Appendix D1

Underground Route Study – Castle Rock, Washougal, and Camas areas

Underground Transmission Phase II

in support of the I-5 Project

I-5 Corridor Reinforcement Project

Bonneville Power Administration
133225

October 10, 2014

Prepared by
HDR

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Contents

Tables

Figures

Appendixes

1.0 Introduction

1.1 Project Description

The Bonneville Power Administration (BPA) is proposing to build a 500-kilovolt (kV) lattice-steel-tower transmission line that would run from a new 500-kV substation near Castle Rock, Washington to a new 500-kV substation near Troutdale, Oregon. The proposed transmission line and substations would increase the electrical capacity and transfer capability of BPA's transmission system in this area. BPA is considering four action alternatives (with options) that include transmission line routes, three sites for the proposed substation near Castle Rock, and one site for the proposed substation near Troutdale. The transmission line routing alternatives and options use varying amounts of existing BPA and new 150-foot wide right-of-way. The routing alternatives and options range from about 67 to 80 miles long. BPA is considering different tower designs (single circuit, double circuit, and triple circuit) for portions of the alternatives and options on existing right-of-way where existing transmission lines may be removed or replaced. In addition to the transmission line and substations, the proposed project includes construction of new access roads and improvements of existing access roads for the line and substations. BPA's preferred alternative is the Central Alternative using Central Option 1. See Figure 1-1.

1.2 Scope of Work

In compliance with the National Environmental Policy Act, BPA is preparing an Environmental Impact Statement (EIS) for the I-5 Corridor Reinforcement Project. As part of the draft EIS, BPA investigated the feasibility and prepared estimated costs to place the proposed transmission line underground in an Underground Route Study, which studied undergrounding the entirety of the I-5 transmission line. In continued support of the EIS process, BPA has enlisted HDR Engineering (HDR) to study the feasibility and potential costs of undergrounding two site-specific portions of BPA's preferred alternative:

Scenario 1: Transition from an overhead design to an underground design and back to an overhead design for a single 500-kV transmission line in or near a city with numerous homes immediately adjacent to the proposed line and where additional high density home development(s) are planned or are expected to occur, and where no right-of-way or lines currently exist. The study area is near Castle Rock, WA and is about 2.7 miles long. See Figure 2-1 and Figure 2-3.

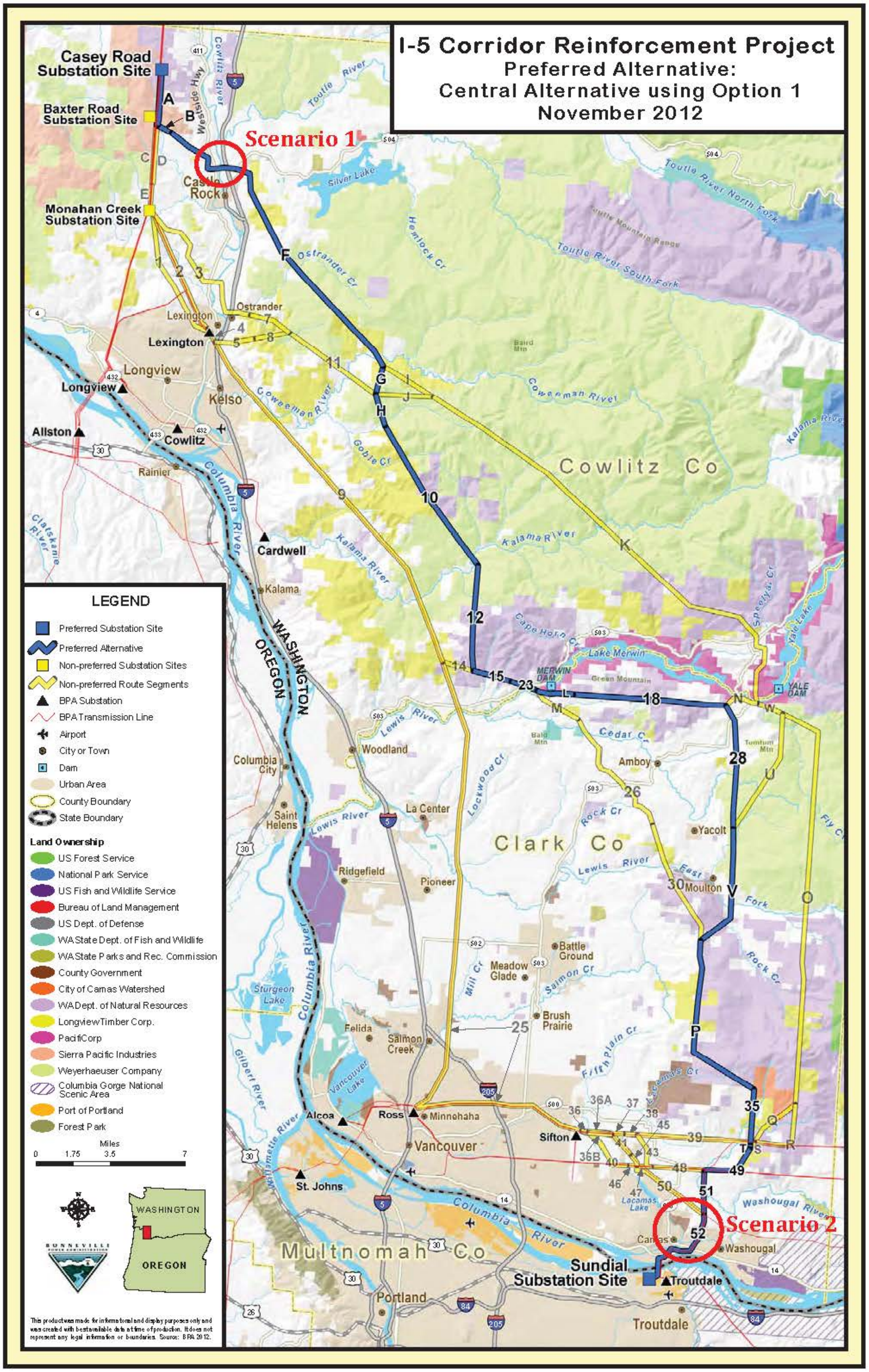
Scenario 2: Transition from an overhead design to an underground design and back to an overhead design for three separate transmission lines (one 500-kV and two 230-kV) in or near a city with numerous homes immediately adjacent to the proposed line and where additional high density home development(s) are planned or are expected to occur, and where right-of-way and lines and towers already exist. The underground lines will utilize the existing right-of-way. The study area is near Camas and Washougal, WA and is about 2.5 miles long. See Figure 2-2 and Figure 2-4.

With its focus on two site-specific study areas, this report considers the existing conditions when determining the feasibility and potential cost of underground transmission construction. These existing conditions include the terrain (ground slope), subsurface features (groundwater, soils, and bedrock), and features to be crossed (rivers and roads). This study investigates the sizing of transition stations, minimum number of underground cables required, layout and cable installation configurations, and various construction methods.

The scope of this study is to also identify future steps to be taken in terms of detailed evaluations to ultimately decide on the implementation of the underground options. This report addresses the following main issues:

- Initial project feasibility assessment based on previous 500-kV projects and feasibility studies for other proposed 500-kV projects
- Technical feasibility of designing, procuring, testing and installing 500-kV cable systems for both scenarios
- Reliability of 500-kV systems and 230 to 400-kV systems
- Cost analysis
- Schedule for construction
- Electrical characteristics analysis such as losses and charging currents
- Future recommendations

Figure 1-1. Project Area



Source: BPA

1.3 Study Approach

This report investigates the feasibility of installing 500-kV and 230-kV underground transmission cables and the requirements for their prospective use in Scenarios 1 and 2. The design parameters and routing for the 500-kV cables (Scenarios 1 and 2) are based on the I-5 Project, which consists of a 500-kV overhead single-circuit with an ultimate rating capacity of 4,560 amperes and length of 67 to 80 miles. The routing for the 230-kV cables (Scenario 2) is also based on the I-5 Project, and the design parameters are based on an ultimate rating capacity of 1,520 amperes as provided by BPA.

As part of the study and analysis, HDR conducted an initial feasibility based on existing and proposed cable installation especially at 500-kV. HDR then evaluated 500-kV and 230-kV cable technologies for prospective use for both scenarios. Next, ampacity calculations for various trench, bore, and cable configurations were conducted to arrive at the number of cables needed and the conductor size. Losses, charging current, and reactive power compensation were also evaluated.

Typical civil engineering drawings for cable trench configurations and trenchless technologies for crossing of rivers, railroad tracks, and highways were developed following the selection of the cable system and ampacity calculations.

As part of the study, HDR advised on the preferred cable system for use at 500-kV and 230-kV cable systems for the project. Cable manufacturers were contacted to provide technical information and costs for cables and accessories. Cost estimates and schedules were developed. Finally, HDR provided conclusions and steps forward to continue the project.

1.4 Summary of Findings

Despite limited worldwide experience with 500-kV underground transmission lines, a 500-kV cable system is technically feasible for installation in both Scenarios 1 and 2 although there are engineering challenges in both Scenarios. The 230-kV cable system for Scenario 2 is feasible due to the widespread worldwide use of 230-kV underground transmission. For both scenarios and voltages, the best cable system option is cross-linked polyethylene insulated (XLPE).

While engineering feasibility is one major consideration, another factor that must be considered is the cost to construct both scenarios. The cost for undergrounding of the 500-kV and 230-kV overhead sections is substantial (see Table 1-1), which makes economic feasibility a major consideration in the decision process going forward.

Table 1-1. Underground Cost Summary

	Scenario 1	Scenario 2	Total
500-kV Underground Cable System	$ 135M	$ 129M	$ 264M
230-kV Underground Cable System	N/A	$ 27M	$ 27M
Transition Stations (2 EA per Scenario)	$ 44M	$ 44M	$ 88M
Total	$ 179M	$ 200M	$ 379M

See Section 18.0 for more detailed cost estimates and assumptions.

2.0 Underground Cable Routes and Options

The high cost of undergrounding 500-kV and 230-kV cables intuitively leads to selecting the shortest possible route, which would be a straight line between end points. This is not feasible for either Scenario 1 or Scenario 2 given the existing residential and commercial conditions. Also, for Scenario 2, the underground cables will need to be constructed within BPA’s existing right-of-way.

Regardless of route length, it is imperative to study and evaluate the practicalities of potential routes by considering the topography and terrain, geotechnical data (ground conditions including ground stability and soil thermal resistivity), the availability of access for transportation of material, construction and future repair and maintenance, and the need for specialized installation requirements such as cable utility bridges, micro-tunnels, flexible troughs (in unstable ground), jack and bores, directional drilling, etc. Environmental considerations and community concerns play an increasing role in the selection of routes and often eliminate shortest route options. The sheer size and complexity of undergrounding 500-kV and 230-kV cable circuits pose greater installation challenges in comparison to other longitudinal infrastructure projects like gas and water pipelines.

There are two locations studied for undergrounding, which are described in more detail below.

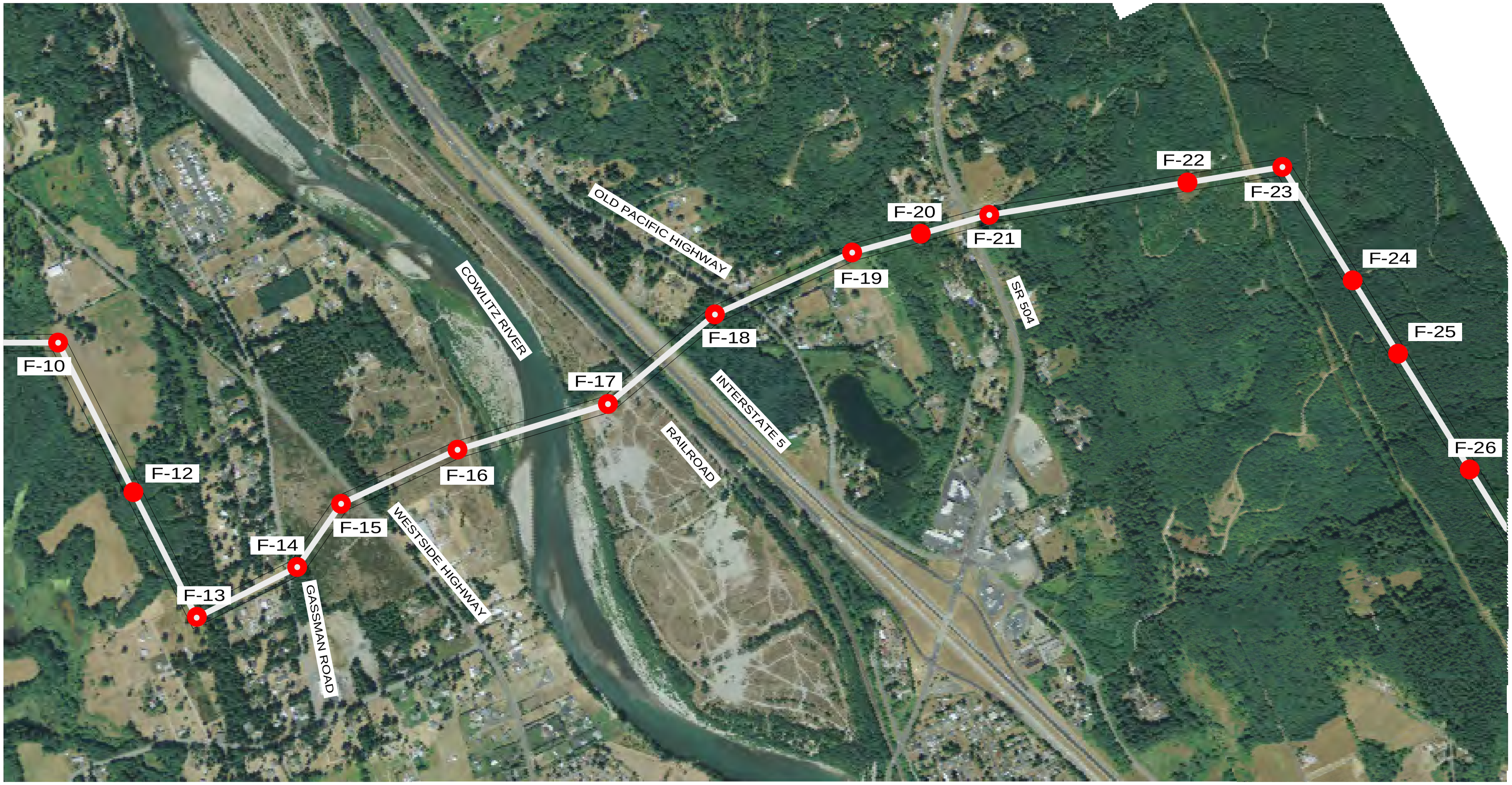
2.1 Scenario 1

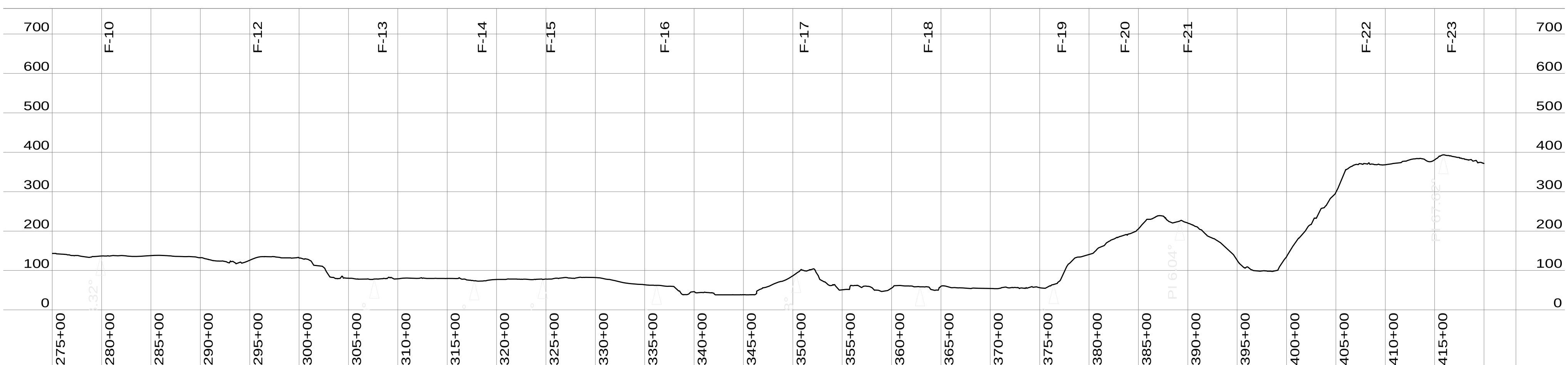
2.1.1 Route Description

The study area for Scenario 1 is near Castle Rock, WA and is about 2.7 miles long. Under this scenario, the I-5 Project will transition from an overhead design to an underground design and back to an overhead design for a single 500-kV transmission line. The study area is near a city with homes immediately adjacent to the proposed line and where additional high density home development(s) are planned or are expected to occur, and where no high-voltage transmission lines or rights-of-way currently exist. See Figure 2-1 and Figure 2-3.

Based on field observations and project survey data, the landscape for routing the cables consists of farmland, grassy areas, forested areas, and hilly areas with steep terrain. The routing would traverse a countryside which is essentially rural with sparsely few dwellings on the northern side of the city of Castle Rock. The hilly areas with the steepest terrain are on each end of the study area, while the middle portion of the study area is flat to rolling terrain. Constructing and installing the cables in the steep terrain would require construction of access roads for transporting construction materials and equipment and for future access for repair and maintenance.

PLS-CADD Drawing





PROJECT MANAGER	GTP
PROJECT ENGINEER	JIL
DESIGN ENGINEER	GJW
PROJECT NUMBER	133225

LEGEND

PROPOSED ALIGNMENT

PROPOSED STR LOCATION

BONNEVILLE POWER ADMINISTRATION
I-5 CORRIDOR REINFORCEMENT 500kV
UNDERGROUND STUDY PHASE 2

SCENARIO 1 ROUTE
4/2/2014

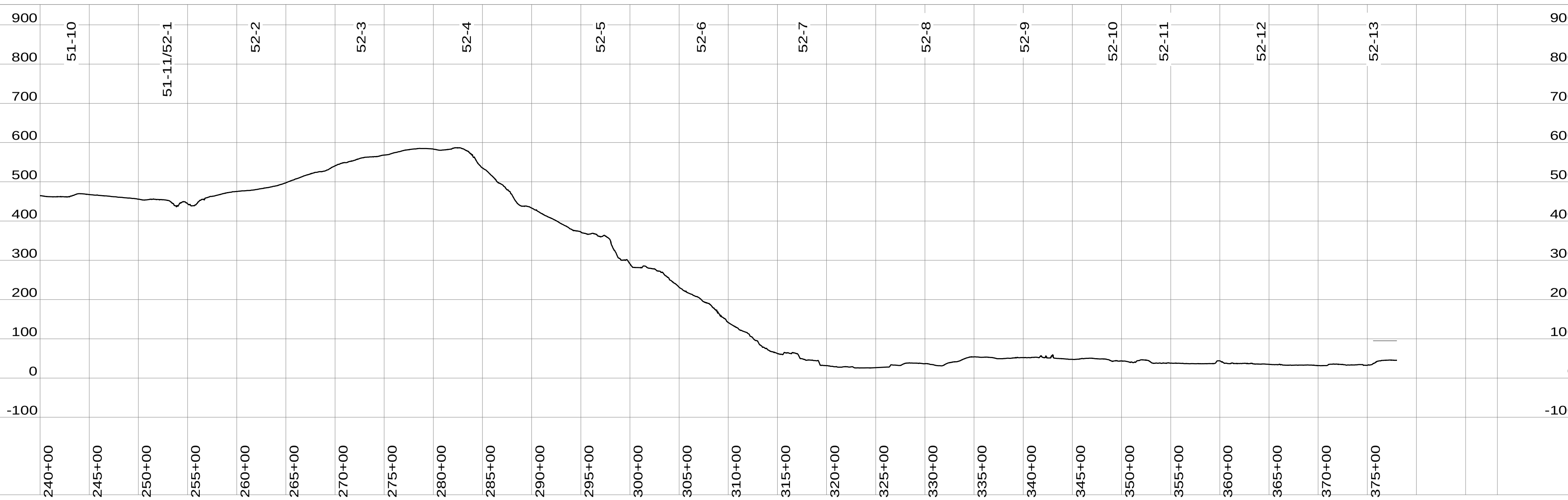
PLAN & PROFILE

PRELIMINARY

1500.0 ft. Horiz. Scale
375.0 ft. Vert. Scale

SHEET 1 of 1

PLS-CADD Drawing



BONNEVILLE POWER ADMINISTRATION

HDR

PROJECT MANAGER GTP
PROJECT ENGINEER JIL
DESIGN ENGINEER GJW
PROJECT NUMBER

LEGEND
PROPOSED ALIGNMENT
PROPOSED STR LOCATION

BONNEVILLE POWER ADMINISTRATION
I-5 CORRIDOR REINFORCEMENT 500kV
UNDERGROUND STUDY PHASE II

SCENARIO 2 ROUTE
5/8/2014

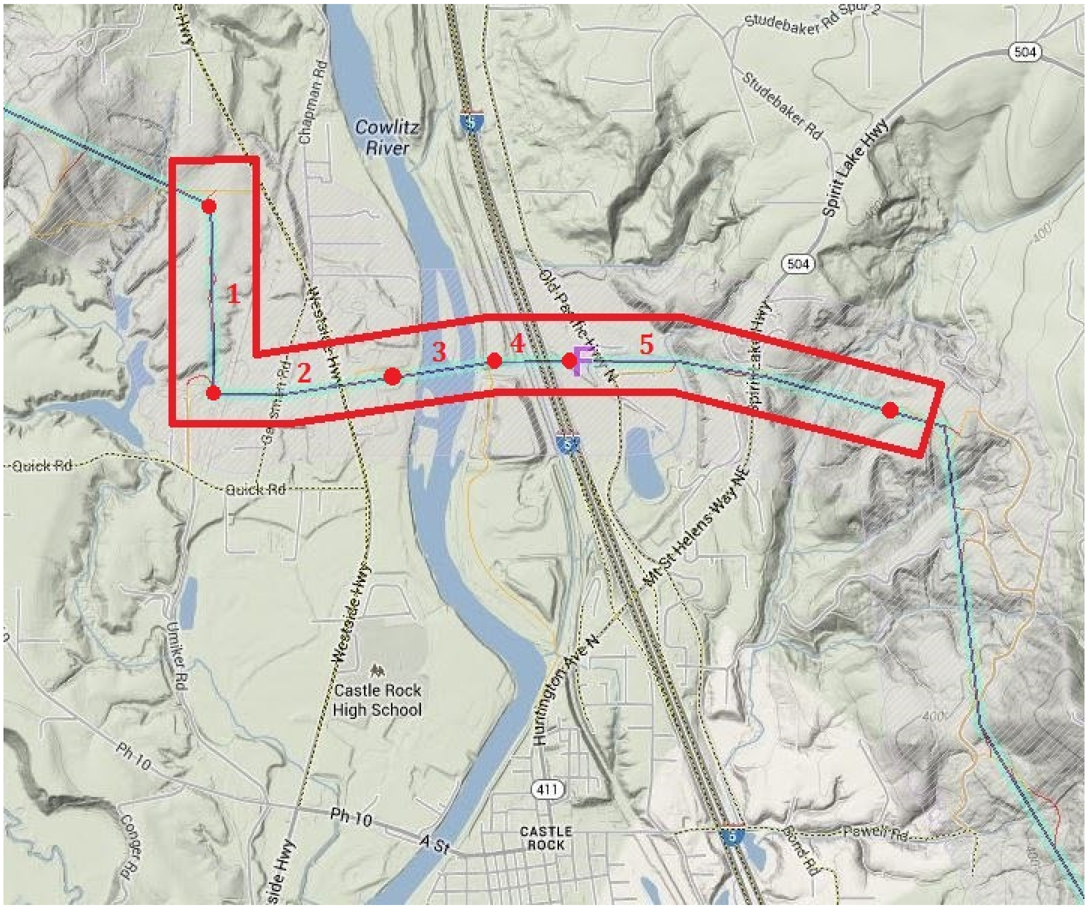
PLAN & PROFILE

PRELIMINARY

1500.0 ft. Horiz. Scale
375.0 ft. Vert. Scale

SHEET 1 OF 1

Figure 2-3. Scenario 1



2.1.2 Route Construction Options

Because of the varied terrain and existing crossing features in the Scenario 1 study area, multiple construction methods would be employed to build the 500-kV underground cable system. The study area was subdivided into five sections, which are shown on Figure 2-3. The project features and construction methods for each section are proposed as follows:

Section 1 – In the vicinity of proposed transmission tower F-10 (see the interactive map for the I-5 Project at http://gis.bpa.gov/gis/I-5/gmviewer.html) the proposed overhead transmission line would terminate and connect to a new transition station (See Section 20.0 and Appendix E). From the transition station, the underground cable system would be installed by open cut trenching.

Section 2 – Through this section, the underground cable system would be installed by open cut trenching.

Section 3 – Open cut trenching would be employed until reaching the western bank of the Cowlitz River. The cable system would cross underneath the Cowlitz River by horizontal directional drilling (HDD).

Section 4 – From the east side of the Cowlitz River, the cable system would be installed by open cut trenching until reaching the western side of the existing railroad tracks. Jack and bore would be employed to install the cable system under the railroad tracks and Interstate 5.

Section 5 – From the east side of Interstate 5, the cable system would be installed by open cut trenching until reaching a new transition station in the vicinity of proposed transmission tower F-22. At this point, the underground section would terminate and continue as overhead transmission.

The construction methods listed above are described in greater detail in Section 9.0.

2.1.3 Major Crossings

This scenario would cross a number of significant natural and manmade features, which are tabulated below:

Table 2-1. Scenario 1 Major Crossings

Crossing	Approximate Width (FT)	Crossing Length (FT)	Proposed Crossing Method
Gassman Road	50	50	Trench
Westside Highway	63	63	Trench
Cowlitz River	408	1,100	HDD
Railroad and I-5	440	560	Jack & Bore
Old Pacific Highway	60	60	Trench
SR 504	57	57	Trench

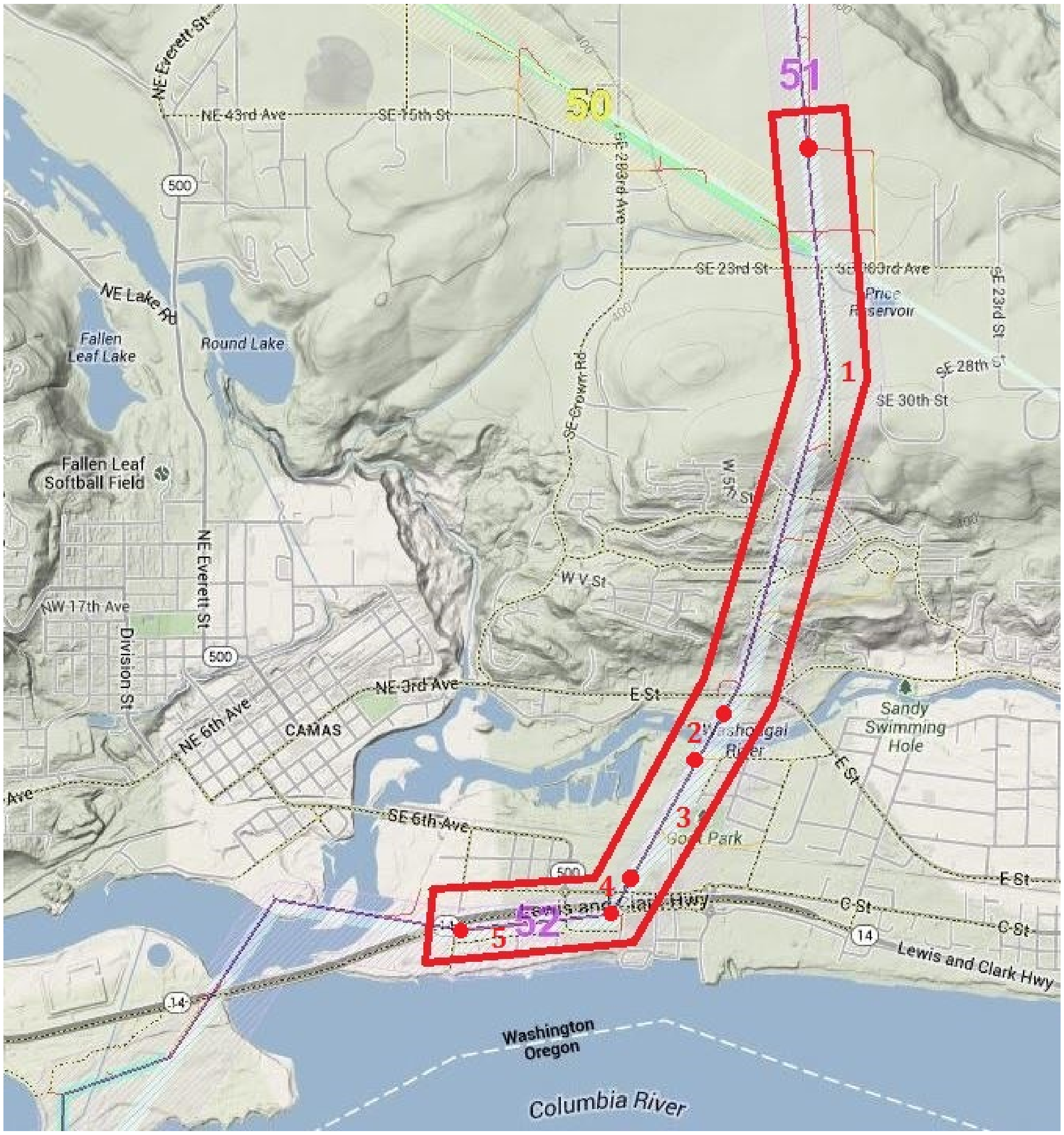
2.2 Scenario 2

2.2.1 Route Description

The study area for Scenario 2 is near Camas and Washougal, WA and is about 2.5 miles long. Under this scenario, the I-5 Project will transition from an overhead design to an underground design and back to an overhead design for a one 500-kV transmission line and two 230-kV transmission lines. The two 230-kV transmission lines included under this scenario would be BPA's existing North Bonneville-Troutdale lines. The three underground cable systems would be constructed within the existing 250-foot wide right-of-way of the North Bonneville-Troutdale lines. The study area is in or near a city with numerous homes immediately adjacent to the proposed line and where additional high density home development(s) are planned or are expected to occur, and where right-of-way and lines and towers already exist. See Figure 2-2 and Figure 2-4.

Based on field observations and project survey data, the landscape for routing the cables consists of farmland, grassy areas, and hilly areas with steep terrain. The routing, within the existing right-of-way, would traverse a combination of undeveloped, commercial, and residential areas in the cities of Camas and Washougal, WA. The steep topography immediately north of the Washougal River would present difficult and challenging conditions from a constructability perspective. The SR-14 crossing would require jack and bore construction and so suitable areas for a jacking pit and a receiving pit, which may be difficult on the south side of the highway due to an existing residential building. The study area contains wetlands that might need to be spanned by guided directional drilling due to impacts from open cut trenching. Stormwater detention ponds were recently created on the south side of SR-14 when the highway was widened, which would be impacted by trenching and by the transition station. These conditions combine to make this scenario less than optimal for installing the underground cable systems, though it would be feasible.

Figure 2-4. Scenario 2



2.2.2 Route Construction Options

Because of the varied terrain and existing crossing features in the Scenario 2 study area, multiple construction methods would be employed to construct the 500-kV underground cable system. The study area was subdivided into five sections, which are shown on Figure 2-4.The project features and construction methods for each section are proposed as follows:

Section 1 – In the vicinity of proposed transmission tower 51-10 (see the interactive map for the I-5 Project at http://gis.bpa.gov/gis/I-5/gmviewer.html) the proposed overhead transmission lines would terminate and connect to a new transition station (See Section 20.0 and Appendix E). From the transition station, the underground cable systems would be installed by open cut trenching to the northern side of the Washougal River, south of E Street/Evergreen Highway.

