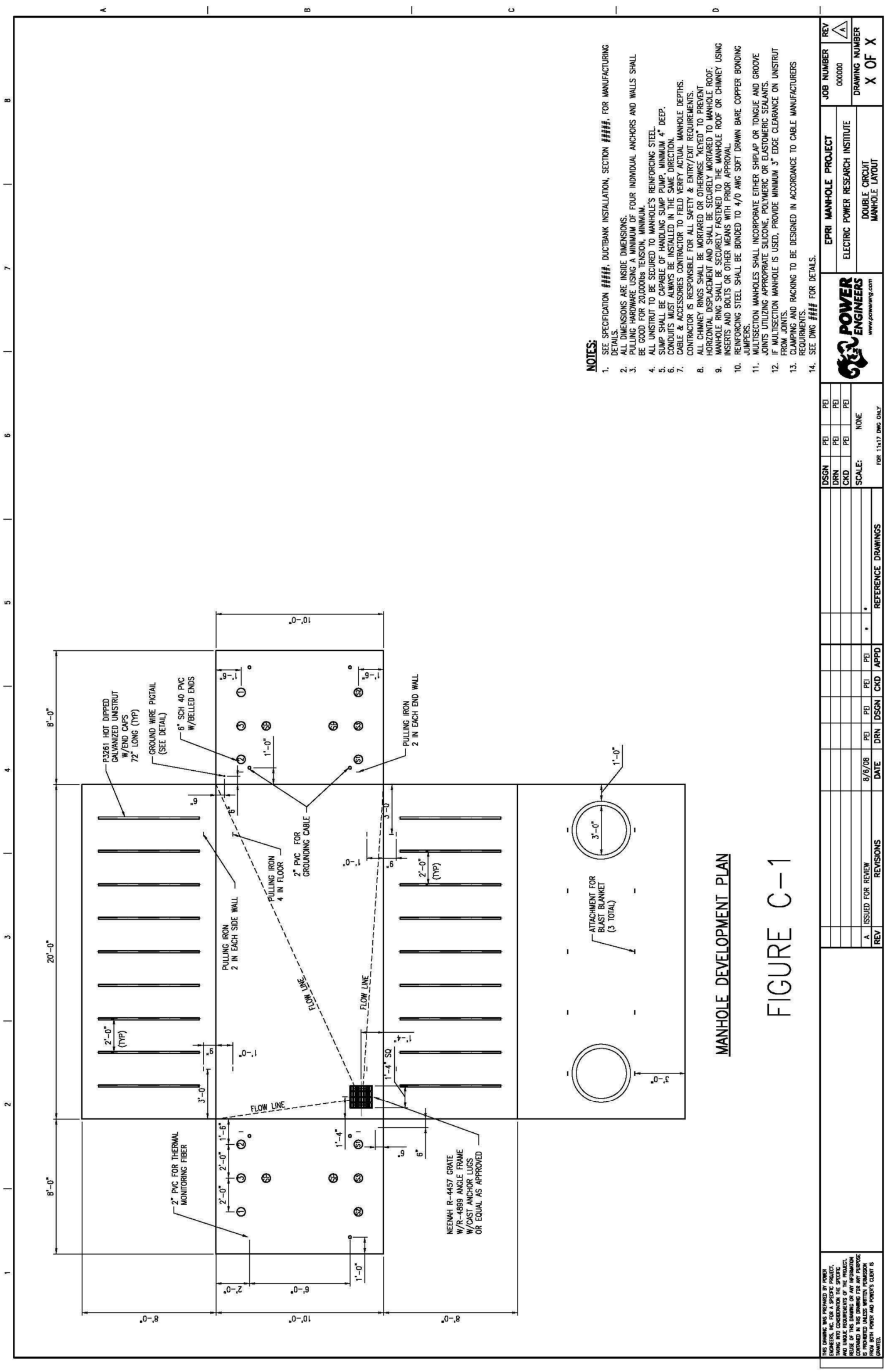


Figure C-1
Typical Double-Circuit Manhole Layout