Section 2 – The cable system would cross underneath the Washougal River by horizontal directional drilling (HDD).

Section 3 – From the south side of the Washougal River, the cable system would be installed by open cut trenching until reaching the north side of the existing railroad tracks. Jack and bore would be employed to install the cable system under the railroad tracks. Open cut trenching would be used from the south side of the railroad tracks to the north side of SR-14.

Section 4 – The cable systems would cross underneath SR-14 using jack and bore construction.

Section 5 – On the south side of SR-14, the cable systems would be installed using open cut trenching until reaching a new transition station in the vicinity of proposed transmission tower 52-13. The transition station would be constructed within the existing right-of-way in between SR-14 and SE 11th Avenue. Construction of the transition station would impact the stormwater detention ponds created when SR-14 was recently widened. At this point, the underground section would terminate and continue as overhead transmission.

The construction methods listed above are described in greater detail in Section 9.0.

2.2.3 Major Crossings

This scenario would cross a number of significant natural and manmade features, which are tabulated below:

Table 2-2. Scenario 1 Major Crossings

Crossing	Approximate Width (FT)	Crossing Length (FT)	Proposed Crossing Method
SE 23rd Street	22	22	Trench
N 4th Street	40	40	Trench
W Lookout Ridge Drive	48	48	Trench
N Lebrun Drive	54	54	Trench
N Lebrun Drive	50	50	Trench
NE 3rd Avenue	68	68	Trench
Washougal River	100	1,100	HDD
Railroad Tracks	65	80	Jack & Bore
SE 8th Avenue, SR-14 and Frontage	330	450	Jack & Bore
Frontage & SE Union	125	125	Trench

2.3 Additional Route Information Required

If a decision is made to move forward with the design of either one or both underground transmission Scenarios, additional data and analyses would need to be acquired and completed. Some of these investigations are also needed for the overhead transmission lines, such as route surveying and geotechnical investigations, though with additional investigation required to obtain the necessary information specific to underground transmission lines.

2.3.1 Geotechnical Analysis

Geotechnical data will be required and obtained by soil borings and will include soil composition and other considerations for the cable system installation, such as directional drilling for crossing of the rivers and jack and bore to cross highways. The railroad company owners may also require soil borings and soil analysis for crossing under the railroad tracks.

The geotechnical report should include detailed bore logs, standard soil classifications (gravelly sand, silty gravel, etc.), sieve analyses of granular materials, and compressive strength of soil and rock samples.

It is very important to know where bedrock is located in the native soil, as well as the type of bedrock and its compressive strength. The rock/soil type and classification determine the required size of the drilling rig, the types of reamers, the drill bits needed, and daily productivity rates.

2.3.2 Thermal Resistivity Analysis

A thermal resistivity testing and analysis of the soil along the route, at 1,000 to 2,000 feet intervals, will be required to obtain the in-situ native soil thermal resistivity, which will be used in ampacity calculations to optimize the conductor size and trench geometry. The thermal resistivity measurement should be made in the late summer months when moisture content in the native soil is low.

Soil thermal resistivity testing and analysis to determine the soil dry out curves are required prior to final design. This data will be used in ampacity calculations in order to validate initial assumptions used in calculations and to finalize the cable conductor size. For the railroad and river crossings, test bore holes shall be required down to the proposed cable depth to obtain the thermal resistivity of the various soil layers. The bore, however, shall not be made directly over the cable alignments but at least 40 feet away. This is necessary to prevent hydraulic fractures for trenchless installations employing drilling fluids.

2.3.3 Temperature Analysis

An earth temperature analysis of the route should be conducted in the winter months to determine actual temperatures at the proposed cable depth during cold weather temperature operation. This data should be used for cable tests at the factory to demonstrate cold weather performance, if so required by BPA. A similar analysis shall be conducted in the summer months to determine the ambient earth temperature at the depth of the cable sections requiring HDD.

2.3.4 Route Survey

It is recommended that route surveys be conducted, as needed, for the design of the conduit and manhole system. These surveys are necessary to determine the proper siting for the conduits, manholes, and bores.

2.3.5 Identification of Existing Substructures and Obstacles

In conjunction with the route survey, in order to establish the final feasibility of the underground installation route, any existing above ground and underground structures paralleling or crossing the route must be identified and plotted on construction or survey drawings. Buried infrastructure which will require paralleling or crossing would consist of the following:

- Electric distribution lines
- Gas or petroleum pipelines

- Water pipelines
- Communication lines
- Storm drain and sewer lines

2.3.6 Permits Needed for Critical Crossings

Crossing under the railroad tracks in both Scenarios, which are owned by the BNSF Railway, will require permits from the Railway. Additionally, the use of the Railway's right-of-way for construction work will also require permits.

The river beds in Washington State are owned and overseen by the Washington State Department of Natural Resources (WADNR). Plans for boring under the Cowlitz River in Scenario 1 and Washougal River in Scenario 2 will have to be submitted to WADNR for approval and permitting.

Additionally, permits may be necessary to cross under and work within the rights-of-way of major roadways. In Scenario 1, this may include engaging officials from Cowlitz County, Washington State, and the US Federal Highway Administration. In Scenario 2, this may include engaging officials from the cities of Camas and Washougal and also Washington State.

2.3.7 Environmental Considerations

Environmental considerations and community concerns must be considered in the final decision on the project with respect to the underground approach. Important considerations are as follows:

- Any adverse impacts to the flora and fauna during construction stages
- Long term aesthetics by installation of vertical steel transmission structures
- Any traffic disruptions
- Electromagnetic fields (EMF)
- Biological and cultural disruptions and disturbance

Environmental considerations and impacts were investigated in the initial Underground Route Study prepared for the I-5 Project, which is available here: http://www.bpa.gov/Projects/Projects/I-5/Pages/Draft-EIS.aspx

3.0 Initial Feasibility Assessment

An initial feasibility assessment for the installation of the two 500-kV segments is presented in this section and other relevant information has been presented in other parts of this report. The feasibility of installation depends on four main factors which are as follows:

1. Availability of supply of 500-kV cable systems
2. Availability of expertise for the installation of the cable system
3. Previous experience of other similar installations
4. Reliability

3.1 Availability of Supply for 500-kV Cable Systems

Four different cable system types were investigated in this report with three of them being viable for installation at 500-kV. They are Cross-Linked Polyethylene (XLPE) insulated cables, Single-Conductor Fluid-Filled (SCFF) cables, and Gas-Insulated Lines (GIL). As indicated in Section 4 of the report, each presents its advantages and disadvantages.

The preferred choice is the XLPE insulated cable system. Over the last 30 years, improvements in polymer chemistry for raw materials has led to super-clean compounds, and coupled with improvements in manufacturing process, XLPE insulated cable systems have become the preferred choice at 500-kV installations. This is evidenced by existing installations in Japan and China.

An installation in a duct and manhole system is ongoing in Chino Hills in Southern California by Southern California Edison (SCE) to underground a 3.7-mile section of the 500-kV Tehachapi Renewal Transmission Project. Various manufacturers have been invited to participate in the bidding to construct the project.

For the I-5 Project, manufacturers such as Prysmian (Italy and France), ABB (Sweden), Brugg (Switzerland), JPower (Japan), LS Cables (Korea), Nexans (Belgium and France), Sagem/General Cable (France), Sudkabel (Germany), Taihan (Korea), and Viscas (Japan) are potential suppliers. In conclusion, the ability to manufacture cables and accessories is currently available.

3.2 Availability of Installation Expertise for Cable Systems

The expertise for the installation of the project depends both on the engineering and construction of the conduit and manhole system, engineering of the cable system, and the cable system installation.

While tunnel and direct buried installations are popular in other parts of the world, in the US, the system of choice has historically been the conduit and manhole system for transmission voltages at 69-kV and above. Conduit and manhole systems date back to the 1930s, although there have also been many installations of pipe-type cable systems where the steel pipe serves as the conduit for the cables.

Within the last 15 years, new installations for 138-kV to 345-kV XLPE cable systems in the US have been predominantly in concrete encased duct and manhole systems installed by open cut trench in conjunction with trenchless construction methods such as jack and bore to cross rail tracks or roadways and horizontal directional drilling to cross rivers and wetlands. The installation process for the trench and trenchless method is described in Section 9.0. There are several companies in the US that have expertise with the installation of conduit and manhole systems.

The installation of the cable system will require uniquely trained, skilled, and highly-specialized expertise for assembly of the cable joints and terminations. These resources are typically only available from the overseas cable manufacturers. Correct assembly of cable jointing and terminating, in accordance with manufacturer drawings and instructions, will be most critical in ensuring the reliability of the entire system, especially for the 500-kV cables.

3.2.1 500-kV Cables – Scenarios 1 and 2

The total length of the 500-kV system will be approximately as follows:

Scenario 1: 2.7 miles or 14,256 feet which with an average spacing of 1,782 feet between manholes will require 7 manholes or 21 splices for cable group or a total of 84 splices for four cable groups.

Scenario 2: 2.5 miles or 13,200 feet which with an average spacing of 1,885-foot between manholes will require 6 manholes or 18 splices per cable group or a total of 72 splices.

In total, 156 splices will be required plus 48 terminations for the 500-kV cables.

3.2.2 230-kV Cables – Scenario 2

The total length of the 230-kV system will be approximately 2.5 miles or 13,200 feet. With the same 1,782-foot spacing, six manholes or 18 splices per circuit for a total of 36 splices for the two circuits will be required.

Trained and skilled jointers for assembly of both cable joints and terminations are available and can be acquired from the cable supplier as part of the cable supply contract for initial installation.

3.3 Current 500-kV Underground Installation and Operational Experience

There are currently no 500-kV underground cable installations in the United States having both cables and accessories although, as mentioned previously, one project is ongoing in Southern California by SCE.

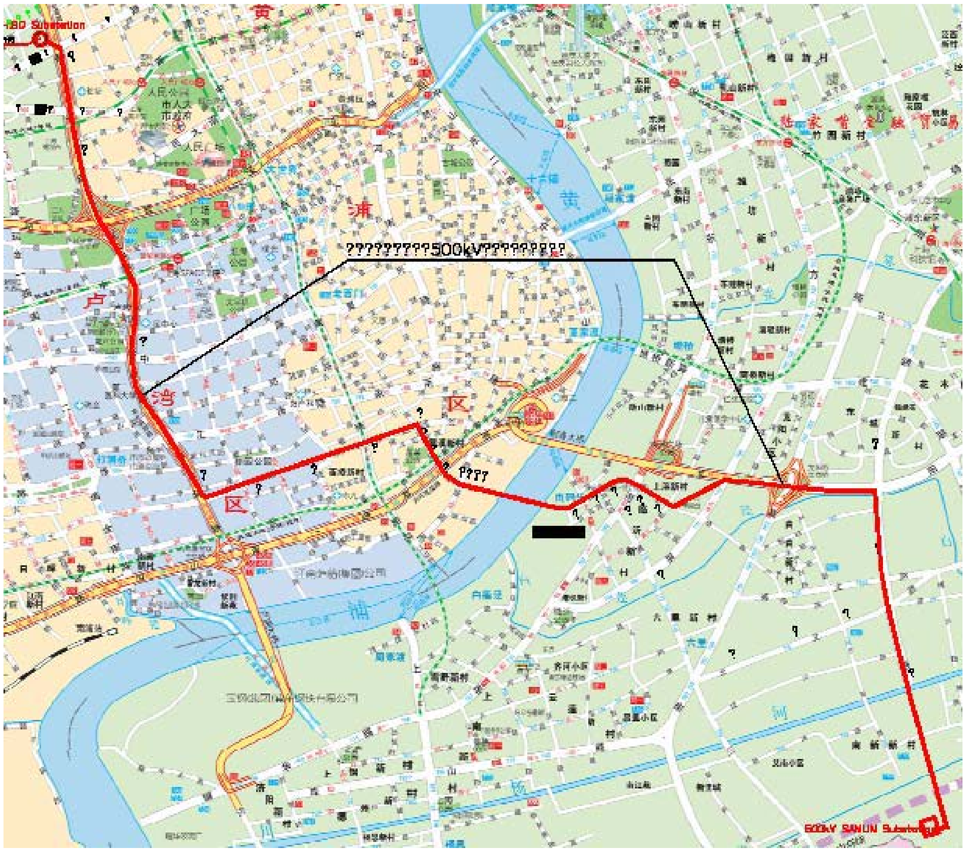
3.3.1 Existing 500-kV Cable Systems

Worldwide there are four 500-kV installations that have cables, joints, and terminations:

Shanghai-Shibo Line: The Shanghai-Shibo Line, shown in Figure 3-1and Figure 3-2, is a tunnel installation 17-km (10.6 miles) in length that was installed in 2010 and used an XLPE insulated cable system containing 147 joints. The tunnel for underground routing starts from the 500-kV World Expo Station at West Beijing Road, crosses downtown Shanghai above the Huangpu River, and connects the cable tunnel of the San-lin station. This line sustained a failure in 2012 after two years of operation.

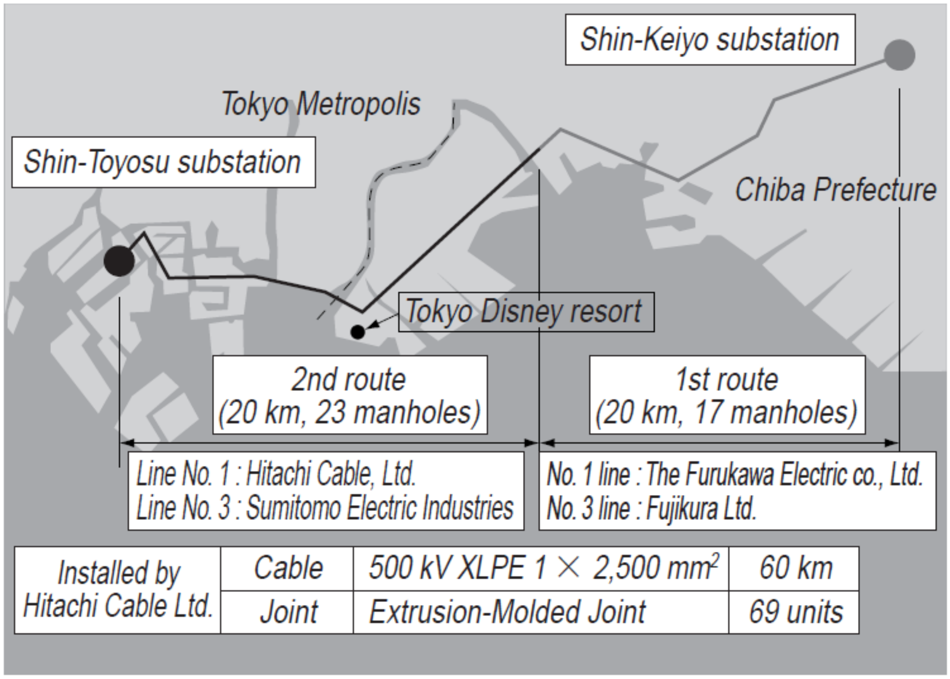
Figure 3-1. 500-kV Cables in Tunnel on Shibo-Shanghai Line

Figure 3-2. Shanghai-Shibo 500-kV Underground Route



Shinkeiyo-Toyosu Line: The Shinkeiyo-Toyosu line (see Figure 3-3) is a tunnel installation 20 km (12.4 miles) in length that was installed from 1996 through 1999 and uses an XLPE insulated cable system containing 240 joints. The line connects the Tokyo Electric Power Company's Shin-Keiyo and Shin-Toyusu substations with two circuits. This line stained a failure in 2001 after two years of operation.

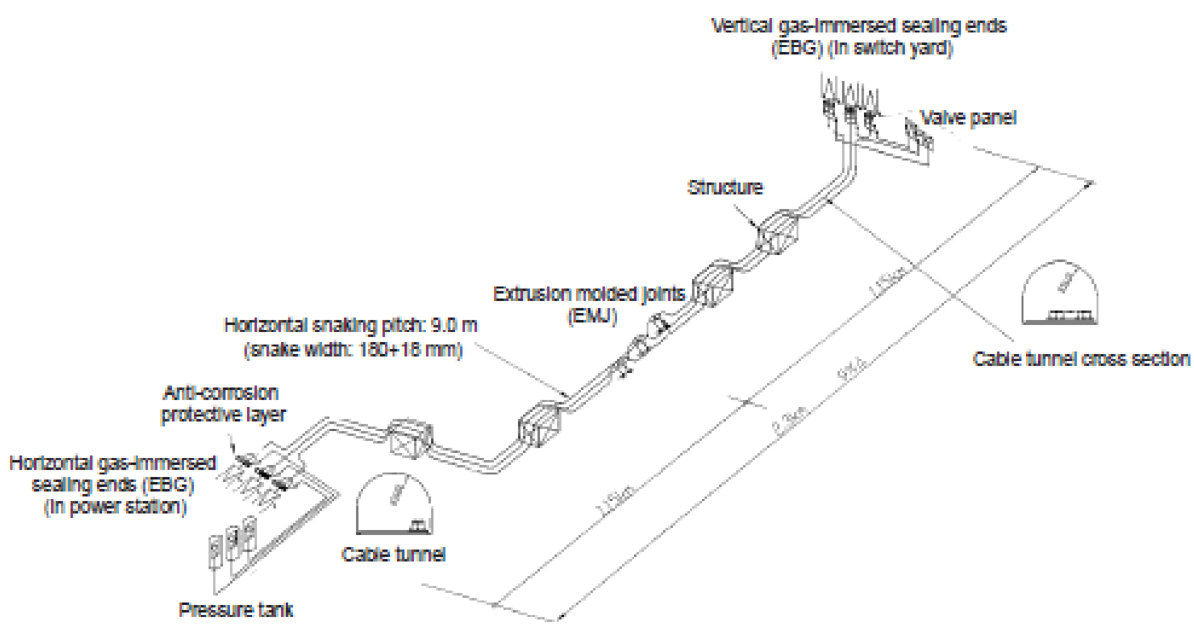
Figure 3-3. Shinkeiyo-Toyosu 500-kV Underground Route



525-kV Submarine Installation: A 525-kV submarine cable installation from mainland Canada to Vancouver Island including both a 9 km (5.6 miles) and a 30 km (18.6 miles) section that were installed in 1984 and used a single-conductor fluid-filled cable system. No failures have occurred.

Kazunonogawa Power Station: The Tokyo Electric Power's Kazunonogawa Power Station is a tunnel installation 2.3 km (1.4 miles) in length that was installed in 1999 and uses and a XLPE insulated cable system containing 3 joints. The line connects the power station to the switchyard, see Figure 3-4.

Figure 3-4. Kazunonogawa Power Station 500-kV Cable Installation



The first three installations listed all have a cable system length that is longer than the 2.5-mile and 2.7-mile sections of 500-kV underground cable proposed in this report, but these installations are in tunnels and not directly comparable to a conduit and manhole system being proposed in this report.

3.3.2 Proposed 500-kV Cable System Projects

Additionally, three studies of projects were reviewed that evaluated the feasibility of undergrounding 500-kV overhead lines or sections of the lines. However, none of these projects to date have been installed. These studies are described below.

SunZia Transmission Line Project: In 2013, The Department of the Interior (DOI) and the Department of Defense (DOD) investigated the feasibility of installing a 35-mile underground segment of a 500-kV transmission line (SunZia Transmission Line Project) to cross the White Sands Missile Range Northern Extension Area. The conclusion was that the project was feasible.

Heartland Project: **I**n 2010, Cable Consulting International (CCI) investigated the feasibility of different options, about 6 or 12 miles, to install underground segments of a 500-kV transmission line in the Edmonton (Heartland Project), Canada area. The conclusion was that the project was technically feasible, although cost was a major consideration.

Everglades Project: In 2010, Patrick Engineering examined the feasibility of undergrounding about 6 miles of 500-kV transmissions to cross the Everglades for the Department of the Interior. Again, the conclusion was that undergrounding the 6-mile segment was technically feasible, but ultimately the decision was made to go overhead as a result of costs associated with the underground installation.

Chino Hills Underground Project (CHUG): **I**n July 2013, the California Public Utility Commission required Southern California Edison's to underground 3.7 miles of the 500-kV Tehachapi Renewable transmission line project. The CHUG project is a 3.7 mile cable installation which traverses portions of the City of Chino Hills in Southern California. The installation uses a duct and manhole system and currently is in the procurement and design stages. The CHUG project is scheduled for completion in mid 2016.

3.4 Reliability Factors

Overall reliability of underground lines, based on experience and statistical analysis, is examined in Section 6.0 of this report. The four existing projects listed previously have operated reliably with only one, the Shanghai-Shibo Line, sustaining a failure in 2013. For the 500-kV Heartland Project underground transmission line feasibility study, Gregory and Williams investigate reliability from Conseil International des Grands Réseaux Électriques (CIGRE) and concluded that failure rates can be assumed to be as follows:

- Cables: 0.066 cable faults for 100 km of cable per year
- Splices: 0.026 faults for 100 splices per year

The reliability of the 500-kV and 230-kV project under consideration will depend on several factors:

Completion of Prequalification Testing by Cable System Manufacturers: Cable suppliers should provide test data certified by an independent third party that prequalification tests or PQ tests which are long term tests in excess of 8,000 hours have been successfully carried out in accordance with IEC 62067 on a similar cable system having the same cable and accessories to demonstrate long term performance.

Completion of Type Tests by Cable System Manufacturers: Cable suppliers should also show test data confirming that type tests have been carried out on a similar cable system to demonstrate successful operation at conductor temperature of 105°C.

Prequalification of Cable Manufacturers: Factory audits should be performed to observe equipment, manufacturing processes, and quality controls used to ascertain production of a reliable product.

Factory Inspection and Witnessing of Tests: During the cable system manufacturing, witnessing and verification of routine production tests, electrical tests on completed cables and other tests such as type tests should be completed in accordance with AEIC or IEC standards before acceptance of the cable system. This will verify compliance with specifications and standards in order to ensure overall reliability of the project.

System Design: The system design, for both the civil engineering design for conduit and manhole system and the electrical design for the cable and accessories selection and installation, should be based on site conditions, environmental conditions, topography, and site surveys to ascertain overall reliability.

Installation: Installation of the cable system should be performed by trained and highly skilled personnel, especially for jointing and terminating of the cables in accordance with reviewed and approved drawings and instructions. Construction quality control and assurance to verify assembly in accordance with approved drawings and instructions will also be important for overall reliability. Involvement by BPA engineers for construction oversight and quality control will also contribute to the overall reliability of the project.

4.0 500-KV AND 230-KV CABLE REQUIREMENTS

The information provided below details the requirements used for the study of the 500-kV cable and 230-kV cable systems.

4.1 500-kV Cables – Scenarios 1 and 2

Functional requirements for the 500-kV underground cables are as follows:

- Number of circuits: 1
- Total route length of underground cables: 5.2 miles
  - Castle Rock 2.7 miles
  - Camas 2.5 miles
- Nominal system voltage: 500-kV
- Line capacity requirements for cable ampacity:
  - Continuous ultimate operation 4,650 A or 3,950 MVA
  - Emergency operation None required

4.2 230-kV Cables – Scenario 2

Functional requirements for the 230-kV underground cables, only in Scenario 2, are as follows:

- Number of circuits: 2

- Total route length of underground cables: 2.5
- Nominal system voltage: 230 kV
- Line capacity requirements for cable ampacity:
    - Continuous operation 1,520 A or 605 MVA
    - Emergency operation None required

4.3 Ambient Earth Temperatures

Ambient earth temperatures for the purpose of conducting ampacity calculations are given below. These temperatures are assumed for this report but ambient earth temperatures should be determined by actual measurements taken during thermal resistivity measurements:

- Summer: 68°F (20°C) at 4 feet below grade
- Summer: 57°F (14°C) at 20 feet or greater below grade

4.4 Ambient Air Temperatures

Figure 4-1 shows the mean seasonal and minimum recorded temperatures for Castle Rock. The minimum ambient temperature recorded was 1°F (-17 °C). Figure 4-2 shows the mean seasonal and minimum recorded temperatures for Camas. The minimum ambient temperature recorded in Camas was -30°F (-34°C).

Figure 4-1. Mean and Minimum Temperatures for Castle Rock, WA

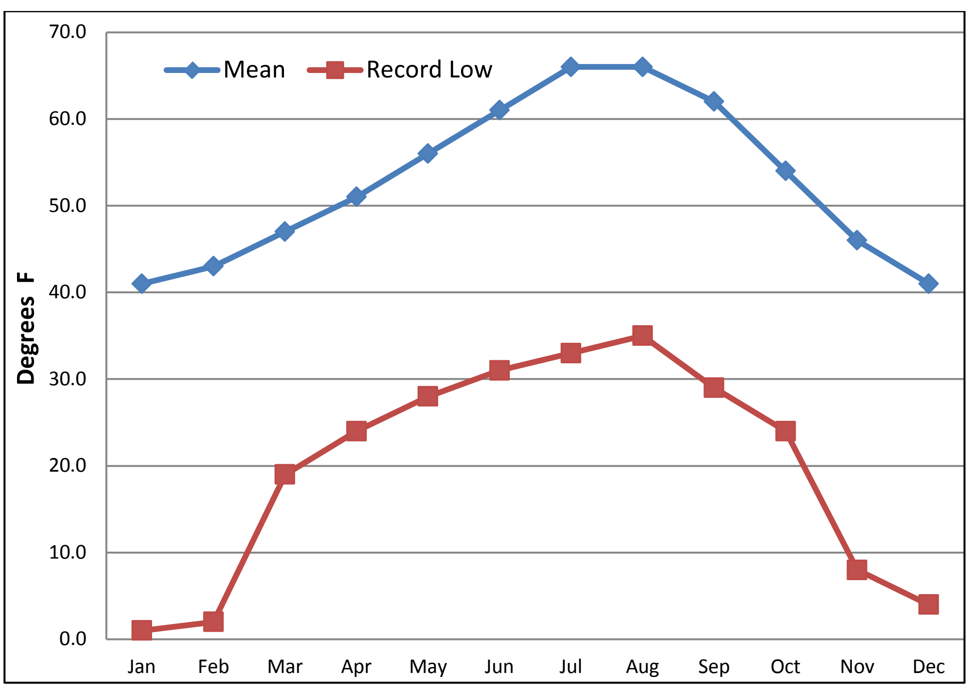
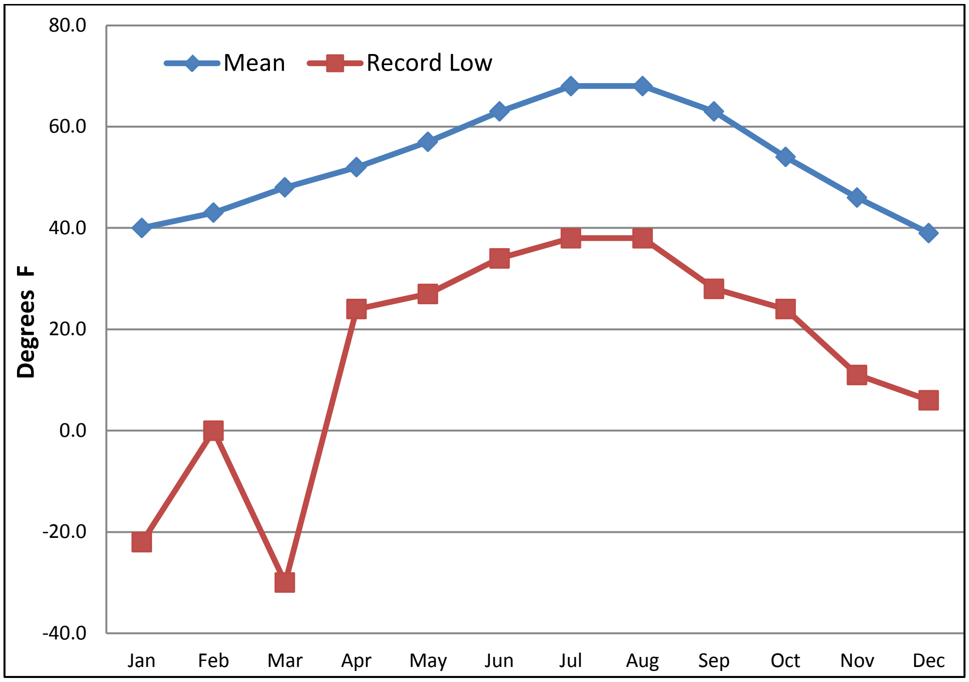


Figure 4-2. Mean and Minimum Temperatures for Camas, WA



Although the mean temperatures appear to be moderate, the recorded low temperature may be of concern with respect to the operation of the cables and accessories. It may seem prudent to adopt the recommendations listed below based on the minimum measured ambient air temperatures. Manufacturers should demonstrate that the 500-kV and 230-kV cable terminations can perform reliably to a minimum temperature of -44°F (-42°C) as this gives about a 14°F (8°C) degree margin to the minimum temperature recorded of -30°F (-34°C) at Camas.

Similarly, for the Heartland project in Edmonton, Canada, Gregory and Williams analyzed actual ambient air and earth temperatures obtained by distributed temperature sensing. They found that the minimum overall ambient air temperature was -50°F (-45.5°C) at the terminations, 18°F (-7.9°C) in vaults, and 18°F (-7.6°C) in conduits and concluded that manufactures should demonstrate reliable performance as follows:

- High voltage terminations to a minimum temperature of -58°F (-50°C)
- High voltage joints in air-filled manholes to a minimum temperature of -4°F (-20°C)
- Cables in air-filled conduits at 4 feet below grade to a minimum temperature of 5°F (-15°C)

Based on the analysis for the Heartland project, the design temperatures for this project should be as shown in Table 4-1

As indicated previously, it is recommended that ambient earth temperature be taken at several locations along the route at Castle Rock and Camas in the winter months to determine actual ambient earth temperatures. These temperatures shall then be used to validate the performance requirements indicated above. This becomes important when the cables are de-energized for long periods of time in the winter months.

Table 4-1 summarizes the minimum design temperatures for the cables.

Table 4-1. Minimum Design Temperature Requirements for Cables and Accessories

Description	Temperature
Cables in Conduits: Minimum ambient earth temperature at 4 feet below grade	5°F (-15°C)
Joints in Manholes: Minimum ambient earth temperature at 4 feet below grade	-4°F (-20°C)
Termination in Air: Minimum ambient air temperature	-44°F (-42°C)

4.5 Concrete Backfill and Earth Thermal Resistivity

Thermal resistivity for the purpose of conducting ampacity calculations are given below. These assumed values are probably conservative and actual values need to be determined through actual measurements.

- Conduit concrete encasement: 85 °C-Cm/W
- Grout for filling of bore casings: 110 °C-Cm/W
- Earth for open cut trenching: 110 °C-Cm/W
- Earth for deep bores: 110 °C-Cm/W

5.0 ASSESSMENT OF UNDERGROUND CABLE SYSTEM TECHNOLOGIES

This section evaluates existing cable technologies that could be utilized for this project.

5.1 High-Pressure Pipe-Type Cables

5.1.1 General

High-Pressure Pipe-Type (HPPT) cables were developed in 1932 by the Okonite-Callender Company which called them the “Oilstatic Cable System.” The main type is referred to as the HPFF or high-pressure fluid-filled which can be gas-filled (HPGF) or oil-filled (HPOF). The majority of the installations in the US are either gas-filled or oil-filled. HPGF cables are available to voltages of 138-kV while the HPOF cables are available to 345-kV. Consolidated Edison of New York installed the first 345-kV HPOF cable in 1963.

From 1969 through 1971, 500-kV HPOF cables were successfully tested at the EPRI Waltz-Mills testing facility in Pennsylvania. No purchase orders followed and there are no commercial operations worldwide. In 1982, EPRI and the US Department of Energy successfully developed and tested a 765-kV HPOF cable. No orders followed and there are no commercial operations worldwide.

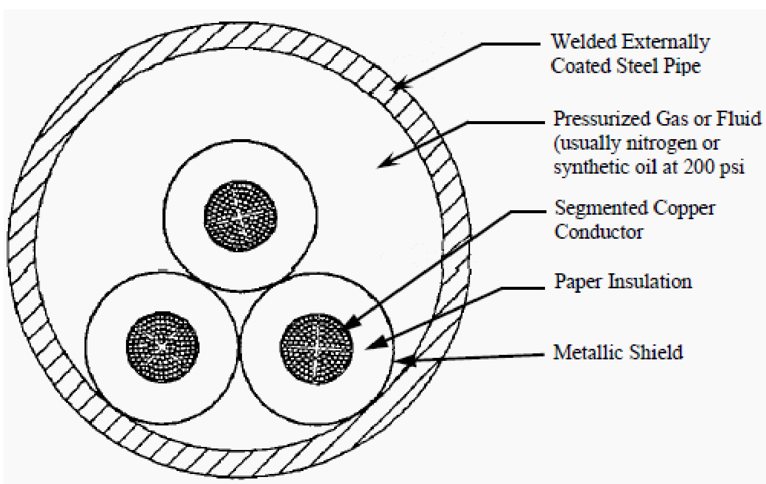
In 1987, the PPLP or paper polypropylene insulated HPPT cable was developed. Instead of conventional Kraft paper as the insulation, this system uses a laminated assembly which consists of a layer of polypropylene sandwiched between two layers of Kraft papers.

5.1.2 Cable Construction

The pipe-type cable system consists of three cables installed in a steel pipe as shown in Figure 5-1 and Figure 5-2. The pipe is then filled with nitrogen gas or oil and maintained at a nominal operating pressure of 200 pounds per square inch (psi). The cables consist of copper or aluminum conductors insulated with Kraft or PPLP paper. The conductors are enclosed within a moisture shield and outer brass or stainless steel tape that is wrapped with two D-shaped wires that serve as skids for pulling the cables into the pipe.

Figure 5-1. Pipe-Type Cable

Figure 5-2. Pipe-Type Cable Cross-Section



5.1.3 Experience and Installations

Today there are approximately 4,500 circuit miles of transmission cable installations from 69-kV through 345-kV, and 75 percent of these are pipe-type cables.

5.1.4 Oil Pressurizing System

Pipe-type cables require a nominal operating pressure of 200 psi to prevent ionization within the interstices of the laminar insulation. Normally, the oil pumping plant is located at the lower elevation end of the line. The plant automatically maintains pressure on the cable system and is equipped with alarms for abnormal conditions which are transmitted to a control center. Figure 5-3 shows a typical pumping plant with oil pressurizing ladders in the front and the oil storage tank in the background.

Figure 5-3. Oil Pumping Plant

5.1.5 Disadvantages of HPPT Cables

HPPT cables are not well suited for applications along the route which have large slope changes as a result of the head of hydraulic pressure exerted by the weight of the oil at the bottom of the slope. Stop joints along the cable route are needed to break the cable into hydraulic sections to control internal pressures which increase complexity and cost. In addition, pressure alarms, level alarms, and associated communication systems are required to transmit the alarm to a control center to respond and investigate.

Also, HPPT cables are not environmentally friendly and suffer from spill and leaks during normal operation since it is difficult to maintain oil under pressure. At 230-kV, the pipe would contain about 2 gallons of oil per foot or 29,000 gallons for a 2.5 mile long circuit which poses an environmental risk.

In the event of electrical fault, the fault current can burn through the steel pipe or cause the pipe to split open due to the sudden pressure build up at the fault point caused by the rapid expansion of the oil. This would result in the spillage of a large volume of oil which would require subsequent clean-up.

Maintenance requires specialized equipment and trained and skilled personnel. Also, repairs of cable or accessories failures are complex and require outages of up to 2 months or longer to complete.

5.1.6 Suitability for Use at 500-kV

Pipe-type cables are not suitable for use for this project since there are no commercial installations at this voltage level and therefore, no experience at 500-kV.

5.1.7 Suitability for Use at 230-kV

Pipe-type cables are a suitable solution at 230-kV since widespread installations and experience is available worldwide. However, due to the disadvantages discussed above, an XLPE insulated cable system provides an optimal solution.

The substitution from 230-kV HPPT cables to XLPE cables began to occur in the 1970s and the number of HPPT cable installations worldwide has progressively decreased. Since the 1980s several cable plants that manufactured HPPT cables in the US and abroad have closed plus other manufactures of high-voltage cables have eliminated production of pipe-type cables. Today only two suppliers remain worldwide which are Okonite in the US and Viscas in Japan.

5.2 Single-Conductor Fluid-Filled Cables

5.2.1 General

Single-Conductor Fluid-Filled (SCFF) cables were invented by Mr. Emanueli Pirelli in the early 1900s and have found applications worldwide. The majority of these installations though are at voltages less than 500-kV, but a few installations at the 500-kV voltage class have been made. SCFF cables have been developed and tested to voltages up to 1,100-kV. A relatively short installation at 525-kV AC was at the Grand Coulee Dam.

5.2.2 Cable Construction

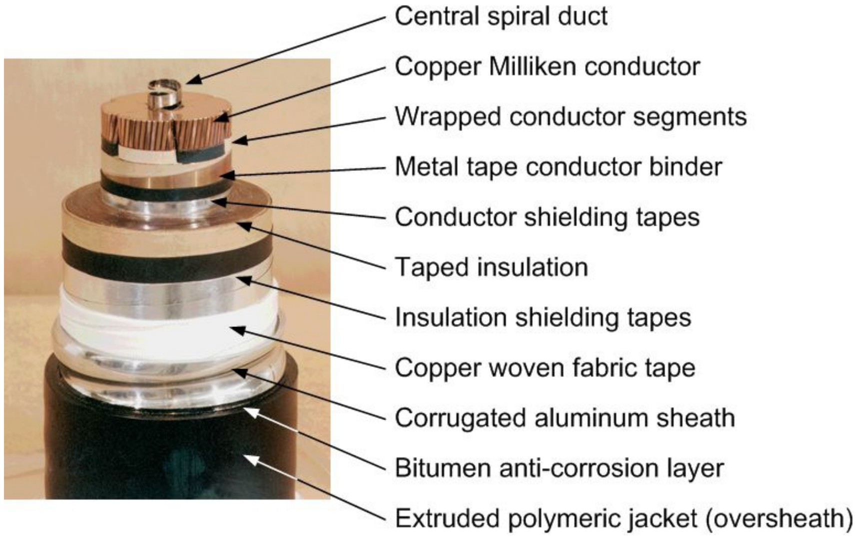
The SCFF cable consists of a hollow copper or aluminum conductor which is filled with a low viscosity dielectric oil or nitrogen gas.

SCFF cables that are oil-filled are referred to as SCOF and cables that are gas-filled to SCGF. The SCOF cables are available in low-pressure to 15 psi, medium pressure to 60 psi and high-pressure configuration to 200 psi. SCGF cables are pressurized to 200 psi and are limited to voltages up to 138-kV.

The cable insulation consists of either Kraft paper or PPLP tapes. Pressure in the cable is maintained either by pressure tanks for low and medium pressure cables or by pumping plants for high pressure cables.

As the case for pipe-type cables, the substitution of SCFF cables to XLPE cables began to occur in the 1970s and the number of SCFF cable installations worldwide has progressively decreased. However, several suppliers remain worldwide such as Okonite in the US, Viscas in Japan, and LS Cable and Taihan in Korea.

Figure 5-4. Typical SCFF Cable Cross-Section



5.2.3 Oil Feeding and Pressurizing Systems

SCFF cables require an oil feeding and pressurizing system for operation which is normally by oil feeding tanks. The tanks are usually installed in separate manholes and connected to termination and stop joints on the SCFF cables. The tanks feed and accept oil to the cables in conjunction with the daily load cycle during oil contraction (night) and oil expansion (day). They automatically maintain pressure on the cable system and are equipped with alarms for abnormal conditions which are transmitted to a control center. Figure 5-5 and Figure 5-6 show typical oil feeding equipment and alarm systems.

Figure 5-5. Oil-Feeding Tank

Figure 5-6. Oil-Alarm and Valve Panels

5.2.4 Experience and Installations of SCFF Cables at 500-kV

SCFF cables have been developed and tested to voltages of 1,100-kV. A short installation at 765-kV was installed and energized at Hydro Quebec Laboratories in Canada for long term testing which were completed in 1991. In 1976, 525-kV cables were installed in tunnels and energized at the Grand Coulee Dam in Washington State. In 1976, a 525-kV submarine cable crossing of approximately 39 km in length in Vancouver Island in Canada was placed in-service. The Honshu-Shikoku line Tokyo Bay in Japan is 22 km long of which 18 km are installed on a bridge. The line consists of two circuits which were installed in stages and placed in service in 1994.

5.2.5 Disadvantages of SCFF Cables

SCFF cables are not well suited for applications along routes that have large slope changes because of the head of pressure that occurs naturally due to the weight of the oil at the bottom of the slope. Stop joints along the cable route are needed to break the cable into hydraulic sections to control internal pressures which in turn increase complexity and cost. Also, pressure alarms and level alarms and associated communication systems are required to transmit alarms to a control center for field response and investigation.

In addition, SCFF cables suffer from spill and leaks during normal operation. In the event of fault, the fault current would breach the cable metallic sheath or the metallic covering on joints and oil spill will result. Lastly, maintenance requires specialized equipment and trained and skilled personnel. Also, repairs are complex and require lengthy outages.

5.2.6 Suitability for Use at 500-kV

SCFF cables are a viable alternative to XLPE cables for this project at 500-kV. However, due to the problem with pressure control on sloping routes, the need for oil reservoirs, oil feeding systems, alarm systems, the potential for leaks and spills, and the skill level required in their installation, maintenance and operation, an XLPE insulated cable system is preferred over a SCFF cable system.

5.2.7 Suitability for Use at 230-kV

As for the case at 500-kV, SCFF cable are a viable solution at 230-kV, but an XLPE insulated cable system is preferred due to its relative simplicity as compared to an SCFF system.

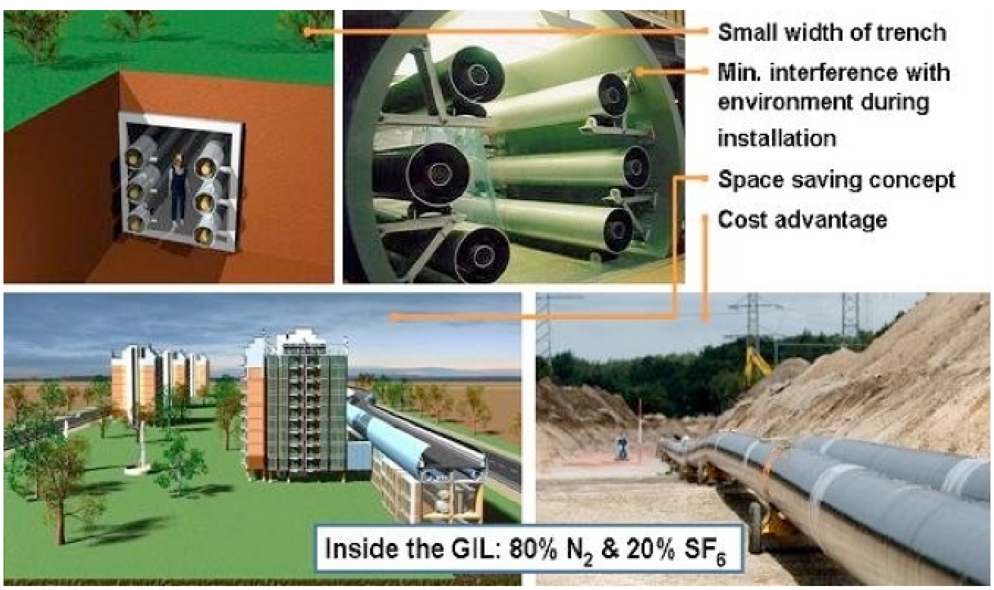
5.3 Gas-Insulated Lines

5.3.1 General

Gas-Insulated Lines (GIL), which are also sometimes referred to as the SF6 insulated electronegative cable system, is a high power transmission system designed for high capacity transfer. GIL for underground transmission is similar to the bus sections in a GIS station and has been available since the 1970s. They were primarily used in above ground installations or shafts in power stations or in tunnels, but its flexibility allows for installations below ground.

The first generation was installed from 1973 to 1975 and supplied by Siemens in the Black Forest of Germany. Siemens developed the second generation of GIL in the 1990s which resulted in cost reductions of 50 percent when compared to the original design. In addition to the cost reduction, the second generation of GIL offers additional features such as flexible installation possibilities enabled by the possibility to bend the GIL pipe and the reduction in the use of SF6 gas by developing a combination of SF6 and N2. Currently, GIL systems are available to 550-KV and 4,000 amperes. Figure 5-7 shows a combined view of cross section of a three-phase GIL in a tunnel installation, above ground and underground.

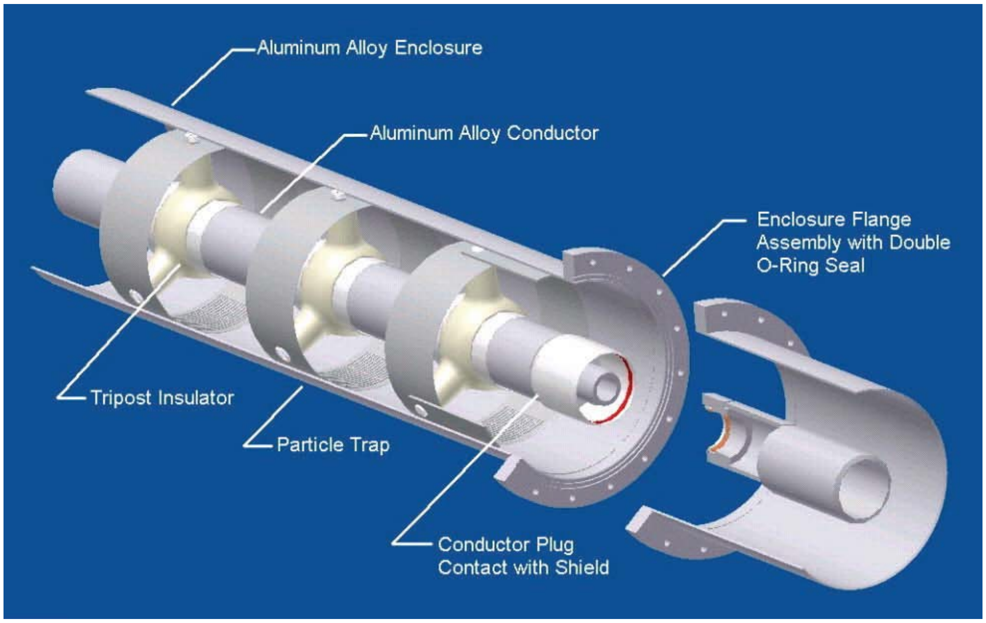
Figure 5-7. Typical GIL Installations in Tunnels (Above and Below Ground)



5.3.2 Basic Design of GIL

The basic design of the GIL is shown in Figure 5-8 and described in more detail below.

Figure 5-8. Gas-Insulated Line



Conductor

The conductor is usually made from aluminum and consists of a hollow tube and available with cross-sectional areas up to 15,000 mm2 or approximately 30,000-kcmil whereas the biggest stranded copper conductor is available to 3,500 sq. mm or 7,000-kcmil.

Due to the availability of large conductors, GILs are able to transmit 3 to 4 times more capacity than conventional cable systems. The load current of 4,560 A for this project is close to the limit of a GIL and possibly one group of three-phase GIL could be equivalent to four groups of conventional cables. Conductor sections are normally 44 feet long and during assembly use plug-in type connections to allow for thermal expansion as a result of heating of the conductor.

Support Insulator

The inner conductor is insulated from the pipe and supported on insulators as shown in Figure 5-8. The insulators are epoxy castings. Special diaphragm insulators are used at the ends of a 'gas section' and isolated gas compartments and are designed to withstand the pressure differential forces when one GIL gas section is depressurized. Also, the diaphragm insulators stop the power arc from entering into the adjacent GIL section, thereby minimizing damage to the conductor and pipe.

Insulating Gas

GIL systems use either SF6 gas or a mixture with concentration of 80 percent SF6 gas and 20 percent nitrogen gas as the filling medium for the pipe. SF6 gas when released into the atmosphere contributes heavily to the green house effect and poses environmental concerns. Therefore, the SF6 and nitrogen gas mixture has been used to alleviate the environmental effects by minimizing the amount of SF6 in the GIL system.

SF6 is an electronegative gas and it is sometimes referred to as a scavenger gas due to its ability to absorb free electrodes, thus the gas has high breakdown strength. Handling of the gas requires specialized equipment for both storage and treatment for re-use in the system.

Particle Traps

Particle traps are positioned on the bottom of the pipe and their function is to locally distort the electrostatic field in order for them to “trap” any conducting particles that may be present in the system.

External Enclosure

The enclosure is basically an aluminum pipe of spiral construction and welded with diameters ranging up to 28-inch diameter and wall thickness of 0.4 inches or 10 mm. The external pipe is designed to contain the gas medium, arcs that occur during short circuits and provide a low resistance path for the return of fault current.

In above ground installation, the pipe is usually left uncoated to allow for more efficient heat transfer but, for underground or tunnel installation, the pipe is coated with a corrosion prevention covering and may additionally require cathodic protection.

5.3.3 Characteristics of GIL

The main characteristics of GIL are as follows:

- Rated voltage: 230-kV – 550-kV
- Rated current: 2,500 A – 4,000 A
- Transmission capacity : 1,000 MVA – 3,800 MVA
- Rated short-time current: 63 kA/3s
- Capacitance: 55pF/m
- Inductance: 220nH/m
- Resistance: 10mW/km (typical)
- Insulation gas: N2-SF6 mixture
- Pipe materials: Aluminum alloys

5.3.4 Assembly of GIL

GIL sections were originally supplied in 38 to 44 feet in length and were provided with flanges which allowed them to be bolted together at the time of installation. The flange system has been replaced by orbital welding of the pipe sections together at the installation site. Figure 5-9 shows assembly of the GIL while Figure 5-10 shows the orbital welding. Orbital welding reduces cost both in the assembly and fabrication of the GIL and reduces the risk of gas leakage.

Figure 5-9. GIL Site Assembly

Figure 5-10. Orbital Welding of GIL

The pipe sections for installation can only be field bent to radius (in the range of 1,300 feet) depending on the aluminum pipe diameter, which makes changes in the routing due to bends for crossing over and under substructures difficult. Bends have to be ordered and fabricated to angles les and radii based on the plan and profile of the route.

5.3.5 Advantages of GIL

The most important advantages of GIL are as follows:

- High transmission capacity up to 500-kV and 4,000 A in forced cooled tunnel
- Low transmission losses
- Low capacitance which allows circuit lengths of up to 60 miles

- Less need for reactive compensation due to the low capacitance
- High reliability
- High operational safety (no fire risk, no external impact in case of internal failure)
- Applicability of automatic reclosure
- No practical ageing of components (long lifetime)
- Very low external magnetic fields
- Suitable for installation in tunnels, aboveground and underground

5.3.6 Disadvantages of GIL

The main disadvantages of GILs are that they cannot readily and easily follow route changes in plan and profile where small radii are required. Also, underground installations present technical difficulties due to pipe expansion and contraction and the possibility of pipe corrosion. In addition, during installation and welding, there is the possibility of introducing contaminants into the pipe which would lead to a reduction in dielectric strength of the system. Furthermore, GIL systems are not environmentally friendly due to the possibility of leakage of SF6 gas into the atmosphere. SF6 is a green house gas with a Global Warming Potential of 22,200. Lastly, GIL systems are much more complex to design, install, and maintain as compared to an XLPE insulated cable system.

5.3.7 Experience and Installations of GIL at 400-kV and Above

Table 5-1 lists GIL installations at voltages of 400-kV and above. The table shows that GIL systems are selected for application where high current capacity is required and that the number of installations worldwide for commercial applications at 400-kV and above is limited.

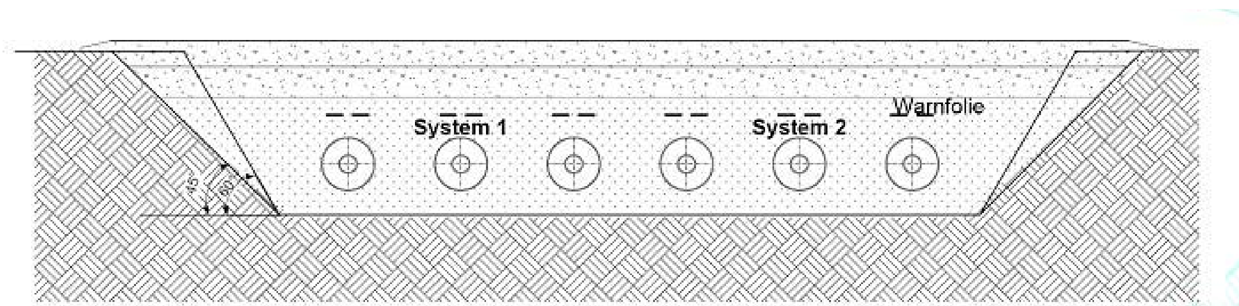
Table 5-1. GIL Installations Worldwide

Year	Length (km)	Voltage (kV)	Current (A)	Installation Method	Installation Type	Location
1975	0.58	500	3,000	Underground	Commercial	US, Ellensburg, WA
1975	1.40	400	820	Tunnel	Commercial	Germany, Wehr
1998	0.07	400	3,200	Tunnel	Test	Germany, IPH Test Site
1998	0.30	400	4,000	Underground	Test	France, EDF Test Site
1999	0.10	400	4,000	Underground	Test	Germany, IPH Test Site
1997-2000	17.00	400	1,200	Stilts	Commercial	Saudi Arabia
2002	1.20	500	4,000	Stilts	Commercial	Thailand, Sai Noi
2004	1.64	400	4,000	Stilts/Covered Trench	Commercial	UK, Hams Hall
2010	1.80	400	2,600	Underground	Pilot/ Commercial	Germany, Frankfurt Airport
2010+	0.16	400		Tunnel	Commercial	Austria, Limberg II

Underground installations are even fewer. The longest installation is at the Frankfort airport at 0.9 km which was completed in 2010. Figure 5-11 and Figure 5-12 show an actual GIL installation in a cable trench and a cross-section and profile of the installation. This installation replaced a segment of OH line and its capacity matches the capacity of the OH Line at 2,600 A.

Figure 5-11. GIL in Open Trench

Figure 5-12. GIL Trench Cross-Section



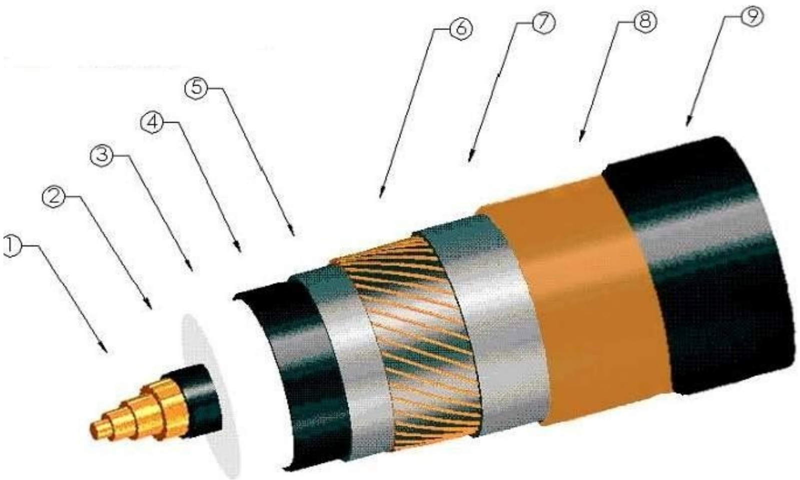
5.4 Cross-Linked Polyethylene Insulated Cable Systems

Cross-Linked Polyethylene (XLPE) insulated cables are now commonly used throughout the US and worldwide since the 1970s and have surpassed installation of oil-filled cables. XLPE cables have been extensively used in North America at voltages from 69-kV up to 345-kV. In other parts of the world, XLPE cables have been installed successfully at 500-kV.

5.4.1 Cable Construction

The components of an XLPE insulated cable are shown in Figure 5-13. The insulation is made from cross-linked polyethylene. The construction appears to be relatively simple and the cable contains no oils or gases and is environmental friendly as compared to fluid-filled cable and GIL systems. The insulation consists of cross-linked polyethylene for which the base compound is linear low density polyethylene. Advances in polymer science and the advent of extra-clean materials and manufacturing improvements have made this cable technology possible at EHV voltages.

Figure 5-13. Construction of XLPE Insulated Cable



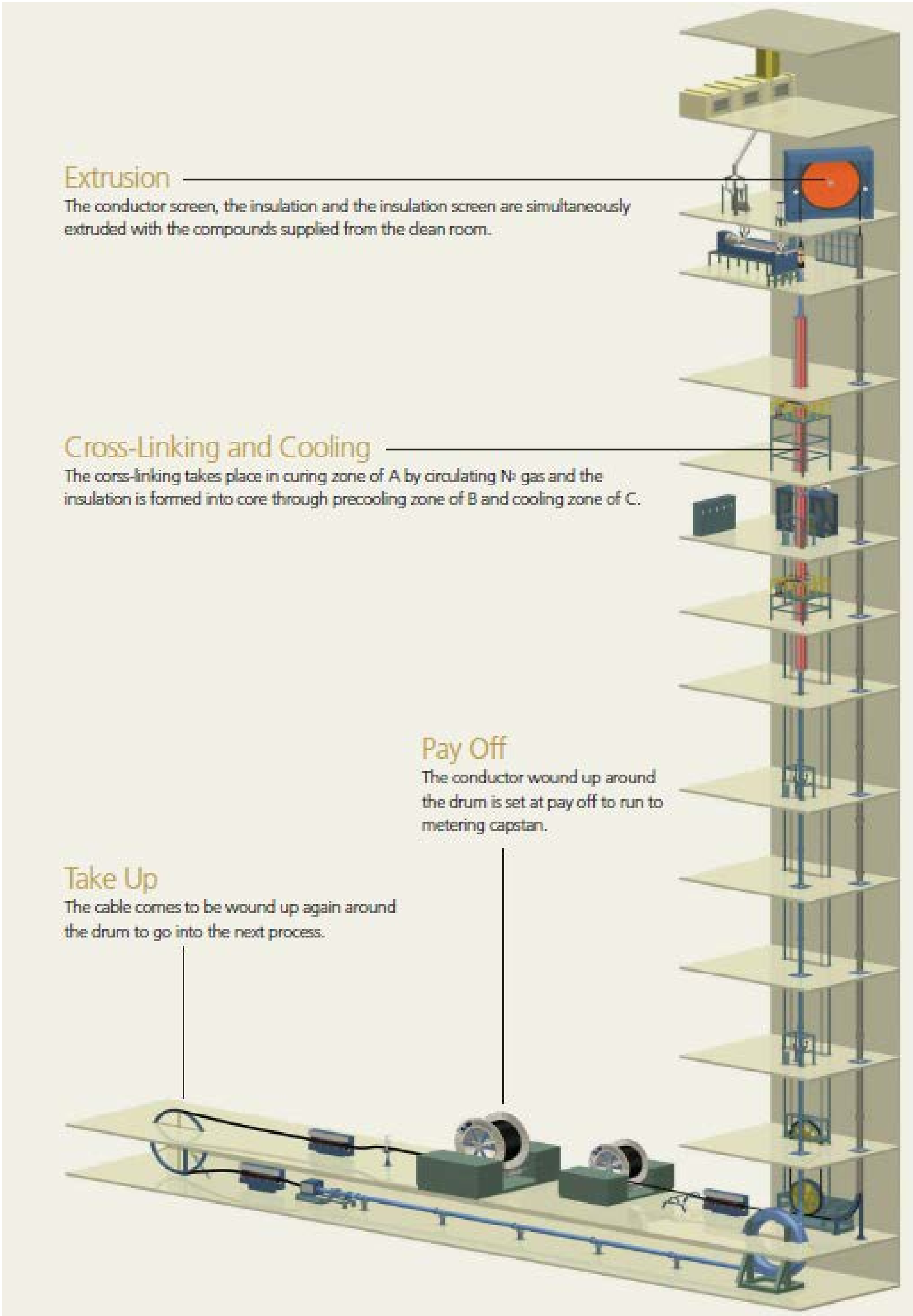
1. Copper Conductor
2. Inner Semi-Conductive Shield
3. Extruded Solid Dielectric Insulation (Cross-Linked PE)
4. Outer Semi-Conductive Shield
5. Semi-Conductive Swelling/ Bedding Tapes
6. Concentric Copper Wire Metallic Shield
7. Semi-Conductive Swelling/ Bedding Tapes
8. Moisture Barrier/Sheath (Copper, Aluminum, Lead, or Stainless Steel)
9. Protective Jacket (Medium-density Polyethylene)

5.4.2 Manufacturing Process

The cables are made by first stranding the conductor from individual wires and then running the conductor through a triple-head extruder where the conductor semiconductive shield, the insulation, and the insulation semiconductive shield layers are extruded in a single-pass through the triple head extruder. Cross-linking of the insulation takes place in a vulcanizing tube after extrusion. The cross-linked insulation is then cooled in the cooling tube where it returns to a solid crystalline state which appears white in color. Figure 5-14 shows the extrusion process in a vertical continuous vulcanizer or VCV line. Catenary continuous vulcanizer or CCV and horizontal continuous vulcanizer l lines are also used for the extrusion process.

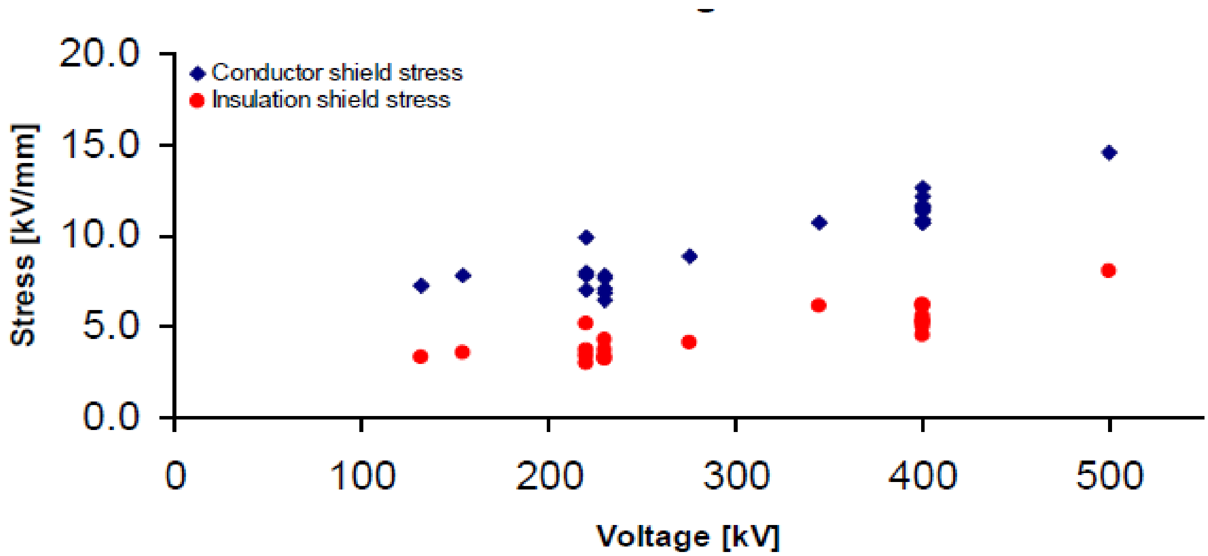
The manufacturing process includes quality controls to prevent the entrainment of contaminants, to minimize the number and size voids within the insulation and to minimize the number and size of protrusions from the semiconductive shields and to maintain eccentricity of the insulation. Companies such as Borealis and Dow Chemical make super-clean compounds which are supplied in pellet form and used by cable manufacturers in the extrusion process to minimize insulation contaminants.