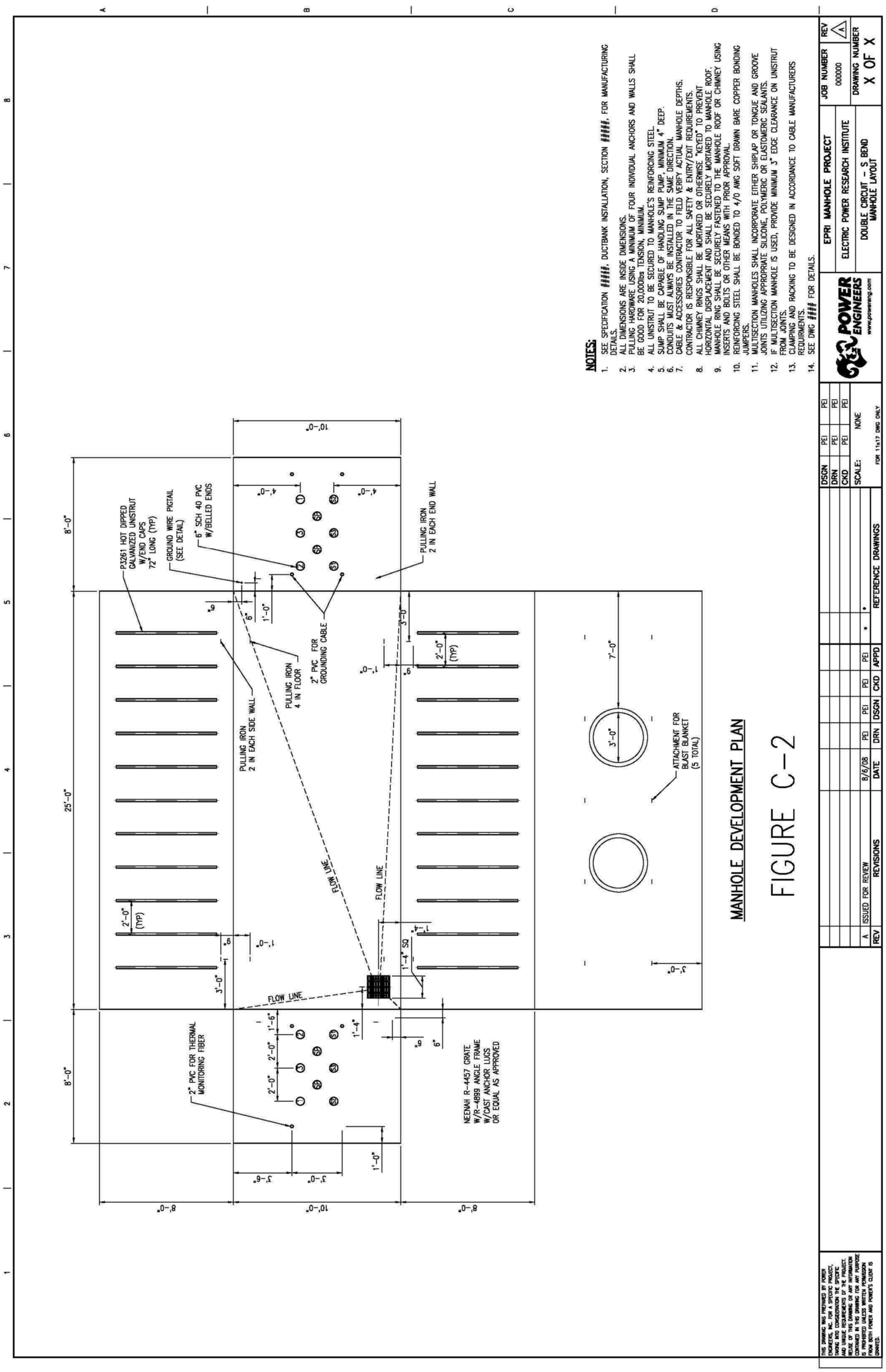


Figure C-2
Typical Double-Circuit S-Bend Manhole Layout

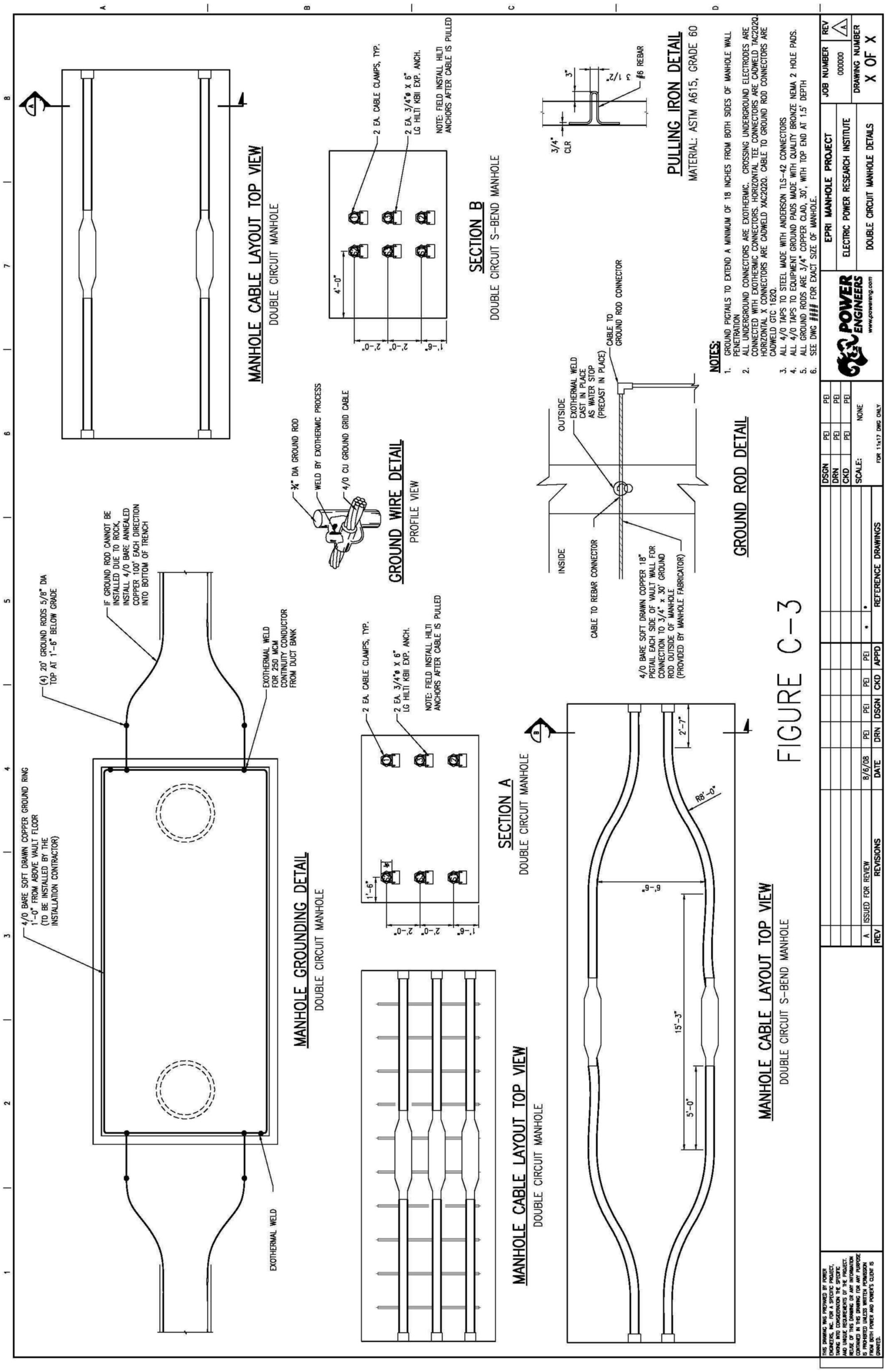


Figure C-3
Typical Manhole Details

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