Figure 5-14. Vertical Line for Extrusion of XLPE Cable



Advances both in material properties and manufacturing techniques have contributed to increases in stress levels within the cable which have resulted in smaller insulation wall thickness. Figure 5-15 shows that the electrical stresses at the conductor shield and insulation shield have increased from approximately 7 kV/mm and 3 kV/mm, respectively, to 15 kV/mm and 7 kV/mm, respectively, thus leading to the development of the 500-kV cable class.

Figure 5-15. Evolution of Stress Levels in XLPE Cables



5.4.3 Advantages of XLPE Cables

The advantages are mainly in the fact that XLPE cables have less insulation losses and thus higher current capacity, less capacitance and less charging current, and they do not require ancillary equipment such as oil tanks, pressure alarms and communication systems. In addition, XLPE insulated cables contain no filling oil or gases and thus pose no environmental threat since they eliminate the possibility of oil leaks and spills. Also, there is no risk of fire due to lack of insulating oils. Lastly, XLPE insulated cables have lesser maintenance costs due to the elimination of ancillary equipment and insulating fluids.

5.5 XLPE Cables Joints and Terminations

5.5.1 Cable Joints Designs

Cable joints or splices are used to join individual cable lengths or spans after installation. Cable shipping length in excess of 5,000 feet have been supplied per single reel, however, the reel size and weight at these lengths present logistical challenges in shipping, port of entry, and transportation at installation sites.

Joints are either of the one-piece premolded (OPJ) type shown in Figure 5-16 or three-piece prefabricated molded type (PMJ) shown in Figure 5-21. The OPJ by comparison of the two figures presents a simpler solution for installation plus it is more economical in terms of material cost, installation time and installation cost and requires lower skill level for assembly.

One additional type called the extrusion molded joint (EMJ), shown in Figure 5-17 was used originally at extra high voltages (EHV) and consisted of an extrusion molding process shown in Figure 5-18. This process, in essence, replicated the fabrication of the cable at the field location where splicing was occurring. These joints have been successfully used in Japan at 500-kV on circuits like the Shinkeiyo-Toyosu line.

Figure 5-16. Premolded One-Piece Joint

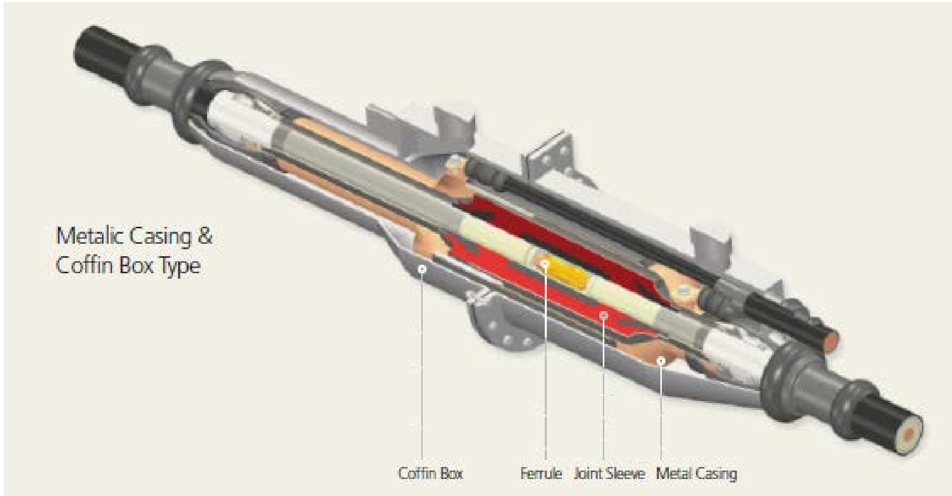
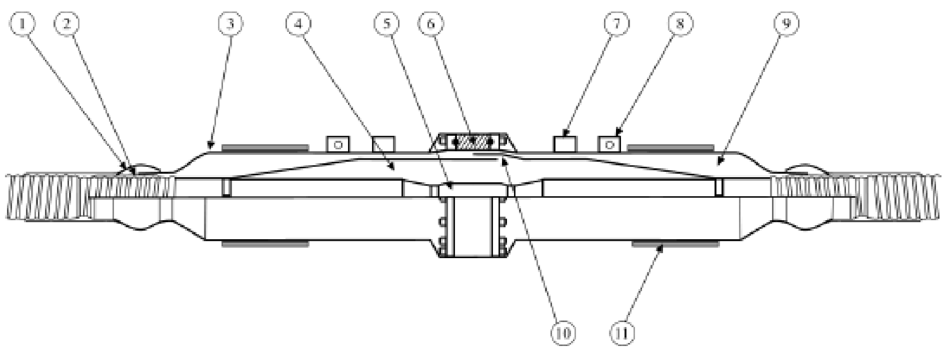
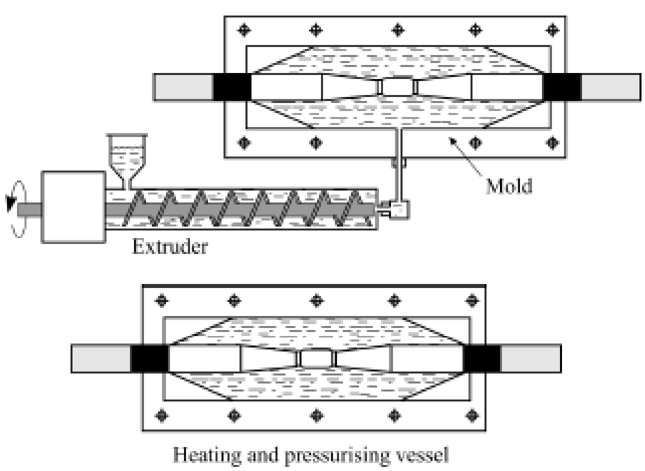


Figure 5-17. Field Molded Cable Joint



1) **Wipe**
2) **Metallic sheath**
3) **Metallic joint casing**
4) **Extrusion molded insulation**
5) **Conductor ferrule**
6) **Insulating barrier**
7) **Gas trap**
8) **Bonding lug**
9) **Joint filler**
10) **Shield gap**
11) **pd sensor**

Figure 5-18. Extrusion Process for Field Molded Cable Joint



5.5.2 One-Piece Premolded Design – Ethylene Propylene Diene Monomer Rubber

The one piece design consists of a premolded rubber body, Figure 5-19, or block made of ethylene propylene diene monomer (EPDM) rubber or silicon rubber.

The joint body is manufactured with a smaller diameter than the cable diameter over the insulation. When installed over the cable ends during splicing, the bore diameter expands by 20 to 30 percent. This stretch of the bore applies a compressive force to the interface between the inner surface of the joint body and the outer surface of the cable insulation.

The compressive force is critical in preventing voids formation at the interface which could lead to the inception of partial discharges in the voids during transient overvoltages on the cable or at applied line voltage which in time could result in the joint breakdown.

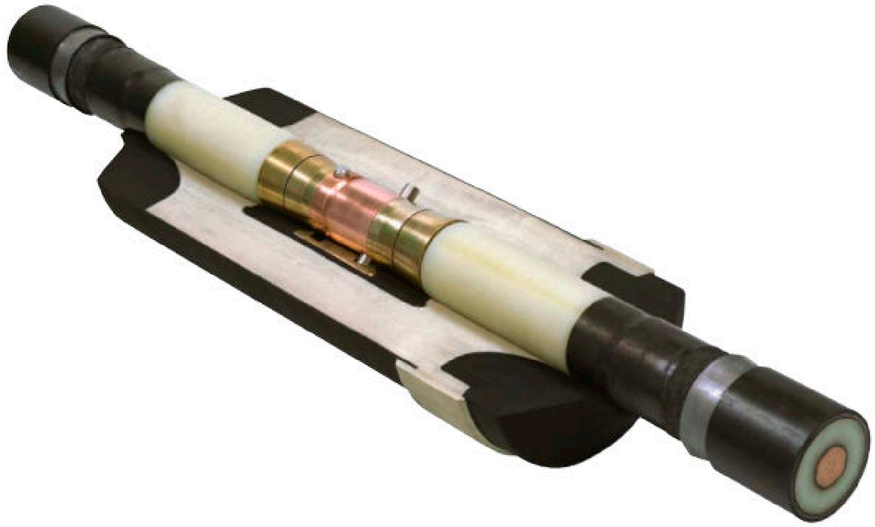
The rubber body is formulated to have elastic properties such that the stretch in the joint body and the resulting compressive force do not relax with time which would lead to the formation of voids at the interface.

Figure 5-19. One Piece EPDM Joint Bodies

5.5.3 One Piece Design – Silicon Rubber

This design, shown in Figure 5-20, is similar to the EPDM type except that silicon rubber is used which is softer and conforms well to the cable surface.

Figure 5-20. Silicone Rubber One Piece "Click Fit" Joint

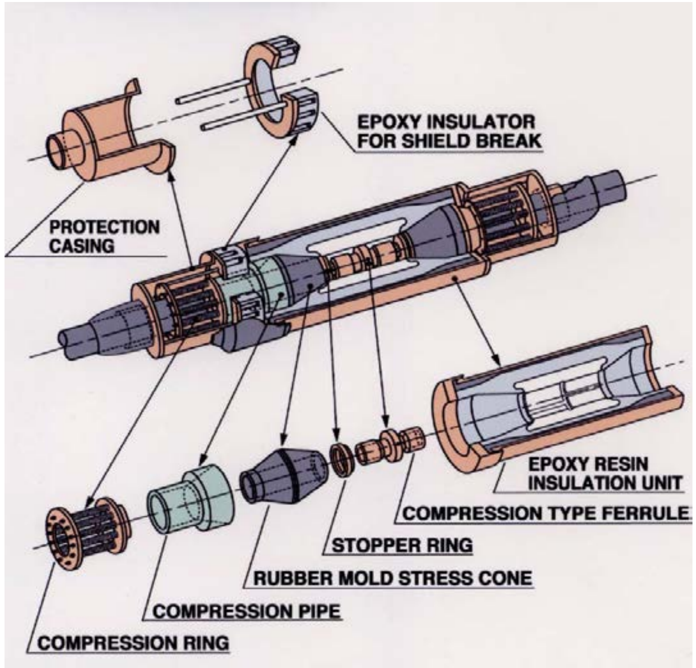


5.5.4 The Three-Piece Prefabricated or PJ

The three-piece design, Figure 5-21, consists of a center epoxy body, premolded stress cones and tensioning spring assemblies. The stress cones are made from EPDM and conform to the cable ends in a similar fashion to the one-piece EPDM body. The stress cones are pushed into the epoxy body during the assembly process and the tensioning springs are set to apply pressure to the stress cones. The spring assembly allows for the expansion and contraction of the joint components. Currently, there is not significant experience with this design at 500-kV, but they are an option at 230-kV.

These joints are also referred to as anchor joints since they lock or "anchor" the cable conductor into the epoxy body and prevent longitudinal movement of the conductor. The joints can withstand asymmetrical forces in excess of 15,000 pounds and should be a consideration for cable installed along routes with significant elevation changes to prevent downhill movement of the cables.

Figure 5-21. Prefabricated Three Piece Joint

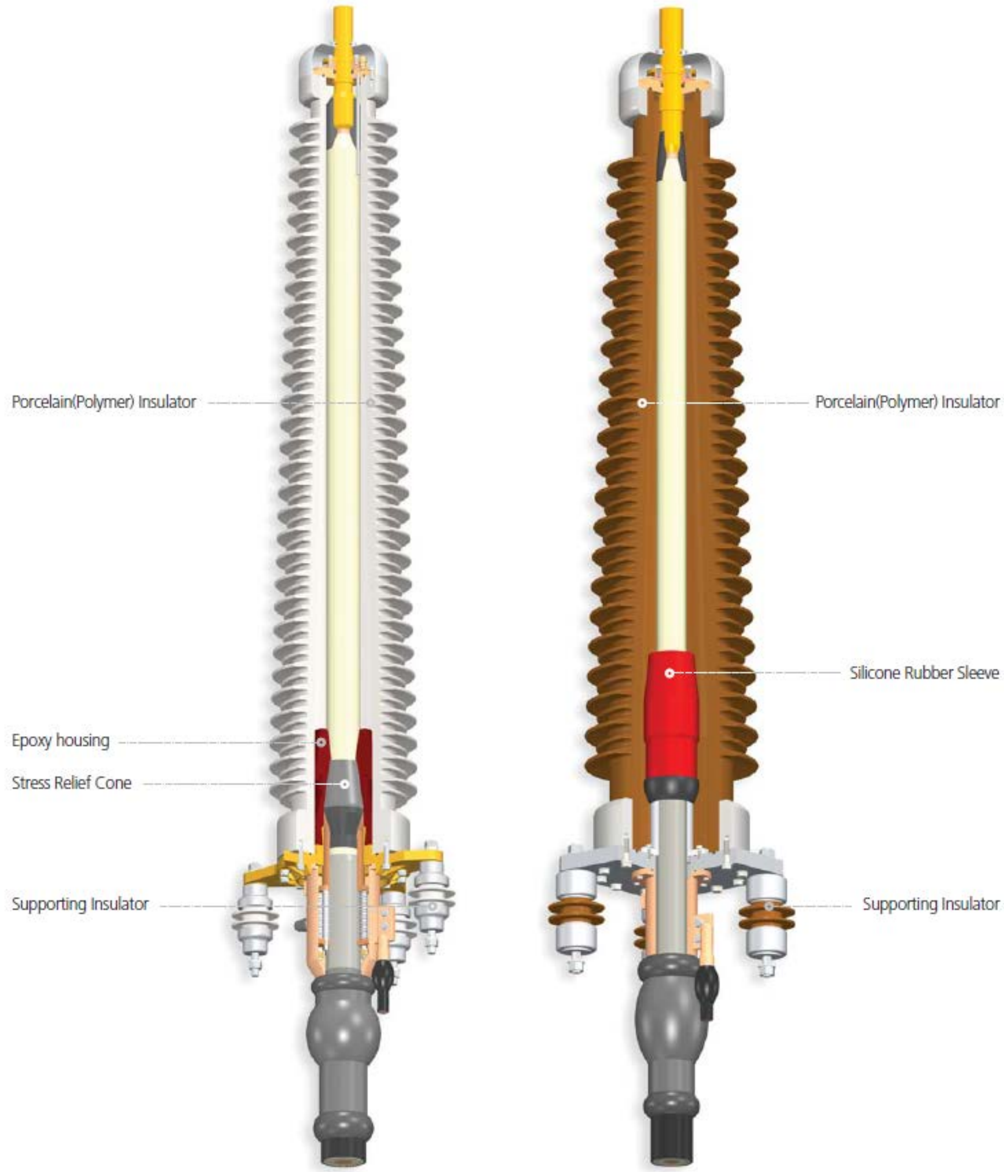


5.6 Cable Terminations

Cable terminations, Figure 5-22, are needed to transition from the underground cable to an overhead system. As in the case of joints, terminations are also available in a premolded type shown at right in Figure 5-23 and in a prefabricated type with the epoxy housing and tensioning springs shown also in Figure 5-23. Again, the premolded type presents a simpler solution for installation plus it requires less time and cost. The external bushing or housing is available in porcelain or as a polymer composite which consists of a fiberglass tube bonded to EPDM rubber.

Figure 5-22. 345-kV Cable Terminations

Figure 5-23. Cable Terminations



5.7 Worldwide Experience with HV and EHV XLPE Cables

The experience of XLPE insulated cables at voltage levels from 380-kV to 500-kV is described in Sections 5.7.1 and 5.7.2.

5.7.1 Experience with 500-kV XLPE Cables

There is only limited worldwide installation experience with 500-kV AC cables as Table 5-2 shows and most of these are in Japan. Additionally, installations that have joints are even rarer. Overall the table shows that reliability has been good but failures have occurred.

Table 5-2. 500-kV XLPE Installations Worldwide

Year	Phases x Length (ft)	Voltage (kV)	Conductor Size (Kcmil)	Installation Type	Supplier	Reported Failures (Year)	Location / Project
1993	7,873	500	1,578		Hitachi	0	Japan, Okumino Power Station
1996	2 x 65,103	500	4,933	Tunnel	Sumitomo	0	Japan, Shinkeiyo - Toyosu Line
1997	2 x 65,410	500	4,933	Tunnel	Hitachi	1 (2001)	Japan, Shinkeiyo - Toyosu Line
1998	2 x 5,293	500	1,973	Duct	Sumitomo		Japan
1999	1 x 7,217	500	1,973	Tunnel	Viscas	0	Japan, Kazunogawa Power Station
2000	1 x 5,903	500	1,578	Power Station	ABB	0	China, Yunnan Power Station
2001	6 x 1312	500	1,581			0	China, Dachaoshan Power Station
2005	8202	500	1,581		Sudkabel	0	Russia, Bureyskaya Power Station
2007	4,921	500	4,933				Russia
2010	112,532	500	4,933	Tunnel	Nexans	1 (2012)	China, Shanghai-Shibo
2010	17,716	500	1,581	Duct	Sudkabel	0	Columbia, Ponce III Power Station
2016	2 x 19,500	500	5,000	Duct	Not Selected Yet		US California, Chino Hills Underground Project

5.7.2 Experience with 345-400-kV XLPE Cables

There is considerably more worldwide experience with the 345-400-kV class of XLPE insulated cable system as reported in the initial Underground Route Study prepared for the I-5 Project and shown in Table 5-3.

Table 5-3. 345-400-kV XLPE Installations Worldwide

Country	Year	Voltage (kV)	Length (Miles)	Installation Type
Taiwan	2000	345	12.8	Tunnel
Korea	2003	345	12.2	Tunnel
USA	2006	345	8.6	Duct/manhole
USA	2007	345	2.4	Duct/manhole
USA	2008	345	8.1	Duct/manhole

Table 5-3. 345-400-kV XLPE Installations Worldwide

Country	Year	Voltage (kV)	Length (Miles)	Installation Type
Denmark	1997	380-400	13.2	Direct Buried
Germany	1998	380-400	7.8	Tunnel
Denmark	1999	380-400	7.5	Direct Buried
Germany	2000	380-400	6.5	Tunnel
Saudi Arabia	2000	380-400	7	Direct Buried
Iraq	2001	380-400	2.5	
Spain	2002	380-400	3.7	Tunnel
Abu Dhabi	2003	380-400	7.8	Direct Buried
Denmark	2004	380-400	16.8	Direct Buried/ducts
Italy	2006	380-400	10.4	Direct Buried
Spain	2004	380-400	15.9	Tunnel
UK	2005	380-400	12.8	Tunnel
UK	2005	380-400	3.4	Tunnel
Austria	2005	380-400	6.5	Direct Buried/Tunnel
Austria	2005	380-400	6.5	Direct Buried/Tunnel
Netherlands	2005	380-400	2.8	Direct Buried/ducts
Italy	2005	380-400	0.8	Direct Buried
UAE	2006	380-400	1.7	
Italy	2006	380-400	5.1	Direct Buried
UK	2007	380-400	8.3	Tunnel
Italy	2007	380-400	2.2	Direct Buried
Turkey	2007	380-400	8.2	Direct Buried
Netherlands	2007	380-400	0.9	Direct Buried/pipes
Netherlands	2008	380-400	4.9	Direct Buried
Qatar	2009	380-400	0.8	
Abu-Dhabi	2009	380-400	3.7	Direct Buried
Qatar	2009	380-400	10	
France	2009	380-400	3.1	Duct
Qatar	2010	380-400	13.7	Direct Buried
Qatar	2010	380-400	7.0	Direct Buried
Netherlands	2010	380-400	8.0	Direct Buried/pipes
Netherlands	2010	380-400	2.7	Duct
UK	2010	380-400	4.5	Direct Buried

Table 5-3. 345-400-kV XLPE Installations Worldwide

Country	Year	Voltage (kV)	Length (Miles)	Installation Type
UK	2010	380-400	6.8	Tunnel
UK	2010	380-400	1.1	Trough

5.7.3 Experience with XLPE Cables at 230-kV and 230-KV

There is substantial experience worldwide with 220-kV through 275-kV XLPE insulated cable systems and the cumulative experience with large conductor sizes is described by Gregory and Williams in their feasibility study for 500-kV AC cables for use in Edmonton, Canada.

5.8 Preferred Cable System

The preferred cable system for this project, both 500-kV and 230-kV, is a XLPE insulated cable system, which is environmentally friendly, requires less maintenance, and is relatively easier to operate and maintain than a paper insulated and oil-filled cable system such as HPPT and SCFF cables.

6.0 PROJECTED UNDERGROUND CABLE SYSTEM RELIABILITY BASED ON STATISTICAL DATA

6.1 Excerpts from CIGRE Technical Brochure 379

This section projects failure rates for the I-5 Project based on fault statistics for existing underground XLPE cable rated from 220-kV through 500-kV. The analysis is based on data published by CIGRE Working Group B1.10 Technical Brochure 379 titled “Update of Service Experience of HV Underground and Submarine Cables” last published in April 2009. CIGRE sent questionnaires to 73 Utilities in 24 different countries. CIGRE states the following:

- Data was collected for a time period of 5 years of from 2005 to 2009.
- More than 33,000 km of AC cables were in service as of the end of 2005.
- Not all cable systems were captured by the surveys although “it is felt that the data collected is representative and those trends in technology, design and service experience can be quantified.”
- Between the years of 2000 and 2005, almost all installed AC cables have been XLPE or single-conductor oil-SCOF cables with XLPE cables being the preferred type.
- For voltage levels above 220-kV, SCOF cables still account for more than 40% of the cables installed.
- The trend is for using XLPE cables with radial moisture barriers and adopting premolded accessories.
- Almost 50% of the faults were internal faults and 50 % were external faults.
- 77% of faults occurred in cables that were direct buried.
- Third party mechanical damage accounted for 34% of faults.

- The internal failure rates reflect the inherent performance of the cable system.
- It is not possible to compare failure rates of cable and accessories due to different scaling factors.
- Internal failure rates are greater at the higher voltage levels.
- Internal failure rates of SCOF and XLPE insulated cables are in line with previous data.
- Internal failure rates of accessories, particularly on XLPE cable, are of higher and of greater concern. Focus on quality control during jointing operations must be maintained.
- Repairs on SCOF cables take on average 29 days while XLPE cable systems require 20 days.

6.2 Underground Cable Type Installation Statistics

Table 6-1 shows the quantities of AC paper insulated, SCOF and HPOF, cables and extruded polymeric insulated, EPR, PE and XLPE land cable in service at the end of 2005.

Table 6-1. 220-500-kV AC Cables Installed

Cable Type	Sheath/Barrier Type	220-314 kV	315-500 kV	Totals
SCOF	N/A	2,342	724	
HPOF	N/A	579	24	
EPR	Extruded or welded metallic barrier	1		
EPR	No radial moisture barrier			
PE	Extruded or welded metallic barrier	397	1	
PE	No radial moisture barrier			
PE	Laminated barrier			
XLPE	Extruded or welded metallic barrier	1,114	229	
XLPE	No radial moisture barrier	1		
XLPE	Laminated barrier	23	21	
Total Polymeric cables installed 220-500-kV AC circuit length (km)		1,536	251	1,787
Total Paper cables installed 220 to 500-kV AC circuit length (km)		2,921	748	3,669
Total installed 220 to 500-kV AC circuit length (km)		4,457	999	5,456
% (Polymeric cables)		34	25	33
% (Paper cables)		66	75	67

Table 6-1 shows the following trends since 2000:

- For voltages levels above 220-kV, polymeric cables account for 33 percent of all cables.
- For voltage levels above 220-kV, SCOF cables account for 67 percent of the cables installed.
- For voltages above 315-kV, XLPE cables account for 25 percent of all cables.
- Polymeric PE insulated cables are no longer being used.

6.3 Underground Cable Accessories Installation Statistics

Table 6-2 shows the use of cable joints and terminations since 2000 for voltages above 220-kV. The table shows that premolded and site made joints are the type used for polymeric insulated cables.

Table 6-2. 220-500-kV AC Cable Accessories Installed

Cable Type	Sheath/Barrier Type	220-314 kV	315-500 kV	Totals
Extruded (EPR, PE, XLPE)	Premolded Straight joint	1,876	336	2,212
Extruded (EPR, PE, XLPE)	Site Made Straight joint	2,386	394	2,780
Extruded (EPR, PE, XLPE)	Transition joint	7		7
Extruded (EPR, PE, XLPE)	Outdoor Termination - Fluid filled - Porcelain	1,434	59	1,493
Extruded (EPR, PE, XLPE)	Outdoor Termination – Fluid-filled - Composite insulator	49	12	61
Extruded (EPR, PE, XLPE)	Outdoor Termination – Dry – Porcelain			
Extruded (EPR, PE, XLPE)	Outdoor Termination – Dry- Composite insulator	17	36	53
Extruded (EPR, PE, XLPE)	GIS or Transformer Termination – Fluid-filled	2,254	193	2,447
Extruded (EPR, PE, XLPE)	GIS or Transformer Termination – Dry	625	12	637
SCOF	Straight joint	10,909	2,936	13,845
SCOF	Stop joint	929	442	1371
SCOF	Transition joint	13		13
SCOF	Outdoor Termination Porcelain	3,367	775	4,142
SCOF	Outdoor Termination Composite Insula tor			
SCOF	GIS or Transformer Termination – Fluid-filled	2,809	1,023	3,832
HPOF	Straight joint	904	19	923
HPOF	Stop joint	8	8	16
HPOF	Trifurcating Straight joint	36	2	38
HPOF	Trifurcating Stop joint	8		
HPOF	Outdoor Termination Porcelain	214	30	244
HPOF	GIS or Transformer Termination – Fluid-filled	109		109
HPOF	Outdoor Termination Porcelain			
HPOF	GIS or Transformer Termination – Fluid-filled			
HPOF	Outdoor Termination Porcelain			

Table 6-2. 220-500-kV AC Cable Accessories Installed

Cable Type	Sheath/Barrier Type	220-314 kV	315-500 kV	Totals
HPOF	GIS or Transformer Termination			
HPOF	Transition joint			
Total number of installed AC accessories to the end of 2005		27,954	6,277	330,958

6.4 Underground Cable and Accessories Fault Statistics

Table 6-3 provides failure rates for underground XLPE cable systems and SCOF cable systems for 220-kV and above.

Table 6-3. Failure Rates for XLPE and SCOF Cables

A. Total – All Failures		XLPE Cables 220-500-kV	SCOF Cables 220-500-kV
Cable	Failure rate [failure/yr 100 cct.km]	**0.133**	**0.248**
Joint	Failure rate [failure/yr 100 comp.]	**0.048**	**0.014**
Termination	Failure rate [failure/yr 100 comp.]	**0.050**	**0.028**
B. Internal-Origin Failures		**XLPE Cables 220-500-kV**	**SCOF Cables 220-500-kV**
Cable	Failure rate [failure/yr 100 cct.km]	0.067	0.107
Joint	Failure rate [failure/yr 100 comp.]	0.026	0.010
Termination	Failure rate [failure/yr 100 comp.]	0.032	0.015
C. External-Origin Failures		**XLPE Cables 220-500-kV**	**SCOF Cables 220-500-kV**
Cable	Failure rate [failure/yr 100 cct.km]	0.067	0.141
Joint	Failure rate [failure/yr 100 comp.]	0.022	0.004
Termination	Failure rate [failure/yr 100 comp.]	0.018	0.013

CIGRE provides data for cable failures in 100 circuit-Km per year. Table 6-4 provides figures for failures for cables per year for 100 circuit-mile and for joints and terminations per year for 100 components for XLPE insulated cable systems from 220-kV through 500-kV.

Table 6-4. Failure Rates for XLPE Cables

Component	Units	Failure Rate
Cables – All Causes	Failures/Yr*100 circuit-mile	0.214
Joints – All Causes	Failures/Yr*100 components	0.048
Terminations – All Causes	Failures/Yr*100 components	0.050

6.5 Projected Failures for the I-5 Project

As described in Section 5.7.1, there is limited worldwide experience with 500-kV AC cable installations. Two failures have occurred as shown in Table 5.2. The limited 500-kV dataset makes failure projections for this voltage class impractical. As a result, the report utilizes the cumulative CIGRE statistics for failure rates of underground 220-kV to 500-kV cables and accessories, to project failure rates for cables, joints, and terminations for the I-5 Project, which are listed in the tables below. Table 6-5 shows anticipated failures occurring in the first year of operation. Table 6-6 contains the estimated number of failures in the system over a 40-year operational period. These tables indicate very low failure rates for both Scenarios and all components of the underground system.

Table 6-5. Projected Failures on I-5 in the First Year of Operation

Description	Units	Scenario 1 500-kV	Scenario 2 500-kV	Scenario 2 230-kV
Route Length	Miles	2.7	2.5	2.5
Groups of Cables	Each	4	4	2
Total Cable Length	Circuit-Miles	9.6	10.0	5.0
Number of Joints	Each	72	84	36
Number of Terminations	Each	24	24	12
Cable Failures	No.	0.023	0.021	0.011
Joint Failures	No.	0.040	0.035	0.017
Termination Failures	No.	0.012	0.012	0.006

Table 6-6. Projected Failures on I-5 for Forty Years of Operation

Description	Units	Scenario 1 500-kV	Scenario 2 500-kV	Scenario 2 230-kV
Route Length	Miles	2.7	2.5	2.5
Groups of Cables	Each	4	4	2
Total Cable Length	Circuit-Miles	9.6	10.8	5.0
Number of Joints	Each	84	72	36
Number of Terminations	Each	24	24	12
Cable Failures	No.	0.924	0.856	0.428
Joint Failures	No.	1.613	1.382	0.691
Termination Failures	No.	0.480	0.480	0.240

7.0 CABLE AND CONDUIT SYSTEM SELECTION AND DESIGN

7.1 Preferred Cable System

For high-voltage installation, the supply of a cable system has been either an XLPE insulated cable or a an oil-filled PPLP insulated cable system but the trend worldwide is for the use of the XLPE insulated cables due to their relative simplicity of installation, maintenance and repair as compared to SCFF cables. Also, the number of suppliers for SCFF cables has gradually decreased and few remain while ample supply exists for XLPE insulated cables. Therefore, the recommended cable system for the 500-kV cables and 230-kV cables is an XLPE insulated system. As the project progresses, BPA will consult with cable manufacturers and other entities for the selection of the cable system and components and the type of installation, which will determine the ultimate system configuration. The cable system and installation type described in this report are for scoping purposes only.

- Appendix A provides detailed information and drawings for the 500-kV XLPE cable system.
- Appendix B provides detailed information and drawings for the 230-kV XLPE cable system.

7.2 Cable Construction Used for the Study

The cable construction for the 500-kV and 230-kV cables used in this study is shown in Figure 7-1.

Figure 7-1. XLPE Cable Construction

7.2.1 Conductor

Detailed information on the cable construction for the 500-kV cables and the 230-kV cables is provided in Appendix A and Appendix B, respectively.

The following conductor type has been used for the study:

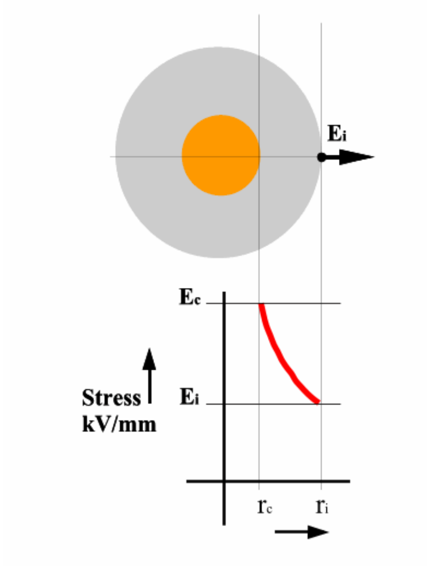
- Cross-sectional area: 5,000-kcmil copper segmental conductor for 500-kV cables

- Cross-sectional area: 5,000-kcmil copper conductor for 230-kV cables
- Construction: Milliken-type conductor construction with 5 or 6 segments
- Wires: Annealed enameled copper to reduce skin and proximity effects

7.2.2 Insulation

Figure 7-2 shows the electric field or “stress” distribution within the insulation of an AC cable with the stress being highest at the conductor shield and lowest at the insulation shield.

Figure 7-2. Stress Distribution in AC Cable Insulation



The insulation thickness for the 500-kV cable has been selected to provide a stress level of 7.0 kV/mm at the insulation shield which will appear at the interface between cable and joint body when the insulation shield is removed for jointing of the cables.

The stress level of 7.0 kV/mm is considered to be relatively safe for jointing purposes plus it minimizes the insulation thickness and reduces the overall diameter and weight of the cable and possibly the reel size. Additionally, this stress level is in line with other 500-kV AC project as shown in Table 7-1, as reported by Gregory and Williams.

Table 7-1. Insulation Thickness and Stress Distribution in Cables for Various Projects

Location	Cable Manufacturer	Year	Nominal Voltage (kV)	Conductor Size (mm2)	Insulation Thickness (mm)	Stress at Conductor Shield (kV/mm)	Stress at Insulation Shield (kV/mm)	Joints
Japan	Hitachi, Sumitomo, Furukawa & Fujikura	2000	500	2500	27	14.6	8.1	Yes
Japan	Sumitomo	1999	500	800	27	16.6	7.3	No
Germany]	Siemens	1999	400	1600	27	12.2	6.2	Yes

Table 7-1. Insulation Thickness and Stress Distribution in Cables for Various Projects

Location	Cable Manufacturer	Year	Nominal Voltage (kV)	Conductor Size (mm2)	Insulation Thickness (mm)	Stress at Conductor Shield (kV/mm)	Stress at Insulation Shield (kV/mm)	Joints
Germany	ABB	1999	400	1600	29.5	11.5	5.6	Yes
Germany	ABB	2000	400	1600	29.5	11.5	5.6	Yes
Germany	Nexans	2000	400	1600	27	12.2	5.6	Yes
Abu Dhabi	Pirelli	2000	400	800	29	12.7	5.3	Yes
Japan	Hitachi	1988	500	800	35	14.1	5.2	No
Denmark	NKT	1997	400	1600	32	10.9	5	Yes
USA	Sagem	2001	345	630	27	12.2	4.8	No
UK	BICC	1998	400	800	32	11.8	4.7	No
Switzerland	Alcatel	1998	400	800	32	12.3	4.6	No
Australia	Olex	1998	275	1200	27	8.9	4.1	Yes
Bulgaria[	Alcatel	1999	400	500	33.7	13.1	4	No
Singapore	BICC	2000	230	2000	24	7.2	4	Yes
USA	BICC	2000	230	1000	24	8.1	3.9	Yes
Spain	BICC	1999	220	1000	24	7.8	3.7	Yes
USA	Sumitomo	2002	230	1200	27	7.5	3.4	Yes
Ireland	ABB	1999	220	1600	25	7	3.4	Yes

7.2.3 Metallic Covering and Radial Moisture Barrier

HV and EHV XLPE insulated cables require a metallic covering which acts as a radial moisture barrier to the ingress of water and water vapor within the cable. Moisture or water ingress penetrates the insulation and causes a phenomenon called “water treeing,” which is detrimental to the reliability of the cable system. The metallic covering also acts as a low resistance path for the conduction of fault currents during short circuits and allows for bonding and grounding of the cables for safety of operation. There are several constructions of metallic radial moisture barriers available for XLPE and a few of the commonly used are listed below:

- Extruded seamless lead alloy sheath usually 4 to 5 mm in thickness
- Corrugated seamless aluminum (CSA) sheath usually 3 to 4 mm in thickness
- Corrugated longitudinally welded corrugated copper usually 3 to 4 mm in thickness
- Corrugated longitudinally welded stainless steel usually 3 to 4 mm in thickness
- Longitudinally welded smooth aluminum sheath usually 3 to 4 mm in thickness
- Copper wires placed under a lead sheath to reduce lead thickness and to improve transport of fault currents

- Copper wires places under a longitudinally welded smooth aluminum sheath
- Copper wires placed under a copper foil laminated tape
- Copper wires placed under an aluminum foil laminated tape
- Copper wires placed under a lead foil laminated tape

EPRI Report 1001846 titled *Cable System Technology Review of XLPE EHV Cables, 220 kV to 500 kV,* on page 4-32, provides a table listing metallic coverings and related characteristics in terms of suitability. This table is recreated in Table 7-2.

For the project, an extruded seamless lead sheath with copper wire screen has been selected for analysis and scoping purposes for the following reasons:

- It provides excellent protection as radial moisture barrier and good electrical and mechanical properties.
- This type of cable construction is available from most cable manufacturers.
- It provides for excellent corrosion resistance.
- It can be cathodically protected with packaged magnesium anodes placed below the manhole floor.
- The sheath losses can be relatively high, but the copper wires placed under the lead sheath reduce overall losses by improving conductivity.
- The disadvantage is that this construction results in cable which is relatively heavy.
- HV cables with external lead sheath have been used in duct and manhole systems for over 70 years with excellent performance.

Table 7-2. Characteristics of Various Cable Metallic Coverings

Description	Radial Water Barrier	Earth Return Current Capability	Electrical Conductivity	Mechanical Robustness	Corrosion Resistance	Ease of Longitudinal Water Blocking
Corrugated aluminum (thick) – extruded	1	1	1	1	2	5
Corrugated aluminum (thick) – longitudinally welded	2	1	1	2	5	5
Welded aluminum (thin)	2	3	3	4	5	2
Stainless steel – welded	2	6	6	2	3	5
Copper (thin) – welded	2	2	2	3	4	4
Lead – extruded	1	3	3	3	1	1
Aluminum foil laminate	3	5	5	5	7	2
Copper foil laminate	3	4	4	4	6	3/5

7.2.4 Oversheath or Jacket

High voltage cables are normally provided with on oversheath or jacket over the metallic sheath. The jacket provides for corrosion protection of the metallic sheath and it insulates the metallic sheath from ground so that the bonding methods can be implemented to reduce the flow of induced circulating currents. It prevents accidental contact with induced voltages in the metallic sheath.

Jackets for EHV cables are polymeric and thermoplastics and are slightly permeable to moisture. For the study, an extruded medium density polyethylene (MDPE) would be preferred with a solid metallic sheath such as lead or aluminum while a high density polyethylene (HDPE) would be preferred with a copper or aluminum foil laminate.

Either the MDPE or HDPE are acceptable because they provide high resistance to mechanical damage during installation, they provide good protection from environmental stress cracking, and are available from all manufacturers.

7.2.5 Overview of Cable 500-kV and 230-kV Construction

Table 7-3 provides an over overview of the 500-kV and 230-kV cable constructions used for analysis such as ampacity calculations for the study.

Table 7-3. Summary of Cable Construction

Voltage	Conductor Size (Kcmil)	Conductor Type	Insulation Thickness (Mil)	No of Shielding Wires (Ea)	Lead Sheath Thickness (Mil)	Jacket Thickness (Mil)	Semiconductive Layer Thickness (Mil)
500-kV	5,000	5 or 6 Segments	32	60	120	180	20
230-kV	5,000	5 or 6 segments	27	60	120	180	20

7.3 Cable Joints

The cable joint type preferred at 500-kV and 230-kV is, either, the one-piece premolded or the three-piece prefabricated. The three-piece prefabricated provides for anchoring capabilities of the cable conductor. This anchoring ability prevents downhill sliding motion of the cables as a result of asymmetrical forces present along route profile having steep slope changes. However, with respect to the three-piece prefabricated, the one-piece premolded joint provides for a simpler solution, costs less in the supply and installation, requires a smaller manhole, is easier to install, and is available from all EHV cable suppliers.

7.4 Cable Termination

Cable terminations recommended at both 500-kV and 230-kV are of the premolded type or the prefabricated type. Terminations at 500-kV which use paper rolls as condenser cones for electrical stress relief are also a viable option.

7.5 Cable System Installation Options

There are three basic installation types that have been used for cable installations and are as follows:

- Conduit and Manhole System
- Direct Buried System
- Tunnel

For the project, a duct and manhole system installed by an open-cut trench in conjunction with horizontal directional drilling and jack bore to cross large obstructions is the preferred installation as described in Section 9.0.

7.6 Cable System Bonding and Grounding

The preferred bonding and grounding method for both the 230-kV and 500-kV cables will consist of a combination of single point bonding and cross-bonding. The final bonding system scheme will have to be determined at time of final design.

For cross-bonding to be used alone, the number of cable spans or minor sections will need to be divisible by three. If the number of spans is not divisible by three then some of the cable spans will require a single-point bonding system.

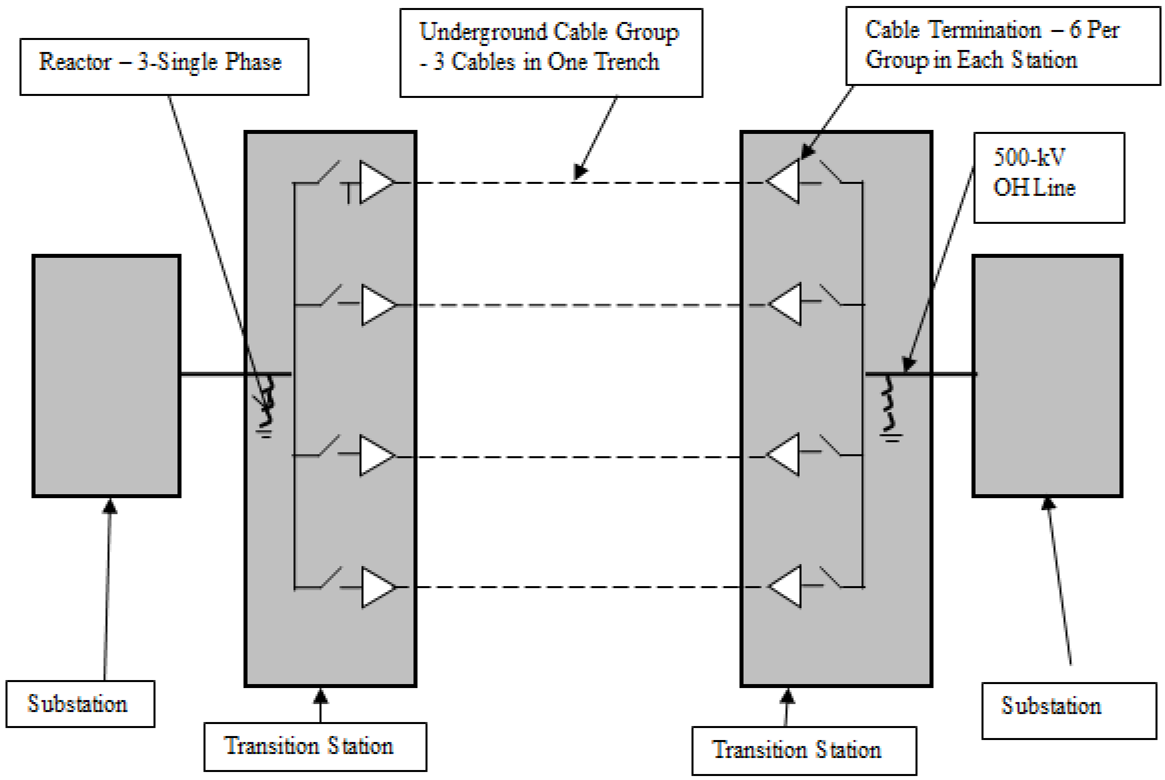
Star impedance bonding, which uses sheath-bonding transformers and is referred to as zig-zag transformers, should be considered as a viable option as it offers advantages over cross-bonding and single-point bonding configurations.

7.7 General Installation Configuration

7.7.1 500-kV Cables – Scenarios 1 and 2

In order to obtain an ampacity of 4,560 amperes equivalent to 3,950 MVA, each overhead circuit phase will require four underground cables per phase for a total of 12 cables, which would be arranged in four cable groups with three cables per group. Each cable group would need to carry 4,560/4 = 1,140 amperes. Figure 7-3 shows schematically the four cable groups with a dashed line representing one cable group.

Figure 7-3. 500-kV Configuration – Scenarios 1 and 2



For this study, an equilateral triangle arrangement was chosen for the cables in trenches as shown in Figure 7-4 instead of a flat horizontal configuration. This cable arrangement provides for the excavation of a narrower trench and less impact, lower induced voltages on the cables metallic sheaths, and lower EMF field above the trench depending on the spacing of the cables.

7.8 Trench Configuration

The ampacity calculations and cost estimating done for this study are based on the equilateral triangular trench configuration shown in Figure 7-4 and using the associated dimensions given in Table 7-4.

Figure 7-4. 500-kV Trench Configuration

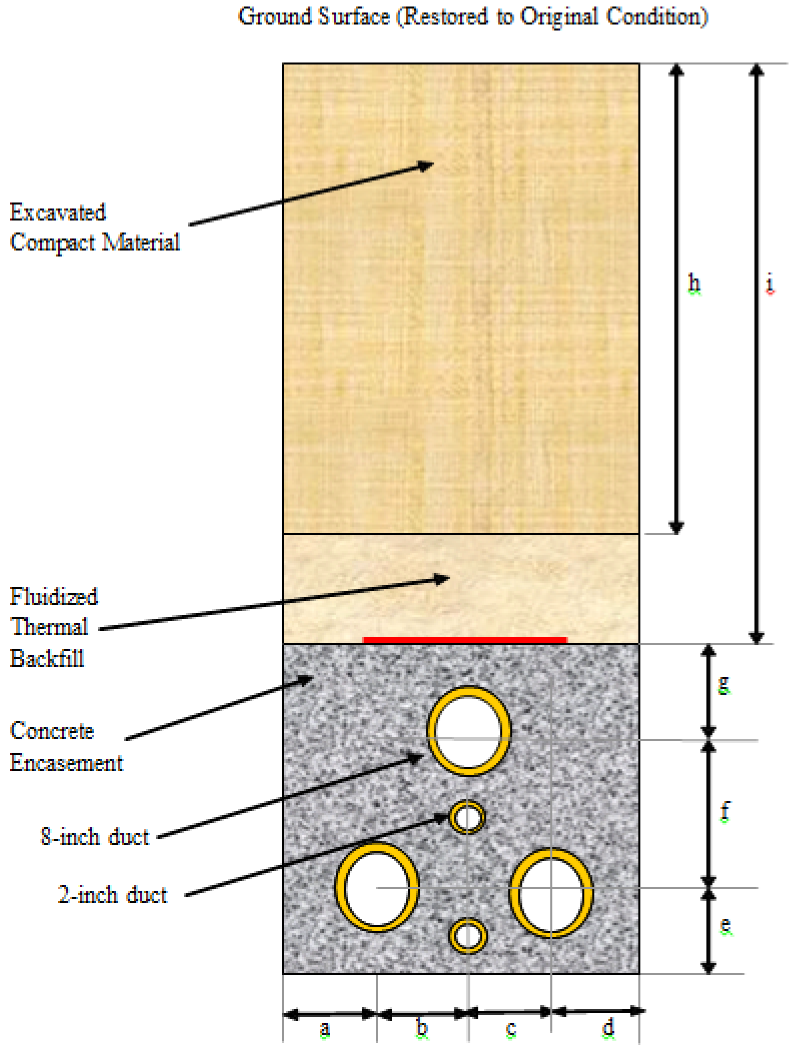


Table 7-4. 500-kV Trench Dimensions

Dimension	Length (in)
a	7.5
b	7.5
c	7.5
d	7.5
e	8.6
f	13
g	8.6
h	36
i	48

7.9 Conduits

The conduits for this installation are PVC, Schedule 40, 8-inch nominal size with 8.865-inch outside diameter (OD). The conduits are encased buried-type with bell and spigot glued-type joints. During construction, the open ends of the conduits in vaults and at terminal locations shall be sealed with plugs to prevent ingress of water and other foreign matter. Polyethylene or PE conduits with fusion welded joints can be used in bore casings for river and highway crossings. Smaller ducts shall be 2-inch nominal size PVC meeting the requirements outlined above.

7.10 Conduit Spacers

Conduits are assembled above the trench or within the trench with plastic conduit spacers in order to maintain the formation and separation between ducts.

7.11 Trench Backfill

In order to meet ampacity requirements and to prevent overheating of the cables, the thermal resistivity of backfills and soils placed around the cables must be known and controlled. As a result, trench backfill will consist of concrete placed around the ducts and thermal backfill placed above the concrete if needed depending on the native soil thermal characteristics along the route. Excavated compacted material can be placed over the thermal backfill if it has suitable thermal resistivity to meet the ampacity requirements.

7.11.1 Concrete

The concrete encasing the conduits would consist of a mix of gravel, sand and cement to provide a compressive strength of 1,700 to 2,000 psi to protect the cables from third party damage but also to be re-enterable in the event that the duct bank must be re-excavated for repair. The thermal resistivity of the concrete has been taken at 85°C-CM/Watt.

7.11.2 Thermal Backfill Placed Above the Concrete Encasement

The thermal backfill placed above the concrete encasement is part of the overall thermal circuit for the cables and would be a fluidized thermal backfill (FTB) consisting of a weak mixture of sand, cement and fly ash and having a thermal resistivity of not more than 110°C-Cm/Watt at less than 1 percent moisture as determined by dry out thermal resistivity curves.

The FTB could also consist of a fluidized mixture of sand, gravel and cement having a thermal resistivity of not more than 110°C-Cm/Watt at less than 1 percent moisture. The FTB compressive strength should be less than 200 psi to allow for ease of removal and access to the concrete encased conduits and cables for repairs.

When crossing minor roads or small streets, the thermal backfill shall extend all the way to below the roadway surface to provide structural support for the pavement. However, when crossing agricultural land, the top of the thermal backfill must be below the disturbance point of agricultural equipment in order to prevent interference and potential removal

7.11.3 Backfill Placed Above Thermal Backfill

The backfill placed above the thermal backfill is also part of the overall thermal circuit for the cables and can consist of compacted excavated material if having suitable thermal properties. Likewise, the soil or ambient earth surrounding the trench is also part of the thermal circuit.

The native natural soil should have a thermal property of 110°C-Cm/Watt at 2 to 3 percent moisture. In-situ thermal resistivity measurements shall be made at 1,000 feet interval along the route to determine the in-situ thermal resistivity. Additionally, samples of the native soil shall be taken and reconstitute in a laboratory setting to 90 percent proctor density and the density and dry out thermal curves shall be determined to determine suitability for re-use as a trench backfill.

If the native soil thermal properties do not meet the above requirements, then the fluidized thermal backfill or other suitable material shall be used. If unsuitable soil conditions are found along parts of the trench such as the content of organic material, then this soil shall be removed and replaced with other suitable material. The amount of removal will depend on site conditions at time of trench excavation.

Local regulation may govern when topsoil can be removed, the type of storage required during construction activities, and its final replacement for permanent restoration.

7.12 Warning Tape

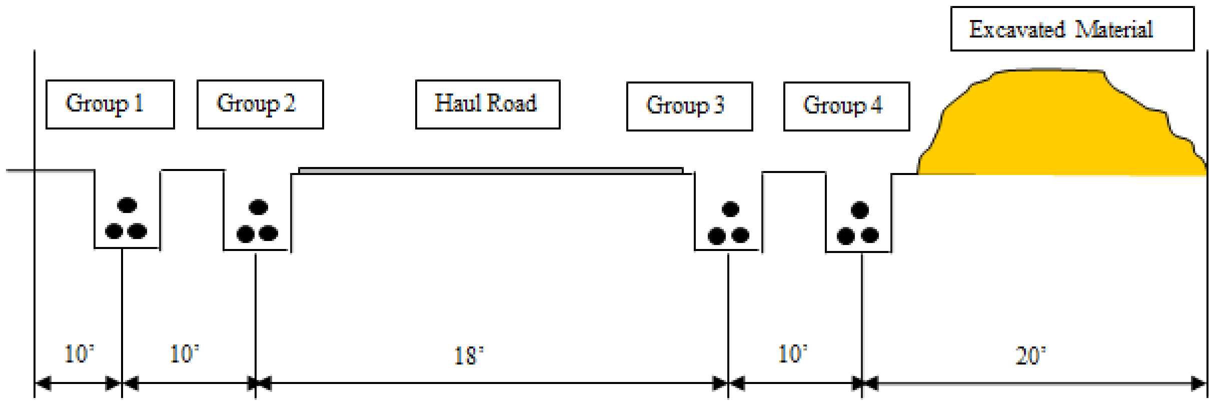
A plastic warning tape shall be placed above the concrete encasement below the thermal backfill for the entire trench length for every cable group to warn of the presence of high voltage cables below to minimize third party damage.

7.13 Number and Spacing of Trenches for Scenario 1

Each three-cable group is installed in a separate trench for a total of four trenches as shown in Figure 7-5. Groups 1 and 2 and Groups 3 and 4 are spaced 10 feet apart and separated by a haul/maintenance access road. The spacing between Group 2 and Group 3 is 18 feet as this provides room for an access road between the two sets of cable groups. This arrangement provides for an ampacity rating of 1,140 amperes per cable group up to a depth of 10 feet. Placing the cables in separate trenches provides better protection in limiting third party damage and most likely repairs would be limited to one cable group in one trench.

For the Cowlitz River crossings, where each cable group will be in a 30-foot deep casing, ampacity calculations shall be conducted during final design using data obtained by in-situ thermal resistivity measurements in order to ensure that the required 4,560 A rating can be met with natural cooling. There are other obstructions such as the crossings of the BNSF railroad tracks and Interstate 5 where ampacity calculations will need to be repeated based on actual in-situ thermal resistivity measurement data.

Figure 7-5. Cable Group Arrangement – Scenario 1

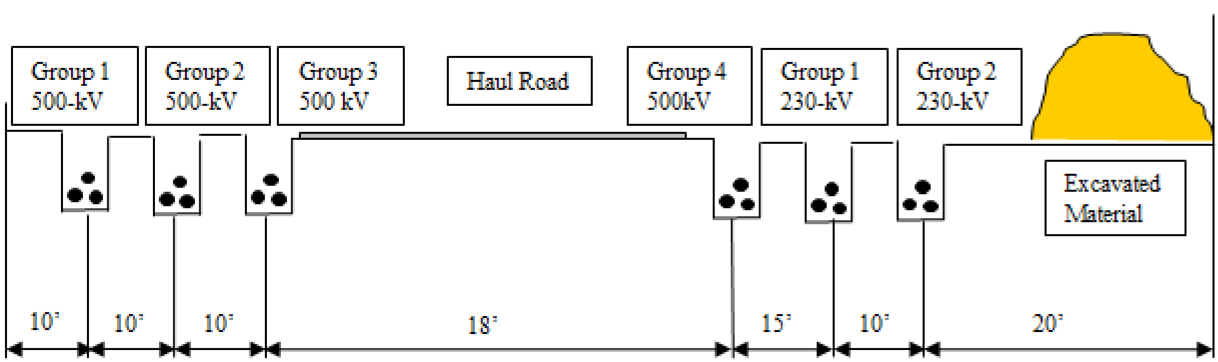


7.14 Number of Trenches and Spacing for Scenario 2

Each 500-kV and 230-kV cable group is installed in a separate trench for a total of six trenches as shown in Figure 7-6. The spacing between the 500-kV Cable Groups 1, 2, and 3 is 10 feet. The 500-kV Cable Groups 3 and 4 are spaced 18 feet apart and separated by an access. The spacing between the 500-kV Cable Group 4 and the 230-kV Cable Group 1 is 15 feet while the spacing between the 230-kV Cable Groups 1 and 2 is 10 feet. This arrangement provides for an ampacity rating of 1,140 amperes per cable group for the 500-kV cables and 1,520 for the 230-kV cables down to a depth of 10 feet to the top of the concrete encasement. As indicated earlier, placing the cables in separate trenches provides better protection against third party damage plus repairs only impact the affected cable group in a particular trench.

For the Washougal River crossing, where each cable group will be in a 30-foot deep casing, ampacity calculations shall be conducted during final design using data obtained by in-situ thermal resistivity measurements in order to ensure that the rating of 4,560 A for the 500-kV cables and 1,520 A for the 230-kV cables can be met with natural cooling. There are other obstructions such as the crossings of the BNSF railroad tracks and SR-14 where ampacity calculations will need to be repeated based on actual in-situ thermal resistivity measurements.

Figure 7-6. Cable Group Arrangement – Scenario 2



7.15 Manholes

The preferred manhole type for this installation would be precast concrete tunnel-type, as seen in Figure 7-7. This type of manhole is manufactured in prefabricated sections consisting of two end sections and rectangular tunnel-type middle sections. The overall length of the manhole can be increased by adding additional middle sections. The manhole sections are prefabricated and delivered to the installation site on a transport vehicle. The sections are installed from the transport vehicle into the excavations by means of a crane.

The length of the manhole for jointing purposes will vary depending on the type of joint used and also on the equipment arrangement in the manhole as recommended by the cable supplier. Typical manhole dimensions would be 36-48 feet long by 10 feet wide by 10 feet tall, which are all outside dimensions depending on the type of joints selected and the equipment arrangement in the manhole. The wall, ceiling, and floor concrete thickness should be 12 inches. A poured concrete slab or an I-beam structure is recommended to be placed at the bottom of the excavation to ensure alignment and leveling of the manhole sections.

Arrangement of the cable in a straight-through rigid design which does not allow for cable expansion within the manhole but force the expansion within the conduit may require smaller manholes. Arrangement of the cable in an offset design that allows for cable expansion within the manhole may require larger manholes.

A drawing of a typical tunnel type manhole is provided in Appendix D.

Figure 7-7. Tunnel-Type Manhole Installation

7.16 Impact of Interfering Substructures and Major Obstructions on the Route

Existing interfering substructures such as storm drains, sewer lines, pipelines, other underground utilities and major obstructions such as the railroad crossing, the Interstate 5 crossing and the river crossings may cause unfavorable conditions for the selected route. These conditions will have a negative impact on the current carrying capacity of the cables.

The conditions which will be encountered are an increase in the depth of the cables in trenches as a result of crossing under substructures, the installation of cables in deep bores by HDD to cross the rivers, and the installation of cables in bores by jack and bore to cross highways.

An increase in ambient earth temperature resulting from steam lines or other electrical cables crossed or paralleled by the 500-kV and 230-kV cables will also cause a decrease in the ampacity.

Consequently, at final design, as surveys of existing infrastructure are done, soil samples are collected and thermal resistivity studies are conducted; the design may have to be optimized at individual locations to determine ampacity.

To retain the ampacity requirements of the cables at increased depth, it may be necessary to increase the spacing between cables and between cable groups for cable installed in trenches. For cable in deep bore casings, it may be necessary to increase the spacing between the bores when crossing major obstructions. The use of forced cooling especially for cables in deep bores may be considered as an option.

7.17 Trenchless Technology: Jack and Bore and HDD

The crossing of the Cowlitz River, BNSF Railway tracks, the I-5 freeway, and state highways will require the installation of casings by horizontal directional drilling under the obstructions. Likewise, the crossing of highways and railroads will require the installation of casings by jack and bore under the obstructions. The crossing of the Washougal River will require installation of a casing by HDD for the cable to cross. Following the installation of the casings, conduits are installed in the casings followed by the grouting of the casings.

7.17.1 Casings Types for Trenchless Technology

There are three different types of casings that can be used, which are as described below.

Steel Pipe

Steel pipe is used both for jack and bore and HDD and has little effect on the thermal resistance of the thermal circuit due to the steel construction. The pipe is available in sizes up to 110 inches in outside diameter and different wall thicknesses and comes in 20 foot lengths which must be welded together for installation in the bore hole. Railroad companies require a steel casing when crossing rail tracks.

High Density Polyethylene (HDPE) Pipe

HDPE pipe is a HDD application and is available up to 120 inches in diameter and different wall thickness. The wall thickness of the HDPE pipe will introduce another thermal resistance and will slightly decrease ampacity of the power cables. Pipe sections are fused together for installation in the bore hole.

HOBAS Pipe

HOBAS pipe for trenchless installations is a corrosion resistant, centrifugally cast, glass-fiber reinforced polymer mortar, tubular product connected with push-together, rubber ring-sealed joints. The pipe and joints may be pressure or non-pressure rated depending on the application. The nominal diameter range is 18" to 126" with a maximum section length of 20 feet. In all installations, HOBAS pipe is designed as semi-rigid, flexible conduit to withstand all loads without structural aid from old pipes or primary tunnel liners.

7.17.2 Grouting of the Casing Pipe

Grouting of the casing pipe to fill the annular space between the outside of the conduits and the inner surface of the bore casing pipe will be critical to completely fill all void spaces and so prevent a detrimental impact on ampacity. One important factor to be considered for grouting the pipe is the length of the HDD installation because the difficulty of the grouting operation increases with installation length.

Other considerations are the total surface area of all components including the casing, number of conduit spacers, net opening in the spacers, changes in elevation, the diameter of the grouting pipe, the limiting pumping pressure for conduits and joints, the limiting hydrostatic pressure, and the total volume to be filled-in. The type of pumps relating to the rate of pumping and maximum surge pressure plus the pumping method in grouting from one end or both ends of the pipe casing or the use of multiple grouting pipes are additional considerations.

Of critical importance is the quality control and assurance during the actual grouting phase to ensure that the casing is completely filled. The filling grout must be specially formulated to ensure a low thermal resistivity. The grout must also have adequate compressive strength, high fluidity (low time of efflux), low heat of hydration, slow rate of hardening and no segregation or settlement.

The grouting operation, once started, must be conducted without stopping. It is also critical to fill the void between the inner bore hole and the outer surface of the casing. This can be done with bentonite or the grout material.

It is critical to make a mock-up of the bore installation followed with grouting to verify the conditions in the actual installation and to ensure that any unforeseen problems or technical problems with the grout and pumpability are found and resolved at this stage.

7.17.3 Configuration for BNSF Railroad and Interstate 5 (Scenario 1) and SR 14 Crossing (Scenario 2) by Jack and Bore

The study assumes a launching pit of 40 feet by 10 feet and a receiving pit of 20 feet by 10 feet with four individual holes bored for Scenario 1 and six individual bore holes required for Scenario 2. Steel or HOBAS pipe casings with minimum diameter of 30 inches would subsequently be installed within each bore hole. The spacing between each bore would be a minimum of 10 feet for Scenario 1 and 12 feet for Scenario 2 while the depth of the bores would be a minimum of 5.5 feet below the top of the rail tracks.

Subsequent to the installation of the casings, three 8-inch PVC conduits and two 2-inch PVC conduits would be installed in the individual casings followed by the grouting of the casings.

Geotechnical analyses will be conducted as required and thermal resistivity measurements will be taken down to the depth of the cables. A re-evaluation of the bore diameter and casing diameter and spacing should be conducted following the geotechnical and thermal resistivity analysis of the native soil at different depth down to the cable depth.

7.17.4 Configuration for the Cowlitz River Crossing by HDD (Scenario 1)

The study assumes a launching area of 150 feet by 100 feet and a receiving area of 100 feet by 100 feet with four individual holes bored. Steel or HDPE pipe casings with minimum diameter of 36 inches would subsequently be installed within each bore hole. The spacing between each bore would be a minimum of 30 feet with the depth of the bores being a minimum of 30 feet below the river bed to minimize the possibility of a ‘frac-out” which is the inadvertent release of drilling mud or bentonite.

Subsequent to the installation of the casings, three 8-inch PVC conduits and two 2-inch PVC conduits would be installed in the individual casings followed by the grouting of the casings.

Geotechnical analyses will be conducted. It will be critical to conduct in-situ and thermal resistivity measurements of the native soil down to the depth of the cables. The cables will cross all strata of soil from 4-foot depth to 30-foot depth and the thermal properties of these soil layers must be determined. A re-evaluation of the bore diameter and casing diameter and spacing should be conducted following the geotechnical and thermal resistivity analysis of the native soil at different depth down to the cable depth.

7.17.5 Configuration for the Washougal River Crossing (Scenario 2)

The study assumes a launching area of 150 feet by 100 feet and a receiving area of 100 feet by 100 feet with four individual holes bored for the 500-kV cables and two individual bore for the 230-kV cables. Steel or HDPE pipe casings with a minimum diameter of 36 inches would subsequently be installed within each bore hole. The spacing between each bore would be kept at a minimum of 30 feet. The separation between the 500-kV casings and the 230-kV casings would be 40 feet. The depth of the bores would be a minimum of 30 feet below the river bed to minimize the possibility of a ‘frac-out” which is the inadvertent release of drilling mud or bentonite.

Subsequent to the installation of the casings, three 8-inch PVC conduits and two 2-inch PVC conduits would be installed in the individual casings followed by the grouting of the casings.

Geotechnical analyses will be conducted. It will be critical to conduct in-situ and thermal resistivity measurements of the native soil down to the depth of the cables. The cables will cross all strata of soil from 4-foot depth to 30-foot depth and the thermal properties of these soil layers must be determined. A re-evaluation of the bore diameter and casing diameter and spacing should be conducted following the geotechnical and thermal resistivity analysis of the native soil at different depth down to the cable depth.

7.17.6 Configuration for Wetlands Crossings

Crossing of wetlands would require trenchless construction by HDD. The configuration for the crossings would be the same as for the river crossings as discussed above for both Scenario 1 and 2.

7.18 Thermo-Mechanical Design

Thermo-mechanical design for the project will be critical to assure overall reliability and will require analysis of the cables expansion with loading, sliding or downhill movement of the cables on slopes, the methods of controlling cable expansion and the restraining or fastening of the cables to prevent downhill movement on slopes.

7.18.1 Cable Expansion

The cable will expand and contract daily as a result of the daily load cycle. The amount of expansion will depend on the length of cable between manholes, cable cross sectional area, cable weight, cable young modulus of elasticity, and coefficient of friction between duct and cable. The expansion will be non linear until the cable reaches a critical temperature. Above this critical temperature the cable expansion will be linear and will follow the ideal copper law.

7.18.2 Control of Cable Expansion and Cable Trust Forces

The cables will expand and contract with the daily load cycle which will produce a cyclic expansion and contraction. The expansion of the cables will require investigation through a thermo-mechanical design which will be based on the ultimate cable construction selected, the distance between manholes and the cable configuration or racking configuration in manholes.

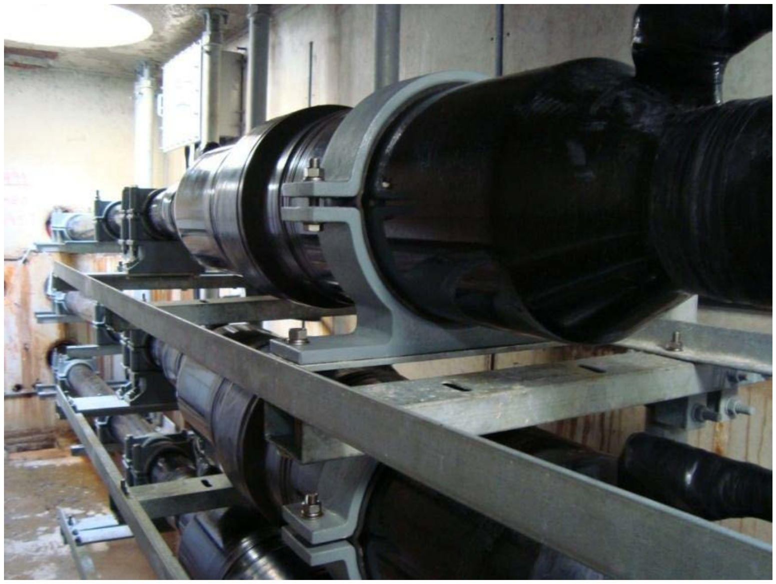
The cable expansion will also produce conductor thrust forces. The semi-rigid and flexible designs allow for the cable expansion to occur in the manhole at cable offsets and produce small thrust forces. Rigid design or straight-through design force the cable to expand in the conduit and produce very large thrust forces which are in the tons depending on the cable construction and conductor size. Snaking and corkscrewing of the cables in conduit can occur as shown in Figure 7-8.

Figure 7-8. Cable “Snaking” in Conduit

7.18.3 Control of Cable Expansion – Rigid Design

The rigid design method is also referred to as the “straight-through” design where the cables and joints are assembled in a linear or straight assembly and both are securely fastened with cleats and clamps so that no movement or cable expansion occurs in the manhole. The cable expansion is forced into the conduit line. Figure 7-9 shows 230-kV cables and joints as a straight-through design.

Figure 7-9. 230-kV Joints in "Straight-Through" Rigid Design



7.18.4 Control of Cable Expansion – Semi-Rigid Design

This semi-rigid design method is also referred to as the "offset design" and it is similar to the floating stiffener design except that the joints are securely fastened to the supporting steel structure and are not free to move. The cables are trained in an "S" shape or offset between the joint and the manhole entry. Figure 7-10 shows a cable offset design with solidly fixed 230-kV three-piece prefabricated joints.

Figure 7-10. 230-kV Prefabricated Joints in Offset Semi-Flexible Design

7.18.5 Control of Cable Expansion – Non-Rigid Design

The non-rigid design method is also referred to as the "floating stiffener design" and is similar to the semi-rigid design except the joints are allowed to move or float on a stiffened steel base. As the cables expand, the joints move toward the manhole wall. The cables will move away from the wall as they cool.

The cables are trained in offset between the joint and the manhole entry. Figure 7-11 shows a non-rigid design with 138-kV XLPE cable joints mounted on floating, steel channel stiffeners. Neither the joints nor the cables are restrained and the assembly is free the move.

Figure 7-11. 138-kV XLPE Cable Joints on Floating Stiffener in Flexible Design

7.18.6 Summary of Thermo-Mechanical Designs

Table 7-5 provides a summary of the characteristics associated with individual cable and joint arrangement designs in manholes.

Table 7-5. Summary of Thermo-Mechanical Designs

	Rigid – Straight-Through Design	Semi-Flexible – Offset Design	Flexible Design
Cable Movement in Manhole	Low	High	High
Joint Movement in Manhole	None	None	High
Thrust Forces	High	Low	Low
Cable Clamping	Complicated	Simple	Simple
Installation Type	Direct Buried or Duct and Manhole	Duct and Manhole	Duct and Manhole

7.19 Methods of Securing Cables in Steep Terrain

Cables installed in conduits in areas with steep terrain must be fastened in order to prevent downhill movement of the cables as a result of cable expansion with the daily load cycle. Cables with armoring such as steel wires and flat straps have been used on steep slopes and on risers. The steel wires and/or straps are secured to an anchoring device inside the manhole or at the riser location to prevent downhill sliding of the cables.

Three other methods that have been used alone or in combination to secure high voltage cables on steep terrain are fastening the cables with cleats or clamps in pull-through manholes, fastening the cables in manholes with cleats or ratcheting devices, and the installation of three-piece prefabricated anchoring joints which have been previously described in Section 5.5.4.

7.19.1 Fastening of Cables in Pull-Through Manhole

In this system, pull-through manholes are installed between splicing manholes. Subsequently, the cables inside the pull-through manhole are secured with cleats or ratcheting devices. Drawings of the cable cleating arrangement in the pull-through manhole and of cable cleats or clamps are provided in Appendix C. The advantage of this system is that it allows for additional fastening points of the cables along the cable route in addition to the splicing manholes. A disadvantage is a significant cost increase due the installation of additional manholes.

7.19.2 Ratcheting Device

Ratcheting devices have also been used to restrain cables on slopes. A drawing of the ratcheting devices is provided in Appendix C. With reference to the drawing, the device consists of the following two main components:

1. Eight longitudinal coil springs which are fastened at one end of the manhole end wall and allow for the cable to move longitudinally into the manhole, and
2. A cable cleat with through bolts fitted with springs to allow for cable radial expansion and prevent deformation of the cables.

The principle of operation behind the ratcheting device is to allow the cleat to move into the manhole against the reaction force supplied by the 8 coil springs, see Figure 7-12. This movement reduces the thrust exerted by the cable to a value which one cleat can still grip. Ideally, the cleat should never reach this condition as the cable would permanently move into the manhole.

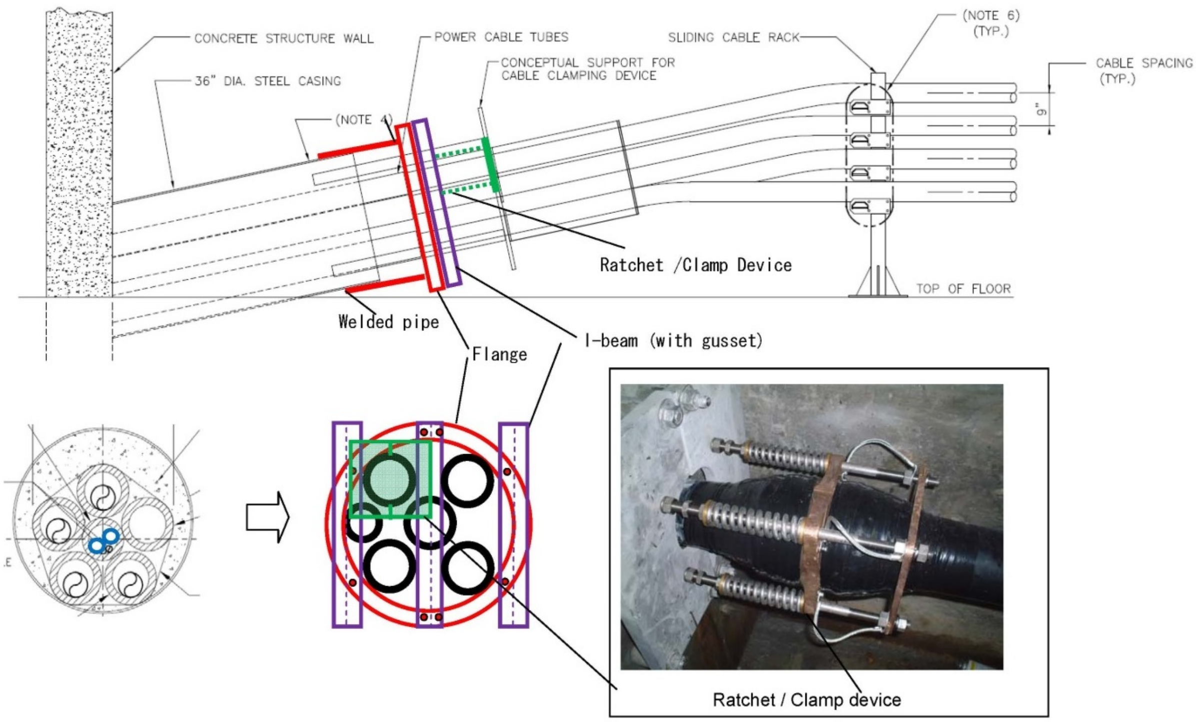
The ratcheting devices have to be individually designed for specific section lengths, slope, and forces. The highest gripping strength is in the order of 1,500 Kgf or 1.5 tons. If this value is exceeded the cable will slip through the device.

Figure 7-12. Ratchet Devices on 230-kV XLPE Cables with Lead Sheath

Figure 7-12 shows ratcheting devices installed on 230-kV cables as they enter the manhole. The devices are anchored to the concrete at the manhole end wall. This spring loaded cleat-type ratcheting devise can be used on cables with lead alloy sheath or cables having copper, lead or aluminate laminate foils as a moisture barrier.

Figure 7-13 shows a different ratcheting devise design which can been used to fasten cables with corrugated aluminum or copper sheath. This device has a higher gripping force than the spring loaded cleat device shown in Figure 7-12.

Figure 7-13. Ratcheting Device Used to Fasten Cables with Corrugated Type Sheaths



7.19.3 Anchor Joints

Anchor joints may be required in both Scenario 1 and 2 to prevent downhill movement of cables on steep slopes as described in Section 5.5.4.

7.20 Summary of Cable System Requirements for the 500-kV Cables

Table 7-6 provides a quick overview of the system requirements for the 500-kV cables.

Table 7-6. System Requirements for 500-kV Cable Systems

		Scenario 1		Scenario 2	
Item	Unit	Per Cable Group	Total	Per Cable Group	Total
Cable Groups					
Number	EA	1	4	1	4
Length	MI	2.7		2.5	
Voltage	kV	500		500	
Current	A	1,140		1,140	
Cable System		XLPE		XLPE	

Table 7-6. System Requirements for 500-kV Cable Systems

		Scenario 1		Scenario 2	
Item	**Unit**	**Per Cable Group**	**Total**	**Per Cable Group**	**Total**
Cables					
Single-Core Cables	EA	3	12	3	12
Length	FT	42,800	171,200	39,600	158,400
Conductor Size	Kcmil	5,000		5,000	
Insulation Thickness	Mil	1,260		1,260	
Lead Sheath	Mil	120		120	
O.D. (Approx.)	IN	6.4		6.4	
Weight (Approx.)	LB/FT	37		37	
Joints					
Type		OPJ or PJ		OPJ or PJ	
Number	EA	21	84	18	72
Terminations	EA	6	24	6	24
Cable Bond Type		Cross Bond/Single-Point Bond			
Conduit					
Type		PVC		PVC	
Size	IN	8		8	
Number	EA	3	12	3	12
Length	FT	42,800	171,200	39,600	158,400
Type		PVC		PVC	
Size	IN	2		2	
Number	EA	2	8	2	8
Length	FT	28,500	114,000	26,400	105,600
Manholes – Splice					
Type		Tunnel		Tunnel	
Size	FT	34-46 X 8 X 8		34-46 X 8 X 8	
Number	EA	7	28	6	24
Manholes – Restraint					
Type		Tub		Tub	
Size	FT	10-20 X 8 X 8		10-20 X 8 X 8	
Number	EA	TBD	TBD	TBD	TBD
Termination Support Structures	EA	6	24	6	24

7.21 Summary of Cable System Requirements for the 230-kV Cables

Table 7-7 provides a quick over view of the system requirements for the 230-kV cables.

Table 7-7. System Requirements for 230-kV Cable Systems

		Scenario 2	
Item	**Unit**	**Per Cable Group**	**Total**
Cable Groups			
Number	EA	1	2
Length	MI	2.5	
Voltage	kV	230	
Current	A	1,520	
Cable System		XLPE	
Cables			
Single-Core Cables	EA	3	6
Length	FT	39,600	79,200
Conductor Size	Kcmil	5,000	
Insulation Thickness	Mil	27	
Lead Sheath	Mil	120	
O.D. (Approx.)	IN	6.1	
Weight (Approx.)	LB/FT	35.5	
Joints			
Type		OPJ or PJ	
Number	EA	18	36
Terminations	EA	6	12
Cable Bond Type		Cross Bond/Single-Point Bond	
Conduit			
Type		PVC	
Size	IN	8	
Number	EA	3	6
Length	FT	39,600	79,200
Type		PVC	
Size	IN	2	
Number	EA	2	4
Length	FT	26,400	52,800

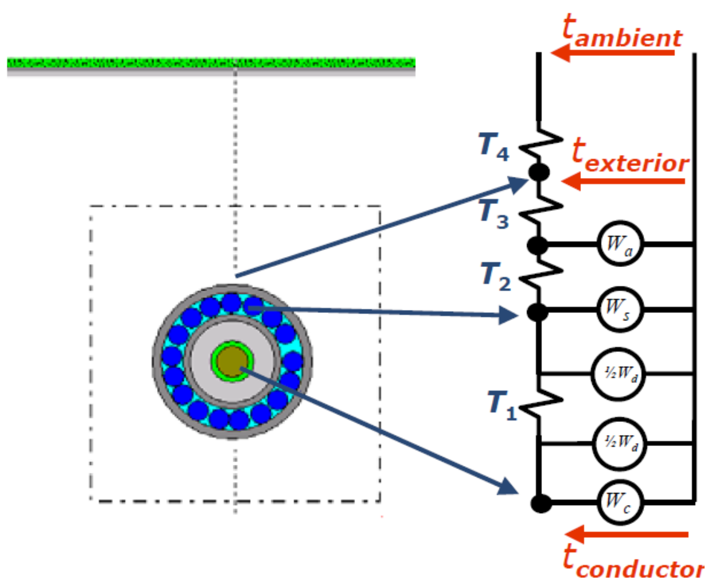
Table 7-7. System Requirements for 230-kV Cable Systems

		Scenario 2	
Item	**Unit**	**Per Cable Group**	**Total**
Manholes – Splice			
Type		Tunnel	
Size	FT	34 X 8 X 8	
Number	EA	6	12
Manholes – Restraint			
Type		Tub	
Size	FT	10-20 X 8 X 8	
Number	EA	TBD	TBD
Termination Support Structures	EA	2	4

8.0 CABLE SYSTEM AMPACITY ANALYSIS

The ampacity, or current rating, of high voltage cables is a critical requirement in designing an underground cable system, since the rating depends on the cable design, geometry of installation and the environmental factors around the cable such as ambient earth temperature and backfill and soil thermal properties. For the purpose of calculating ampacity, the underground cable system is reduced to an equivalent thermal circuit where heat flows from the cables caused by losses are the electrical equivalent of currents and the node temperature are the electrical equivalent of voltages. The thermal equivalent circuit is shown in Figure 8-1.

Figure 8-1. Thermal Equivalent Circuit for a Buried Cable System

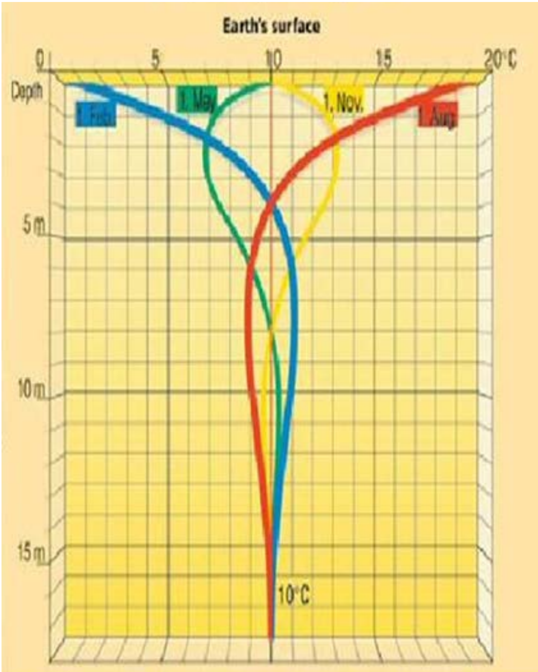


The main parameters that must be considered in the design of an EHV cable system for optimal thermal performance in meeting the load transfer requirements are as described below.

8.1 Ambient Earth Temperature

The ambient earth temperature at the cable depth is used in ampacity calculations. This temperature varies with depth from the earth surface which is the ultimate heat sink for cables as shown in Figure 8-2.

Figure 8-2. Annual Profile of Earth Temperature versus Depth



As seen in Figure 8-2, the temperature decreases with increasing depth between the summer months and increases with depth during the winter months. Neher, in his paper titled *The Temperature Rise of Buried Cables,* found that in Philadelphia the ambient temperature varied as follows:

Table 8-1. Ambient Earth Temperature at Philadelphia

Time Period	Depth = 4 FT	Depth = 25 FT
Summer	66°F (19°C)	52°F (11°C)
Winter	41°F (5°C)	52°F (11°C)

Neher concluded that for depths grater than 25 feet the ambient earth temperature is relatively constant and equal to the average of the annual ambient air temperatures. For the study, the following ambient earth temperatures were used:

- Cable trenches at a depth of 4 feet below grade: 68°F (20°C)
- Cables in deep bores at a depth of 30 feet below grade: 57°F (14°C)

8.2 Native Soil Thermal Resistivity

The native soil thermal resistivity varies with its composition and moisture content and can vary from less than 50°C-W/Cm to over 270°C-Cm/W and has a major effect on ampacity. The thermal resistivity is usually lower at increasing depths than closer to the surface and this is due to the weight of the earth which increases with depth thus increasing the density and lowering the thermal resistivity.

Thermal resistivity is highly dependent on moisture content. Near the earth's surface, the moisture content varies because of rainfall and transevaporation, but at increasing depth the moisture content is often higher and more stable. At some locations, the water table is between 20 and 30 feet deep, which lowers the thermal resistivity of the soil and makes it thermally stable.

Also, at increasing depths, rock or sand and gravel may be present, which lowers the thermal resistivity. Little organic material is found as depth increases, and this type of material has high thermal resistivity.

8.3 Conductor Size

Increasing the conductor size reduces the electrical resistance of the cable which in turn allows for increase in current capacity. Conductor sizes from 3,000-kcmil to 5,000-kcmil were evaluated. The 5,000-kcmil conductor for XLPE is available from several manufacturers and it is an upper threshold for both cable size and weight. Enameled type conductors are also available which provide for reduction in skin effect and proximity effect which produces an increase in ampacity.

8.4 Backfills and Earth Thermal Resistivity

Heat generated by the cables in the conductor, insulation, metallic sheath, and shielding wires travels from the cable to ambient through backfills and earth in order to dissipate. Concrete, thermal backfills and the native soil surrounding the cables constitute a thermal resistance in the equivalent thermal circuit. This resistance is a function of the thermal characteristics of the concrete, backfills, and native soil surrounding the cables. In this stage of evaluation, the thermal properties of the native soil surrounding the cables have not been investigated, so the thermal resistivity was assumed to be 110°C-Watt/Cm at 2 to 3 percent moisture content.

8.5 Installation Depth

The burial depth has an affect on the heat dissipation from the cables as increasing depth increases the thermal resistance from cable to ambient. This decreases the heat flow and in turn causes a loss of current carrying capacity for the cables. Thus, cables placed deeper in trenches or in bores under rivers may require larger conductor sizes and wider separation between cables or between circuits.

8.6 Circuit Spacing

Cables generate heat as a result of losses which cause interference with cables of other circuits in close proximity. This mutual heating lowers current carrying capacity. Therefore, increasing the spacing between parallel circuits increases ampacity. The spacing of the circuits may have to be increased as the depth increases.

Ampacity analyses were conducted in order to arrive at the current capacity required by the project both for the 500-kV cables and 230-kV cables. The ampacity was based on the different conductor sizes, different trench configurations with single and double circuit per trench, different trench depths, different spacing of the cables and the data included in Table 8-2.

Table 8-2. Parameters Used in Ampacity Calculations

Description	Units	500-kV Circuits	230-kV Circuits
Number of OH Circuits	EA	1	2
System Voltage	kV	500	230
Total Current Capacity	A	4,560	1,520
Total MVA Capacity	MVA	3,950	605
Number of UG Circuits	EA	1	2
Number of Cables	EA	12 (4 per phase)	3 (1 per phase)
Spacing of Cables in Trench	IN	12 to 15	12 to 15
Depth to Top of Cables	FT	3 to 4	3 to 4
Number of Trenches	EA	1-4	1-2
Conduit Outside Diameter,	IN	8.865	8.865
Conduit Material		PVC	PVC
Spacing of Circuits in Bores by HDD	FT	20 to 40	20 to 40
Depth of Circuits in Bores	FT	30	30
Number of Bores by HDD	EA	4	2
Load Factor	%	75	75
Conductor Temperatures			
Continuous Operation	°C	90	90
Emergency Operation	°C	---	---
Short Circuit	°C	250	250
Fault Duty, Symmetric	KA	21,000	31,400
Fault Duty, SLG	KA	16,000	28,100
Fault Clearing Time	SEC	5	6
Ambient Temperatures			
Air	°C	35	35
Earth (Depth = 4 FT)	°C	20	20
Earth (Depth = 30 FT)	°C	14	14
Thermal Resistivity			
Concrete Encasement for conduits	°C-Cm/W	85	85
Earth at 4 feet below grade	°C-Cm/W	110	110
Backfill for Bores at 1% moisture	°C-Cm/W	110	110
Earth at 30 foot depth	°C-Cm/W	110	110

8.7 Results of Ampacity Calculations for Trenches and Bores

Ampacity analyses were conducted using commercially available software called CYMCAP produced by CYME International in Canada. The calculation engine is based on the universally accepted Neher McGrath Method and IEC standards.

Analyses were conducted to determine ampacity for both cables in trenches at different depths and in bores. The required ultimate ampacity of the 500-kV transmission line is 4,560 amperes continuous which would require 4,560/4= 1,140 A per cable group. For the existing 230-kV Line 1 and Line 2, the required ampacity is 1,520 A per line.

8.7.1 Cables in Trenches at Castle Rock and Camas

Calculations show that with a 5,000-kcmil copper conductor cable ampacity requirements can be met for both the 500-kV and 230-kV cables in trenches.

Figure 8-3 shows current capacity for the 500-kV cables for Scenario 1 at a depth of 4 feet to the top of the concrete encasement. Figure 8-4 shows current capacity for the 500-kVand 230-kV cables for Scenario 2 at a depth of 4 feet to the top of the concrete encasement.

Figure 8-3. Scenario 1 Ampacity for 4-Foot Deep Trenches

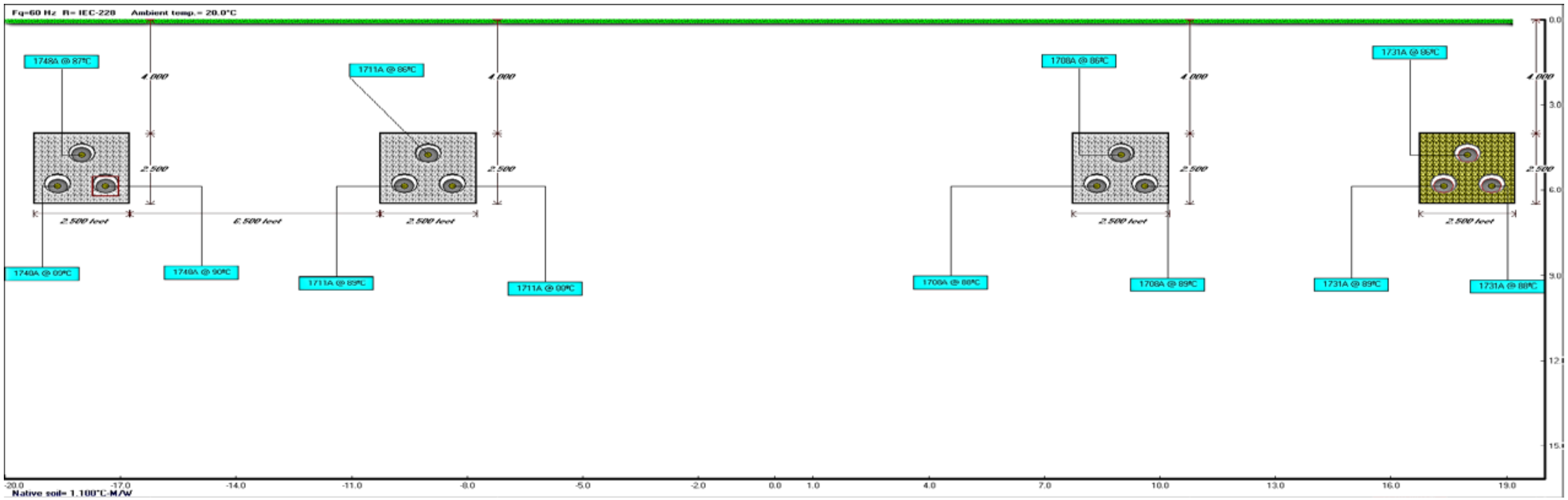
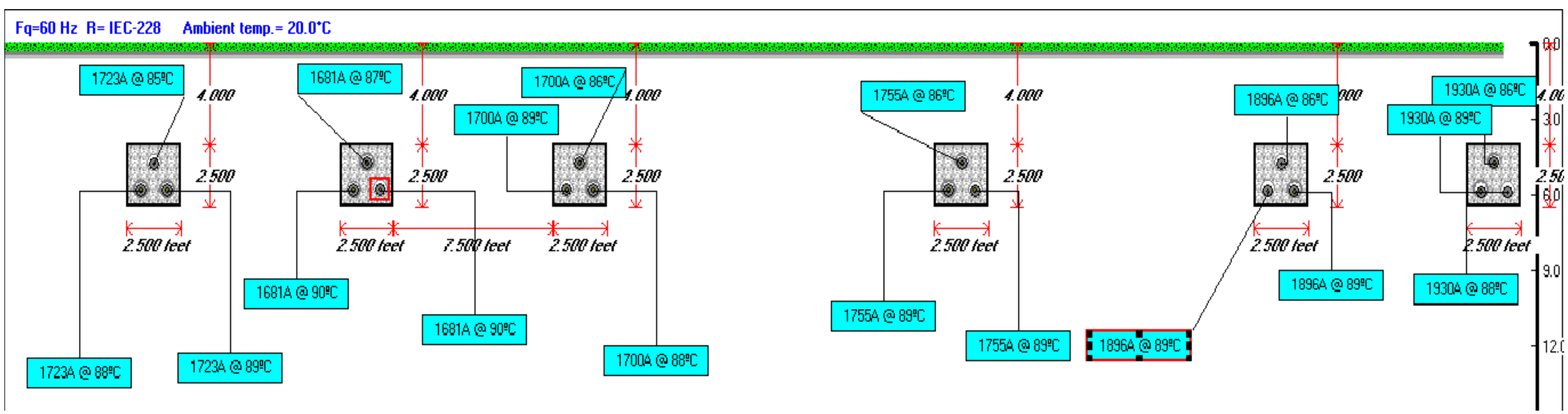
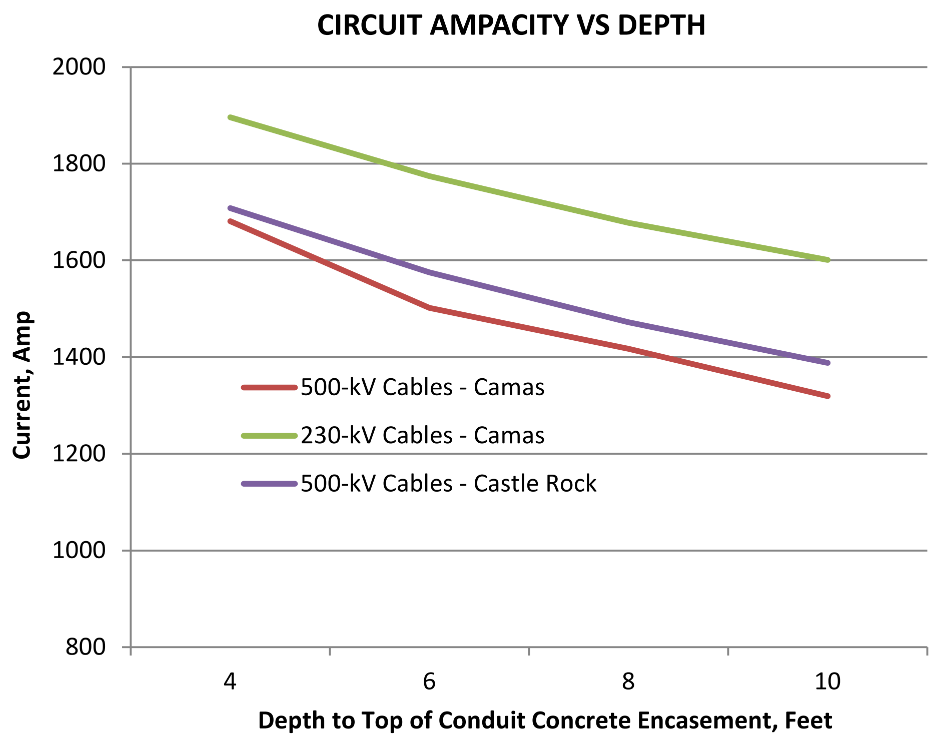


Figure 8-4. Scenario 2 Ampacity for 4-Foot Deep Trenches



The graph in Figure 8-5 shows circuit ampacity for the 500-kV and 230-kV cables in trenches at Camas and Castle Rock as a function of depth to the top of the conduits concrete encasement. The graph shows that current capacity of 1,140 and 1,520 A for the 500-kV and 230-kV cables, respectively, is met with increasing depth. Increased depth of cover may occur in crossing under interfering substructures or other obstacles and for connecting deep conduits at jack and bore locations.

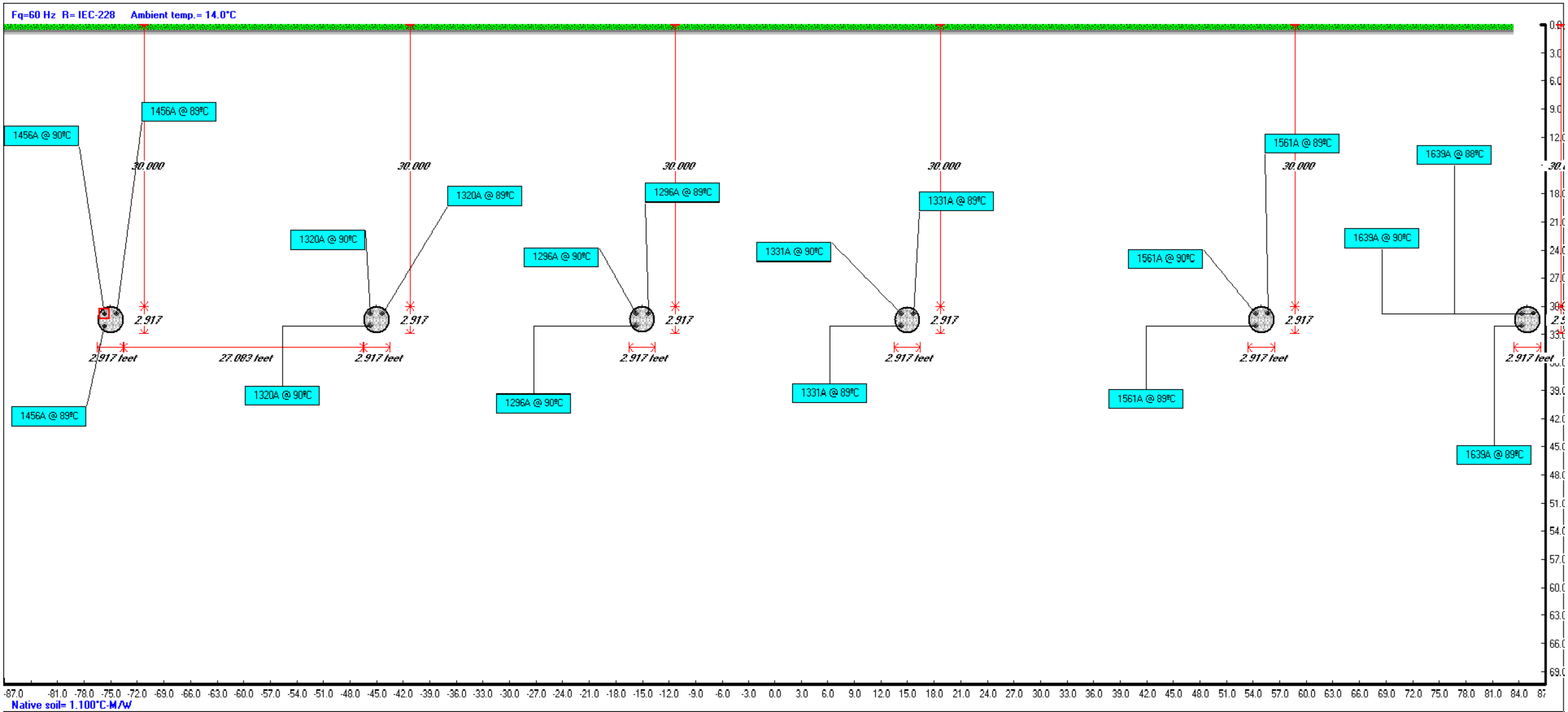
Figure 8-5. Circuit Ampacity for 500-kV and 230-kV Cables vs. Depth



8.7.2 Cables in Deep Bores

Calculations show that with 5,000-kcmil copper conductor ampacity requirements can be met for cables in bores at a depth of 30 feet based on the initial conditions listed in Table 8-2. Figure 8-6 shows ampacity of 500-kV and 230-kV cables at 30-foot depth in deep casings installed by horizontal directional drilling.

Figure 8-6. Ampacity for 500-kV and 230-kV Cables in Deep Bores



8.7.3 Optimization of Design

The ampacity for the cable configurations in trenches and in bores was calculated based on the assumed conditions listed in Table 8-2. Before any final design, in-situ thermal resistivity measurements shall be made along the cable route at the depths traversed by the cables.

Soil samples shall also be taken at the depths traversed by the cables. The samples shall be reconstituted in a laboratory environment for determining the dry out curves of the native soil along the cable route and at the depths traversed by the cables especially for the deep bores where the cables cross all strata down to the final depth of the casings.

The thermal resistivity measurements should be carried out in late August when the soil conditions are driest. In conjunction with the thermal resistivity analysis, measurements of ambient earth temperatures at the cable depth shall be made. These measurements shall also be carried out in late August when earth ambient temperatures are the highest.

Based on the thermal resistivity studies and actual ambient temperatures, the ampacity calculation shall be repeated to validate the initial assumptions made for the purpose of analysis and to optimize the final design for trenches and bores.

9.0 METHODS OF INSTALLATION

There are three feasible methods of installation that have been used historically for underground cables which are the conduit and manhole system installed by open cut trench, the direct buried system installed by open cut trench and the tunnel system installed by the use of a tunnel boring machine for deep tunnels or open cut trench for shallow depth box-type tunnels.

In conjunction with the above methods, there are two trenchless technologies needed for crossing of rivers, railroads tracks and other obstacles which are the jack and bore and the horizontal directional drilling.

9.1 Duct and Manhole System

Worldwide, the most common installation technique for XLPE insulated cables is by direct burial or installation in tunnel. Although direct burial may be a lesser cost alternative initially this approach is not commonly used in North America where the preferred installation method especially in urban areas is the duct and manhole system by open cut trench.

9.1.1 Advantages of Duct and Manhole System

Duct and manhole systems have several advantages. The installation of the cable system is easier to coordinate since the conduit and manhole system can be built independently of the cable system installation.

Only 300 feet of trench needs to be excavated at a time to install the conduit system, which can be covered with steel plates at night to re-establish traffic flow and for safety considerations. Also, duct and manhole systems offer a high degree of protection for the cables since the conduits are encased in a concrete envelope which protects against dig-ins, which is damage caused by third party excavations or other work.

In the event of a cable or joint fault, there is no need to excavate the cables. The fault needs to be located to a particular manhole or between two adjacent manholes to make repairs. Additionally, this system type provides access to joints and cables in manholes for routine inspections and for maintenance and testing.

The cables can move in manholes depending on the equipment arrangement or laterally in the duct due to the clearance in the duct which makes this system thermo-mechanically semi-restrained thus reducing the longitudinal trust on joints and the sidewall pressure at conduit bends.

One of the biggest advantages is that the conduit and manhole system can be re-used after the cables reach their used life and are removed.

9.1.2 Disadvantages of Duct and Manhole System

Duct and manhole systems have also several disadvantages with the main one being that the cost of installing the system is generally higher then for a direct buried system.

Also, the conduits must be proved with a mandrel or inspected via a camera before the cable installation to ensure that there are no foreign materials or obstructions which can damage the cables. Water can enter the conduits and manholes and in a cold temperature climate the water will freeze, which may cause damage to cables and accessories or preclude repairs.

Large asymmetrical forces can occur at joints due to the conductor axial thrust forces as a result of elevation differences along the route or as a result of different route geometries on each side of manholes. This may require the use of anchor joints or well designed cable and joint arrangements in manholes in conjunction with the use of clamping or restraining devices to restrict cable movement or prevent downhill movement of cables on slopes.

The cable expansion as a result of the daily load cycles will cause cyclic bending of the cables in the manholes which in turn can cause the metallic coverings on cables to fatigue and crack.

Cable offsets in the manhole must be properly designed for width, length and bending radius and the cyclic strain calculated to ensure that it is within the allowable limit of the specific metallic covering on the cables.

For this system, there is a need for greater inventory of spare parts as a manhole fire may require replacement of six cable lengths and three joints which is not the case for a direct buried system.

9.1.3 Installation Process for Duct and Manhole System

The installation process consists of saw-cutting or breaking of existing pavement or removing top soil and excavating the trench to the required depth. Excavated material can be disposed of or used for backfilling the trench depending on its thermal properties as determined by field thermal resistivity testing and dry out curves. Depending on the depth and city codes, shoring may be required to prevent caving trench sides especially when excavating in loose materials such as sand.

After excavations, conduits are installed in the trench by utilizing plastic spacers or formers to achieve the design configuration. Smaller size conduits can also be installed for earth continuity conductors or fiber-optic cables. The ducts can be PVC, PE, or FRE type.

PVC ducts are the most commonly used and have bell and spigot joints which are available with a range of pre-formed bends and accessories. They are available in different wall thickness such as Schedule 40 or 80.

PE ducts, depending on size, can be supplied in coils of different lengths varying from 150 feet to 450 feet. Joints are made by heat fusion of conduit ends. Therefore, the longer conduit lengths minimize the number of joints and thus installation time.

Fiberglass reinforced epoxy (FRE) are thin wall ducts which are made on mandrel and are highly durable, resistant to heat, and can survive cable faults better than PVC or PE. FRE claims to have a lower coefficient of friction than PVC or PE conduits, which would allow for longer cable pulls. The joints are bell and spigot type.

After the placement of the ducts and spacers in the trench, concrete of 1,700 to 2,000 psi compressive strength is poured over the assembly to encase them. The conduits are terminated inside the manhole at the end walls. The trench portion above the concrete encasement is then backfilled with clean excavated material or a thermal backfill consisting of weak mix of thermal sand, cement, and water.

Figure 9-1. Typical Trench Excavation

9.1.4 Construction Width Requirements

For the installation of the conduit and associated manholes, a minimum unobstructed width of 68 feet above grade would be required for equipment to excavate and to transport materials.

9.2 Direct Buried System

Direct buried systems for high-voltage cables are not common in North America but have been used with success in Europe, the Middle East, and other parts of the world. It has a lower installation cost than the duct and manhole systems and it is more flexible since trenches can be opened to match the cable reel lengths.

It also produces high ampacity for the same cable size as it is thermally more efficient in eliminating the thermal resistance of the conduit and the thermal resistance of the air space within the conduit so that cables can be spaced closer together thus minimizing trench size requirements and require a smaller conductor size.

Figure 9-2. Typical Direct Buried Cable Installation

9.2.1 Advantages of Direct Buried Systems

Direct buried systems have a lower installation cost and produce higher ampacity for the same cable size because they are more thermally efficient by eliminating the thermal resistance of the conduit and the thermal resistance of the air space within the conduit. As a result, the cables can be spaced closer together which minimizes the trench size requirements plus the cables require a smaller conductor size.

The cables are rigidly secured by the surrounding earth which eliminates cyclic axial expansion and the potential for fatigue of metallic coverings. The direct burial method is mechanically rigid therefore the cables and joints are prevented from moving or sliding down steep slopes as a result of the thermo-mechanical forces caused by cable expansions resulting from the daily load cycle.

9.2.2 Disadvantages of Direct Buried Systems

Direct buried systems have several disadvantages. The main one is that the entire system has to be abandoned when the cables have reached their useful service life of about 40 years.

For installation of the cables, the entire length of trench must be open. For example, for a 2,000 foot cable length, the entire trench must be opened to allow for installation and in urban areas with traffic conditions this may not be permissible. Security systems such as fences are also needed to protect vehicles and persons from falling within the trench and damaging the cables that may be installed. Fencing is also needed to prevent damage to cables and theft.

The cable delivery and installation must be coordinated with the trenching thus reducing the flexibility of installation. Plus, weather condition such a heavy rain may cause damage to opened trenches by flooding which cause delays in installation schedules. Further, direct buried cables are more susceptible to dig-in or other third party damage since the cables are enclosed in a weak mix to facilitate excavation for repairs. Finally, repair of a cable or joint fault has to be done at the point of failure which requires pinpointing the exact fault location for excavations to be made at the point of failure. Repair work requires working in proximity of the other cables.

9.2.3 Installation of Direct Buried System

The installation process consists of saw-cutting or breaking of existing pavement or removing top soil and excavating the trench to the required depth. Excavated material can be disposed of or reused to backfill the trench depending on its thermal properties as determined by field thermal resistivity testing and dry out curves. Depending on the depth and city codes, shoring may be required to prevent caving in of the sides of the trench especially from loose materials such as sand.

After excavations, a layer of well graded sand or low thermal resistivity material consisting of cement bound sand or fluidized thermal backfill is placed at the bottom of the trench and compacted and smoothed. Cable rollers are placed at specific intervals along with skid plates being placed on the sides of the trench at bends. The cables are then pulled in one at a time by attaching a steel cable to a pulling eye on the cable end and by winch pulling at the other end of the trench.

The cables are pulled individually and lifted from the rollers and positioned on the trench bottom and carefully spaced into the required dimensions. Additional cables such as earth continuity conductors can be installed or empty conduits can be placed at the sides of the trench for later use for optical cables.

After the placement of cables and other cables and conduits, they are covered with the required height of a low compressive strength and low thermal resistivity material consisting of fluidized thermal backfill or cement bound sand. Concrete caps are installed over the cables' envelope and plastic warning tapes or markers may be placed above. The trench is then backfilled with the excavated soil.

9.3 Tunnel Installations

9.3.1 Deep Tunnels

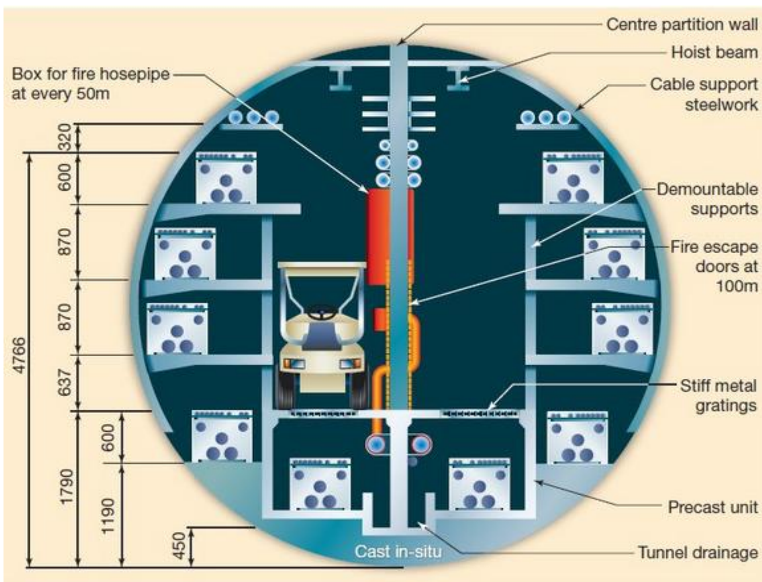
Tunnel installations have been used in large metropolitan cities such as Tokyo, London, and Berlin where due to traffic conditions and other restrictions open cut trenching is impractical or not feasible. Tunnels have also been used for the crossing of large obstructions such as rivers or joint use with other utilities to spread project costs.

Deep tunnels are usually installed 200 to 400 feet below grade by the use of tunneling machines. For cable application, they are normally circular in geometry and have a 10 foot diameter. Cooling of the tunnel by drawing air down a shaft and forced air flow is required due to the inefficient heat transfer through the soil as a result of the depth of the tunnel. The air is then forced out at another shaft to keep the tunnel temperature around 50°F.

Figure 9-3 shows a 132-kV cable installation in a deep tunnel in Australia. Figure 9-4 shows cable and dimensions for installation in Singapore.

Figure 9-3. Deep Tunnel for 132-kV Cables in Australia

Figure 9-4. Deep Tunnel Cross-Section from Singapore



9.3.2 Shallow Tunnels

Shallow or box type tunnels are of the open cut installation type as shown in Figure 9-5. They are rectangular in cross section and are prefabricated and installed in sections. They are lower in cost than deep tunnel and because they are shallow allow heat dissipation from the tunnel through the soil to ambient but forced air cooling is still required.

Figure 9-5. Box Tunnel Installation

9.3.3 Advantages of Tunnel Installations

Tunnels offer several advantages including making the entire cable system accessible for inspection and maintenance, immunity from weather condition and avoiding scheduling delays and excellent protection against dig-ins or third party damage. In addition, the tunnel can be re-used for cable replacement after existing cables reach their expected life or for additional cable systems.

9.3.4 Disadvantages of Tunnel Installations

Tunnels have a high installation cost that can be shared with others if multiple utilities share the tunnel. Another disadvantage is the mutual impact between different systems in the tunnel. For example, a tunnel fire can impact all cable systems of the tunnel. Tunnels also suffer from poor thermal conductivity of heat through soil due to the depth of installation which could reach 100 feet. Therefore, tunnels may require forced cooling or ventilation for heat removal.

9.4 Service Experience with Different Installation Methods at 400-kV and above

The 500-kV Southern California Edison Tehachapi Renewable Transmission Line Project will require a 3.7-mile underground section partially traversing the City of Chino Hills. The project, known as the Chino Hills Underground Project (CHUG), is in the design and procurement stages and will be a duct and manhole installation.

The 10.6-mile long, 500-kV, Shibo Substation project in Shanghai is a tunnel installation. The 25-mile long, 500-kV, Shinkeiyo-Toyosu project in Tokyo is also a tunnel installation. A 13-mile long, 400-kV, installation that went into commercial operation in 2005 in London is also a tunnel installation. There are other 400-kV direct buried installations, such as the one installed in Copenhagen in 1997.

Table 9-1 shows installation type for 400-kV and 500-kV cables.

Table 9-1. Installation Types of 400-kV and 500-kV Cables

Voltage	Conduit and Manhole		Direct Buried		Tunnel	
	Miles	Number	Miles	Number	Miles	Number
400-Installed	0.93	1	140.1	20	68.3	9
500-Installed	0	0	0.93	1	71.0	2
500-Ongoing	3.7	1				
Total	4.63	2	141.0	21	139.3	11

The table shows that the existing EHV cable installations at 400-kV and 500-kV are direct buried or tunnel type installations. However, the SCE CHUG project will be a duct and manhole installation.

9.5 Preferred Installation System

The recommended installation type for the I-5 Project is a duct and manhole system, which is the preferred method in North America.

9.6 Trenchless Conduit Installation Methods

9.6.1 Jack and Bore

The jack and bore method will be utilized for railroad tracks crossing. This method is also normally used to for crossing under roadways and other constructions such as large sewer lines and storm drains and is limited to short distances less than 600 feet where changes in alignment and profile are not required.

The jack and bore method is utilized in essence to place a pipe casing under the obstruction followed by the pushing or pulling of conduits depending on the type used within the casing. The casing can consist of a steel pipe or non-metallic pipe such as high-density polyethylene (HDPE) or fiberglass or reinforced concrete pipe (RCP). The type of casing used has an effect on the current carrying capacity of the cables due to additional thermal resistance of the casing especially if HDPE or RCP pipe is used. Figure 9-6 shows a diagrammatic set-up of the jack and bore operation.

The process starts by excavating two pits. The first one also referred to as the bore pit is used for setting equipment and assembling and installing 20-foot section of casing to be installed into the bore hole. The second also referred to as the receiving pit is used to receive the casing at the opposite of the bore pit. The boring pit would be approximately 10 feet wide by 40 feet long for installation of a single casing while the receiving pit would be 10 feet by 10 feet. The jack or launching pit set-up is shown in Figure 9-7. The depth of the bore and receiving pits will depend on the elevation of the casing to be installed but dimensions will be most likely be as follows for casing pipe at depth less than 16 feet:

- Bore Pit Size: 35'L x 12' W x 16.5' D
- Receiving Pit Size: 10' L x 10' W x 16.5' D

Shoring and or sheathing of the pits will be required based on local and OSHA regulation for safety consideration by preventing caving of the pit’s wall. The extent of the shoring will depend on the composition of the soil to be excavated. Once the jack and bore equipment have been placed in the boring pit, the operation begins and continues until the casing reaches the other side.

The pipe casing size will vary with the number of conduits to be installed and the required bore length. For this installation, a 36 inch casing would be required for six 6-inch ducts and two 3-inch ducts.

After the pipe casing is installed, conduits are installed in the casing and the space between the inner surface of the casing and the outer surface of the conduits is filled with a pumpable grout consisting of sand and cement and having a low thermal resistivity.

Figure 9-8 shows the jack and bore operation for the crossing of Interstate 5 for the 230-kV cables of the San Diego Gas and Electric Sunrise Power Link. Both bore and receiving pit are visible in the picture.

Figure 9-6. Diagrammatic Set-up of Jack and Bore Operation

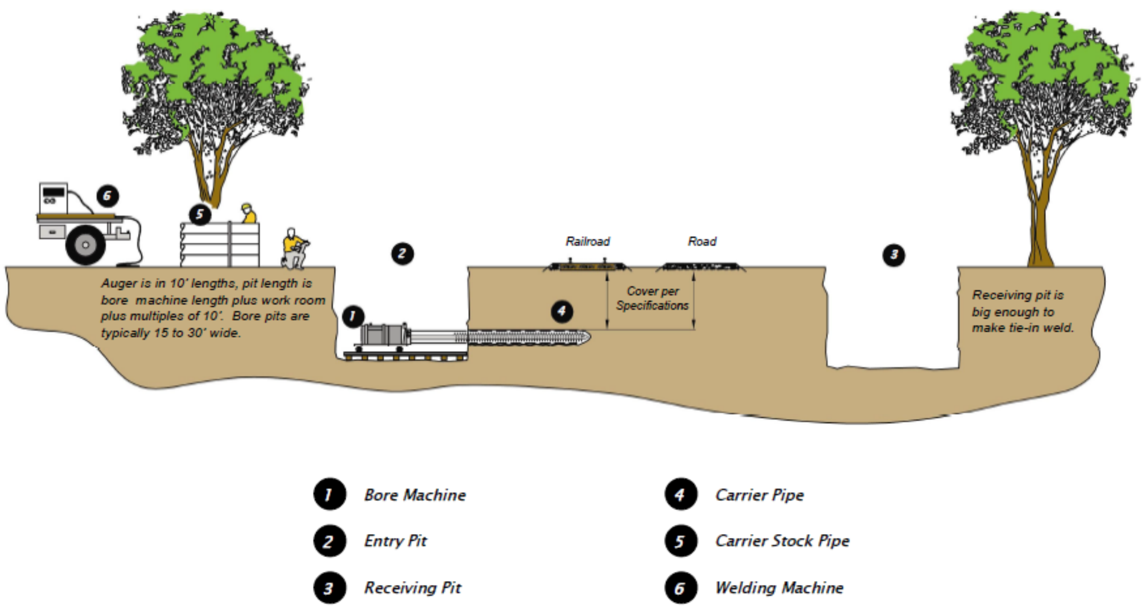
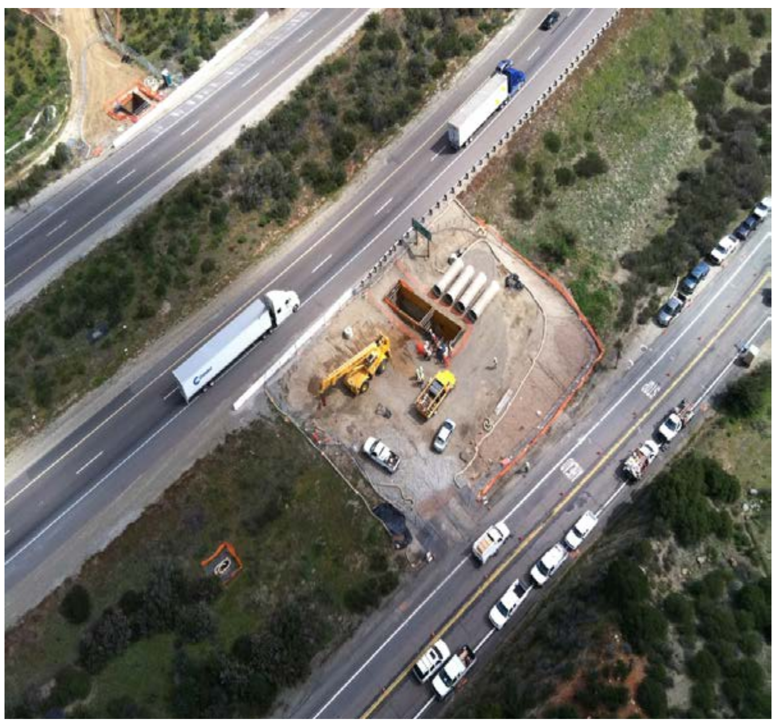


Figure 9-7. Jack and Bore Set-up in Launching Pit

Figure 9-8. 230-kV Jack and Bore Crossing of I-5 near San Diego

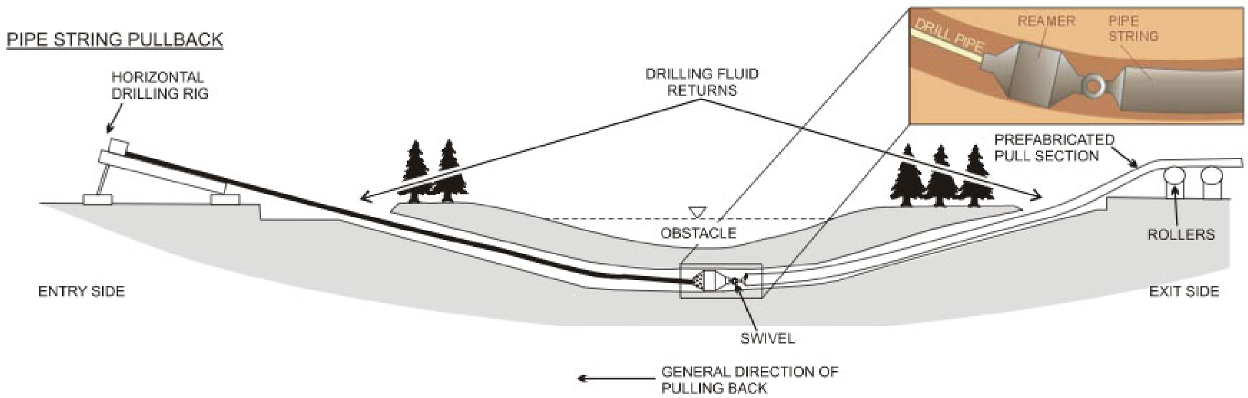


9.6.2 Horizontal Directional Drilling

For this project, HDD will be proposed to cross the rivers. This method can be used for bore length in excess of 3,000 feet and where changes in the vertical profile of the bore are required. An HDD installation for an XLPE cable system consists of installing a casing with conduits inside or just installing the conduits in a bundle by themselves. The construction process of HDD, which is shown in Figure 9-9 involves 5 steps:

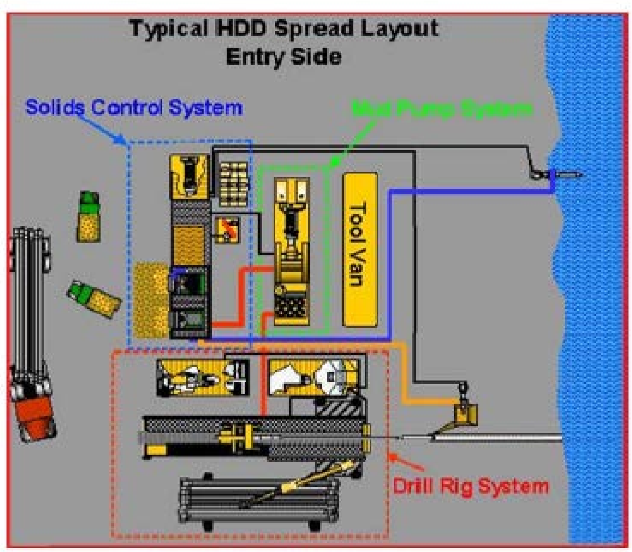
1. Set up of the equipment
2. Drilling the pilot hole
3. Reaming of the hole
4. Pullback
5. Tie-in

Figure 9-9. Diagrammatic Set-up of Horizontal Directional Drilling



Set up of the equipment involves a rig side and a pipe side. The rig side contains such items as the drilling rig, slurry mixing and separation equipment, storage of bentonite, an entry point and a cuttings settlement pit. An example of a medium or large rig side layout can be seen in Figure 9-10.

Figure 9-10. Equipment Layout for HDD



After setting up the equipment, the pilot hole is drilled from the entry point to the exit point. A reamer is then used from the exit hole back to the entry point in order to enlarge the bore hole. Finally, the casing pipe is pulled into the enlarged hole. Figure 9-10 shows the HDD operation and set-up at the drilling side.

As compared to the jack and bore method, the use of HDD allows for the elimination of bore pits and all work can be performed from above grade. However, HDD requires larger areas for the set up of equipment as shown in Figure 9-11 required for the drilling operation both at the entry and exit points. Area requirements for the entry point and exit point are as follows:

- Entry Point Area: 100 feet by 150 feet
- Exit Point Area: 100 feet by 100 feet

Conduits can be installed directly in the bore hole or a casing can be installed in the bore hole. If the casing is installed, the conduits would be pushed or pulled in the bore hole depending on the type of spacer being used for the conduit installation. The space between the inner surface of the casing and the outer surface of the conduits is filled with a pumpable grout consisting of sand and cement and having a low thermal resistivity. If no casing is installed, the conduits would be bundled together using specially designed spacers and then pulled back into the bore.

Figure 9-11. Typical HDD Operation

Crossing of Sensitive Areas

Although HDD is well suited to cross sensitive areas due to the long distances it can span, there are specific factors of concerns, such as the type of area to be crossed (body of water, wetland, or river) and whether it is environmentally sensitive, which may require an environmental impact study.

Permitting may be required for the crossings of sensitive areas because bodies of water and wetlands may be under the jurisdiction of the Army Corp of Engineer (USACE). Measures, from erosion control to the removal of excavated material, must also be taken to preserve the natural water flow.

Because of the use of bentonite which is a clay-type drilling fluid used for lubrication to reduce wear and to stabilize the bore hole a hydro fracture commonly referred to as a “frac-out” may occur within the body of water. Frac-out is the inadvertent return of drilling lubricant or bentonite as a result of excessive drilling pressure which may cause the bentonite to propagate toward the surface and enter sensitive habitats, waterways, and areas of concern for cultural resources. Bentonite is non-toxic but its discharge in water bodies can cause harm to the fauna and flora by asphyxiation due to the bentonite's makeup of very fine particles.

Before proceeding with any HDD operation, a geotechnical analysis is required as previously described and the drilling contractor must prepare a "frac-out" plan in order to address remediation should it occur. Other considerations are the availability of space for the entry point and exit point areas and the location of any access points.

10.0 CABLE SYSTEM MANUFACTURERS, SPECIFICATIONS, AND TESTING

10.1 Preferred Cable System

The preferred cable system for this installation is shown in Appendix A.

10.2 Available Manufacturers

There are manufacturers worldwide that can supply EHV XLPE insulated cables and below is a list of potential manufacturers for the supply of the 500-kV and 230-kV cable systems:

- ABB
- Brugg
- General Cable
- JPower
- NKT
- Nexans
- LS Cable
- Prysmian
- Sudkablel
- Taihan
- Viscas

10.3 Standard Specifications for Manufacturing and Testing Requirements

Standard specifications for the manufacturing and testing of cable systems are available in North America and internationally. Historically, North American utilities have relied on US standards for the specification, procurement and testing while foreign utilities have relied on international standards. The principal standards that apply to EHV XLPE cables are as follows:

- Association of Edison Illuminating Companies (AEIC) CS 9 - Specifications for Extruded Insulation Power Cables and Their Accessories Rated Above 46 kV through 345-kV
- ICEA108-702 - Standard for Extruded Insulation Power Cables Rated Above 46 through 345-kV
- Institute of Electrical and Electronics Engineers (IEEE) 404 – IEEE Standard for Extruded and Laminated Dielectric Shielded Cable Joints Rated 2,500 V to 500,000 V
- IEEE 48 – IEEE Standard Test Procedures and Requirements for Alternating Current Cable Terminations 2.5-kV Through 765 kV

Both the AEIC and ICEA standards extend only to 345-kV class cables. However, both IEEE 404 and IEEE 48 which are applicable to accessories only extend to 500-kV. The principal international standard that applies to the cable systems is International Electrotechnical Commission (IEC) 62067 titled *Power Cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements*.

10.4 Prequalification (PQ) Tests

Prequalification tests are long term, more than 8,000 hours, to demonstrate successful performance of the cable system or in essence to simulate long term performance within one year testing period. PQ tests are required for cable systems above 170-kV.

Prequalification testing has a duration of 8,760 hours or one year and that is performed under realistic installation conditions for the complete cable system such as direct buried in native soil, in conduit, or in a concrete tunnel.

The prequalification test requires a test loop length of at least 100 m containing cable, joints and terminations. Because of these requirements and the installation conditions to be simulated, the tests are conducted outdoor. Figure 10-1 shows the outdoor set up of a PQ test. IEC 62067 requires that for cable systems with rated voltage of 170-kV and higher, a total of 180 thermal load cycles at 1.7 times the rated conductor-to-earth voltage have to be applied over the course of the one year test period.

Manufacturers interested in supplying the 500-kV cable system should be required to provide PQ test reports certified by an independent testing agency showing successful completion of long term PQ tests on components similar to those employed for the project.

Figure 10-1. Test Loop Assembly for PQ Test

Prequalification tests can be conducted in accordance with the following IEC 62067 or AEIC CS9. IEC 62067 require qualification to a conductor temperature to 95°C while AEIC CS9 requires qualification to a conductor temperature of 105°C.

10.5 Type Tests

Type tests are short term duration tests to demonstrate successful performance of the cable system to meet the intended application. The type tests have a typical duration of six weeks including 20 daily loading cycles and are performed on a shorter test loop containing cable, joints and terminations to simulate installation conditions.

Because of these requirements, the tests are conducted indoors as shown in Figure 10-2. IEC 62067 requires that a total of 20 thermal load cycles at an applied voltage of 2.0 times the rated conductor-to-earth voltage have to be applied.

Manufactures interested in supplying the cable system should be required to provide evidence of type testing and/or conduct the test if selected to supply the cable system.

Figure 10-2. Type Test Set-Up

11.0 CABLE SYSTEM INSTALLATION AND COMMISSIONING TESTING

11.1 Cable System Installation

The cable system is installed subsequently or in conjunction with the installation of the conduit and manhole system especially for long circuits in order to minimize installation time. The cable installation process starts with the cleaning of the conduit with cloth swabs. The conduit may also be inspected with a bore scope pulled from one end of the run to the other end.

A mandrel or a short piece of the cable to be installed is then pulled through the conduit. Subsequently, the mandrel or cable piece is examined for scraping, abrasions, or other damage to ensure that no foreign materials such as concrete or rocks are inside the conduit.

A transport carrier with the cable reel mounted is placed at a cable feeding locations such as a terminal location or manhole, Figure 11-1, in accordance with the predetermined direction of pull to yield the lowest pulling tension. The placement of the carrier is also affected by site conditions other factors such as traffic.

A winch truck is parked at the pulling manhole and the steel line from the winch is pulled through the conduit to the feeding manhole where it is attached to the pulling eye of the cable end on the steel reel. The cable is fed through feeding tubes at this manhole while being pulled from the winch truck at the pulling manhole.

While the cable is coming off the reel, a soap and water solution is applied to the jacket to reduce the frictional forces in the conduit. The pulling tensions are monitored at the winch truck to ensure that the maximum pulling tensions are not exceeded and are recorded for QA/QC control. Once the cable reaches the pulling manhole, the cable at the feeding manhole is cut and the end tail is lowered into the manhole.

Figure 11-1. Carrier with 230-kV Cable Reel at the Feeding Manhole

11.2 Cable Jointing

In conjunction with the cable pulling especially for long circuits, the cable ends in the manholes are spliced together by cable splicers or “jointer” as shown in Figure 11-2. At the terminal locations, the cable terminations are installed in order to transition from underground to overheat connections.

Figure 11-2. Assembly of 345-kV Prefabricated Joint

For 500-kV installations, a clean room area is set-up in the manhole to prevent contaminants to be entrained in the splice. Air conditioners and dehumidifiers are also set-up in the manhole to maintain temperature and humidity levels in accordance with the splice manufacturer's assembly instructions.

11.3 Installation of Cable Terminations

For the installation of the cable terminations, normally a scaffold is built around the termination support structure and an enclosure is assembled around the scaffold to protect the area from environmental conditions as shown in Figure 11-3. Subsequently, the terminations are assembled as shown in Figure 11-4.

Figure 11-3. Scaffold and Enclosure for Termination Assembly

Figure 11-4. Installation of 230-kV Termination Bushing on Prepared Cable End

11.4 Cable Commissioning Testing

Following the installation of the cable system, cable commissioning tests are conducted to verify the integrity of the installation. The following tests are conducted:

- Testing of SVLs in the link boxes
- DC jacket integrity test normally done for 1 minute at 10-kV to insure that the cable external jacket was not damaged during installation
- Conductor resistance tests
- Time domain reflectometry to obtain cable traces to be used as reference during fault location
- Insulation resistance test
- High voltage test conducted in accordance with IEC 62067
- Partial discharge testing

Recently, testing equipment has become available in the US to perform high voltage AC and partial discharge (PD) commissioning tests similar to the tests performed at the factory. The high voltage AC test requires a resonant test set or RTS which is shown in Figure 11-5. The test set computer controls automatically find the resonant frequency by matching the reactance of the HV reactor to the capacitance of the underground cable under test to produce a tuned circuit to reduce the charging current and to reduce the size of the test equipment.

Figure 11-5. Portable High Voltage Resonant Test Set (RTS)

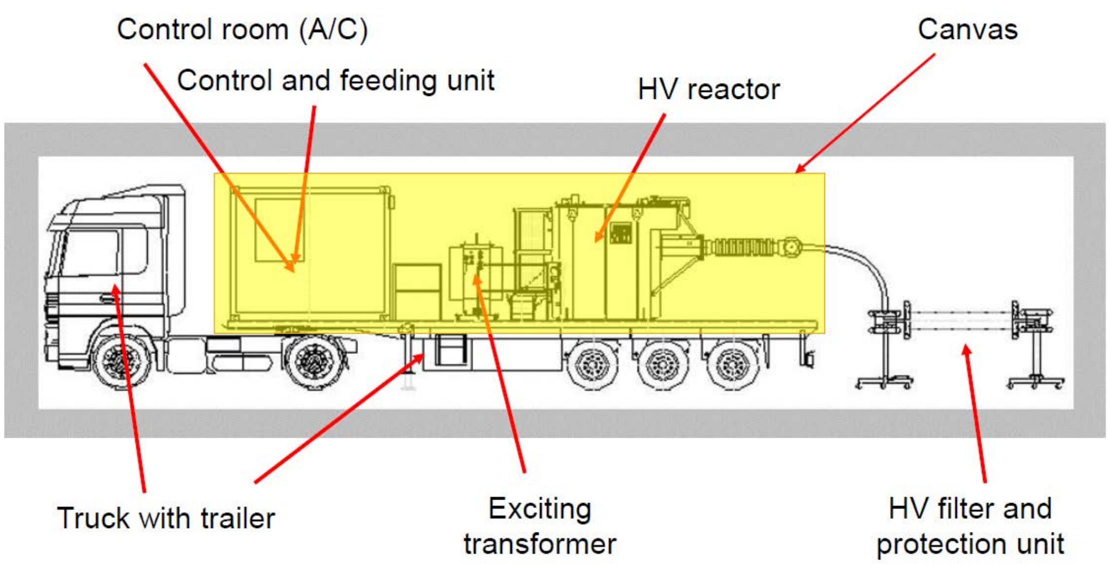


Figure 11-6. AC High Voltage Test Using Resonant Test Set (RTS)

Typically an RTS can supply 285-kV and 80 amperes. At 500-kV, depending on the test voltage and the capacitance of the cable under test, two to four RTSs may be needed and connected in a series parallel configuration to supply both the required test voltage and the capacitive charging current of the cable or cables being tested.

Figure 11-6 shows a high voltage AC test set up using two RTSs. The high voltage test is carried out in accordance with IEC 62067 which allows a test voltage of up to 1.7 UO or 490-kV to be applied for one hour. Cables can be tested individually or together as a group depending again on the test voltage and charging current to be supplied.

12.0 INDUCED CABLE SHEATH VOLTAGES AND CABLE BONDING TECHNIQUES

Alternating currents flowing into the cable conductor induce a voltage by transformer action in the metallic covering of the cable itself and also adjacent cables. The induced voltage causes a current to flow or circulate in the metallic covering if solidly earthed. This current is limited in flow only by the impedance of the metallic covering, which is quite small, and hence circulating currents of several hundred amperes will flow. The sheath induced electromotive force causes two type of losses which are the circulating current losses and the Eddy current losses.

The Eddy currents are induced by the conductor current, sheath circulating currents and currents circulating in close proximity conductors. The Eddy current losses are generated in the metallic covering or sheath of the cable irrespective of the type of bonding system used and are normally smaller in magnitude to circulating current losses.

Circulating currents flow in the metallic covering when grounded at both ends thus providing a path for currents to flow and they are a function of the conductor current, frequency of operation, the impedance of the cable sheath between earthing points and the spacing between cable formation which is in essence a mutual inductance.

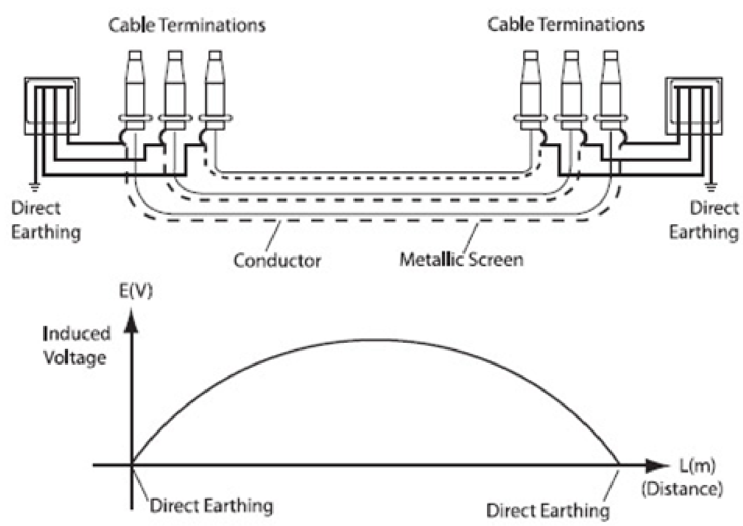
These currents will produce heating and hence losses in the metallic covering of the cables which reduce the allowable temperature rise of the cable conductor and limit the power transfer on the cable system. Special cable metallic covering bonding methods are necessary to limit the circulating currents and the induced sheath voltage. There are four main types of cable bonding and grounding which have been used with high voltage cables and are as follows:

- Solid bonding
- Single point bonding
- Cross bonding
- Star impedance bonding

12.1 Both Ends Solidly Bonded

In this method, the cables are solidly earthed at every joint position and termination and the scheme is shown in Figure 12-1. The multiple ground points cause high circulating currents to flow, therefore, this method is restricted for the most part to distribution class cables and it is not normally used for high voltage cables. For this case, the sheath losses would produce a significant reduction in conductor ampacity, therefore other bonding techniques must be employed for high voltage cables.

Figure 12-1. Both Ends Solidly Bonded



12.1.1 Advantages

The scheme is simple, requires minimal material and it is the most economical if the sheath losses are not a concern. The cable sheaths are grounded at both ends of each section length to provide a path for fault currents and thus minimize ground return current and cable earth grid voltage rise (EGVR). The scheme also does not require an earth continuity conductor (ECC) or sheath voltage limiters (SVL) and it produces the lowest induced standing voltage on the cable sheath.

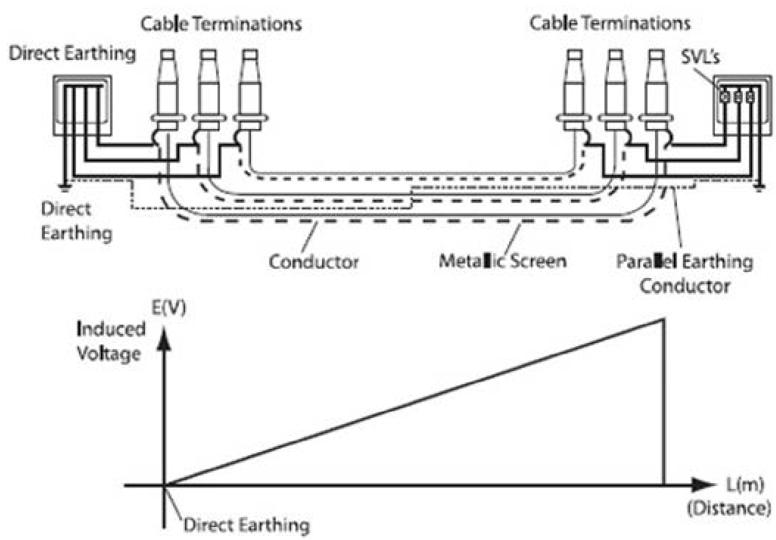
12.1.2 Disadvantages

The scheme produces large circulating current and associated losses thus requiring derating of cables and consequent loss of ampacity. There are transfer voltages between sites when there is an EGVR at one site.

12.2 Single-Point Bonding

This is the simplest form of cable bonding and it is an arrangement which provides no path for the flow of circulating current or fault currents and is shown in Figure 12-2.

Figure 12-2. Single Point Bonding Scheme



In this scheme, the sheaths of the three cable lengths are grounded at one point only through a link box. At the other end, they are kept open by grounding through a link box with sheath voltage limiter (SVL). Figure 12-3 shows the link box with SVLs and Figure 12-4 shows the SVL. As a result, a standing induced voltage will appear between the cable sheath and ground and between the sheaths of the other cables.

The induced voltage will be at its maximum at the open end of the section or at the SVLs and is proportional to the length of cable. Due to the standing voltage, the cable sheath must be insulated from ground for safety reasons to prevent electrocution through accidental contacts. Additionally, sheath voltage limiters must be installed at one end of the cable length to protect the cable insulation during short circuits.

Figure 12-3. Link Box with SVLs

Figure 12-4. SVL

Since there is no path for circulating current to flow longitudinally along the cable sheath, an earth continuity conductor must be installed along the length of the circuit and grounded at the ends of the circuit and at every cable length. The ECC provides a return path for currents during short circuit conditions and limits the voltage rise of the sheath to an acceptable level. The magnitude of the standing voltage on the cable sheath will depend on the geometry of the installation, the cable length, and the current flowing in the conductor and is normally limited to 250 Volts.

12.2.1 Advantages

The advantages of the single point bonding system are simplicity, low cost and the elimination of sheath losses through the elimination of the circulating current.

12.2.2 Disadvantages

The main disadvantage of the single point bonding system is that it requires an ECC along the entire circuit length which increases cost and equipment to be maintained. Plus, the scheme requires SVLs at the open end of the cable end and an induced standing voltage appears at the open end.

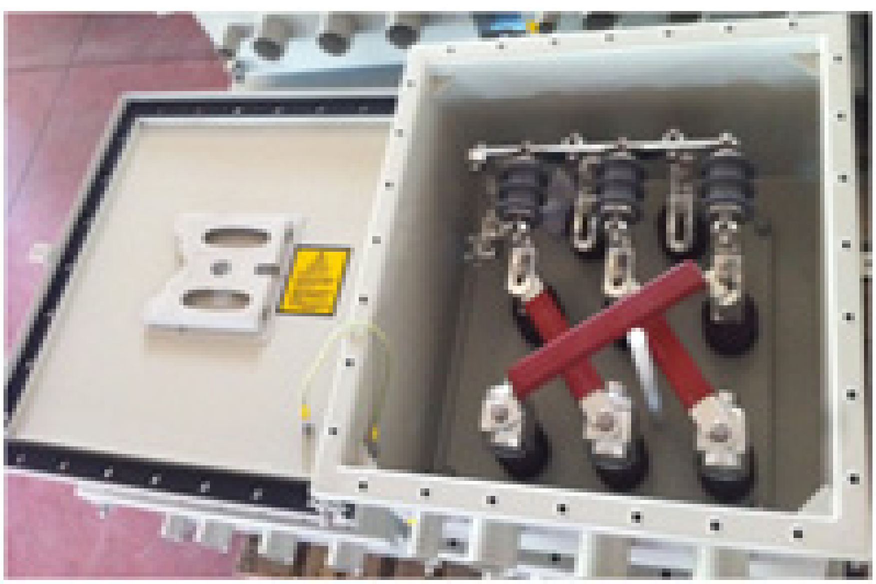
12.3 Cross Bonding with No Transposition and Transposition

For long cable circuits where there are many cable sections, the method of cross bonding of the cable sheaths is normally used. Cross bonding is an arrangement that provides for electrical continuity along the cable sheaths between the earthed circuit endpoints but with the sheaths sectionalized and cross connected to minimize the circulating current.

In this system, no significant circulating current will flow, but an induced voltage will appear between sheath and ground and with the maximum voltage appearing at the cross-bonding boxes. The circuit must be divided into major and minor sections. Each major section consists of three minor sections or individual cable lengths. The number of minor section must be divisible by three for cross bonding to be applicable. The minor section must be of equal length for cross-bonding to be efficient otherwise a circulating current will flow in the cable sheaths and produce heating losses.

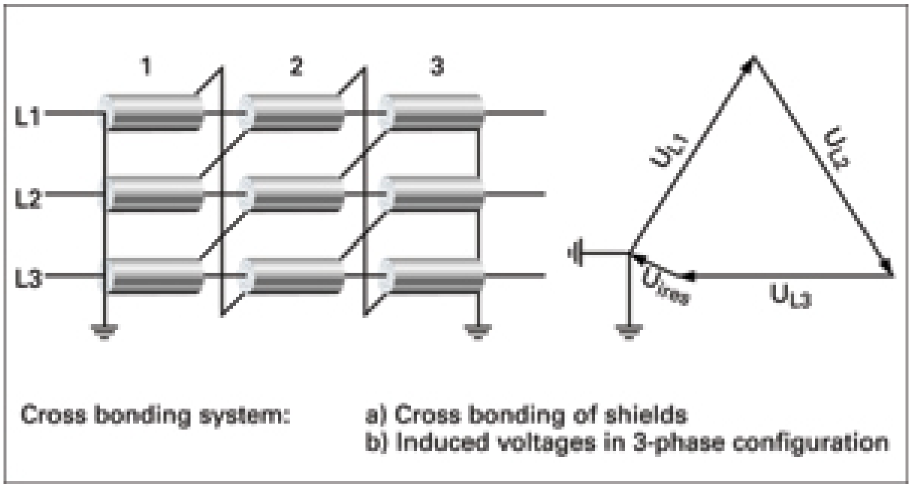
The cross bonding takes places in the cross bonding boxes, shown in Figure 12-5. In this system, the induced sheath voltages are vectorially added to result in a residual voltage of zero, in theory. The induced voltage in each cable length outer sheath will be 120 degrees out of phase.

Figure 12-5. Cross Bonding Box with SVLs



However, due to variations in the length of minor sections and the arrangements of the cable in the trench, a residual induced voltage drop across the major section will appear, as shown in Figure 12-6, and will cause a current to flow. Therefore, some losses will occur and will depend on the amount of circulating current.

Figure 12-6. Cross Bonding with No Transposition



For cables installed in equilateral triangle or trefoil configuration, the sheath induced voltages will be of the same magnitude. However, for other arrangements including right triangle, vertical or horizontal configurations the induced voltage in the cable sheaths of the outer cables, for example for flat formations, will be higher than the induced voltage in the middle cable and the vectorial (phasor) summation is not zero. A circulating current will then flow.

To minimize the circulating current, it will require transposing of the cable in the trench so that a cable occupies every phase position in the trench or conduit bank along the length of the major section plus the cable sheaths must be cross-connected with phase rotation in opposition to that of cable transposition as shown in Figure 12-7. This will equalize or balance out the magnitude of the induced voltage.

Figure 12-7. Cross Bonding with Transposition

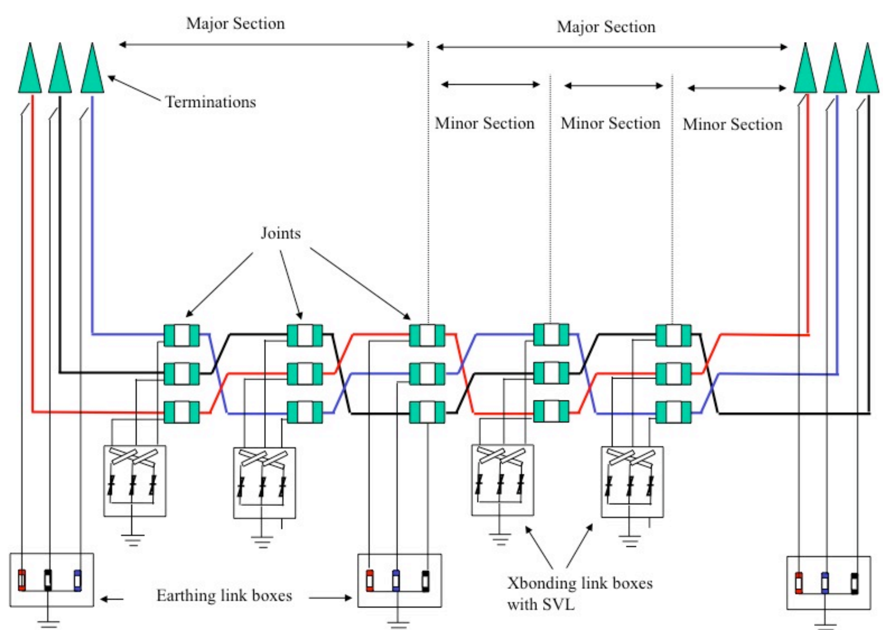
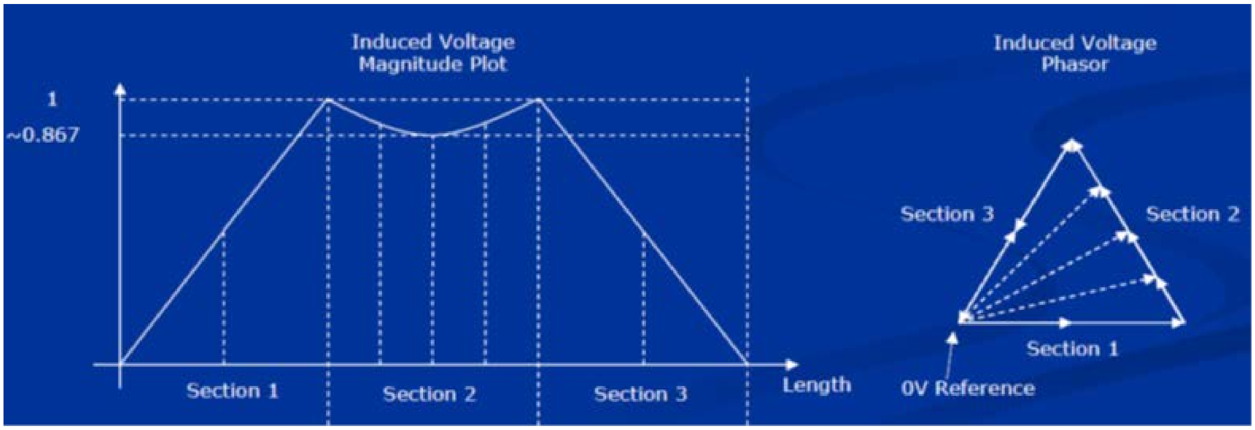


Figure 12-8 shows the induced voltages along a major section with vector diagram for unbalance conditions.

Figure 12-8. Induced Sheath Voltage Profile across Major Section



12.3.1 Advantages

The cross-bonding scheme is universally used and it is suitable for long length circuits. The scheme effectively controls the induced voltages in the cable sheaths and therefore small circulating currents flow resulting in relatively small sheath losses. Another advantage is that the scheme does not require and earth continuity conductor like a single point bond system.

12.3.2 Disadvantages

The main disadvantages are that the cross bonding scheme is more complicated than the solid bonding and single point bonding schemes, is more expensive, and requires transposition of the cables in the trench or at splicing locations in order to balance out the induced sheath voltages.

12.4 Comparison of Bonding Methods

Table 12-1 provides a comparison between the bonding methods.

Table 12-1. Comparison of Sheath Bonding Methods

Bonding Method	Standing Voltage	SVL Required	ECC Required	Application
Solid Bonding	No	No	No	Used for distribution class cables and not for HV or EHV Cables
Single Point Bonding	Yes	Yes	Yes	Has been used mainly for short runs but also used for long circuits
Cross Bonding	Yes	Yes	No	Has been used extensively on long circuit with joints

12.5 Maximum Allowable Standing Voltage

The maximum allowable standing voltage will depend on the utility preference. Some utilities will limit the standing voltage to 65 Volts while others will allow voltages up to 250 Volts and even 400 Volts. The allowable standing voltage will set the limit on the cable span length depending on conductor current, cable dimensions, and trench geometry. A standing voltage of 250 Volts is recommended for this installation in order to maximize cable span lengths.

12.6 Preferred Sheath Bonding Methods for Project

For the I-5 Project, a combination of single bond and cross bonding is preferred to limit circulating currents and sheath losses.

13.0 LOSSES

13.1 Demand and Energy Losses

Losses are produced both in underground cables and overhead lines. There are two types of losses both measured in Watts which are referred to as “demand losses” and “energy losses.” Demand losses are variable, are a function of the current flowing in the conductor, and are as follows:

- Conductor resistance, skin effect and proximity effect losses
- Shielding circulating and eddy current losses

Demand losses are negligible when the cables are unloaded and are at their maximum when the cables are fully loaded.

Energy losses are constant and are independent of load current but are a function of the cable construction and the applied voltage. Energy losses are the insulation losses and the small conductor losses caused by the flow of charging current.

The ratio of demand loss to energy loss is high in an overhead line due to the higher impedance of the line but lower than energy losses. However, the ratio of demand loss to energy loss is low in an underground cable because of the high energy losses in the cable dielectric or insulation.

A critical load exists where the losses in the overhead line equal the losses in the cable. Above this critical load, the cables will have a lower loss. Below the critical load, the cables will have higher losses.

13.2 Loss Calculations

13.2.1 500-kV Cables – Scenarios 1 and 2

The calculated loss at the full load current of 1,140 A flowing in each cable is 1.92 MW for the combined 5.2 circuit miles of 500-kV cables in Scenarios 1 and 2. Table 13-1shows losses for the 500-kV cables for both Scenarios calculated at 100, 50, 25, and 0 percent conductor current. With no conductor current, the dielectric loss due to the cable insulation is 0.64 MW.

Table 13-1. Losses for 500-kV Cables – Scenarios 1 and 2

Scenario	Length (MI)	Cable Groups	Conductor Current, (A)	Conductor Loss (W/FT)	Insulation Loss (W/FT)	Sheath Losses (W/FT)	Total Loss / Cable (W/FT)	Total Loss / Group (W/FT)	Total Loss (MW)
100% Current									
1	2.7	4	1,140	3.698	2.02	0.223	5.941	17.823	1.016
2	2.5	4	1,140	3.698	2.02	0.223	5.941	17.823	0.941
Total	5.2	8	1,140	7.396	4.04	0.446	11.882	35.646	1.957
50% Current									
1	2.7	4	570	0.8526	2.02	0.061	2.9336	8.8008	0.502
2	2.5	4	570	0.8526	2.02	0.061	2.9336	8.8008	0.465
Total	5.2	8	570	1.7052	4.04	0.122	5.8672	17.6016	0.967
25% Current									
1	2.7	4	285	0.209	2.02	0.0154	2.2444	6.7332	0.384
2	2.5	4	285	0.209	2.02	0.0154	2.2444	6.7332	0.356
Total	5.2	8	0	0.418	4.04	0.0308	4.4888	13.4664	0.739
0% Current									
1	2.7	4	0	0	2.02	0	2.02	6.06	0.346
2	2.5	4	0	0	2.02	0	2.02	6.06	0.320
Total	5.2	8	0	0	4.04	0	4.04	12.12	0.666

14.0 CAPACITANCE, CHARGING CURRENT, AND REACTIVE COMPENSATION

14.1 Cable Capacitance, Charging Current, and Reactive Power

In a power system, the cable dielectric or insulation acts as a capacitor due to its ability to store energy when an impressed alternating voltage appears across it.

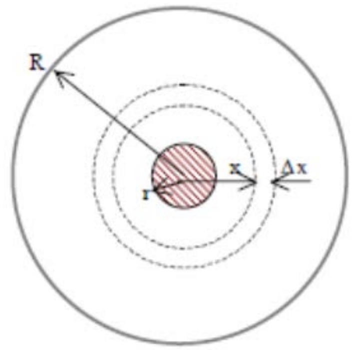
The capacitance of the cable is given as follows:

C =0.8333 Ɛr / (Log10 R/r) µF/mile

where in reference to Figure 14-1

- Ɛr = dielectric constant of the material
- r = radius of core (m)
- R = radius of earthed sheath (m)

Figure 14-1. Cable Diagram



Then, as a result, cables, especially high voltage cables, can draw large charging currents when they are energized. This charging current required by the dielectric at the applied voltage level must be supplied by the rest of the power system. Table 14-1 shows that the 500-kV cables for Scenario 1 will draw a charging current of 399 A per phase while the cables for Scenario 2 will draw 369 A per phase.

Table 14-1. Capacitance and Charging Current for the 500-kV and 230-kV Cables

Scenario	Length, (Mi)	Cable Groups	Capacitance /Cable (µF/Mi)	Capacitance /Cable Group (µF)	Total Capacitance (µF)	Reactive Charging/Cable Group (MVAR/Mi)	Total Reactive Charging/Cable Group (MVAR)	Reactive Charging (MVAR)	Charging Current/Cable (A/Mi)	Total Charging Current/Phase (A)
500-kV										
1	2.7	4	0.339	0.9153	3.66	31.96	86.295	345.18	36.9	398.52
2	2.5	4	0.339	0.8475	3.39	31.96	79.903	319.61	36.9	369.0
Total	5.2	4	0.339	1.7628	7.05	31.96	166.198197	664.7979	36.9	767.52
230-kV										
2	2.7	1	0.396	0.99	0.99	7.9	19.75	19.75	19.8	49.5
2	2.5	1	0.396	0.99	0.99	7.9	19.75	19.75	19.8	49.5
Total	5.2	1	0.396	1.98	1.98	7.9	39.5	39.5	19.8	99.0

Table 14-1 also shows that the 230-kV cables in Scenario 2 will draw a charging current of 49.5 A per phase for each circuit.

14.2 Reactive Power and Compensation for 500-kV Cables

The flow of charging current produces reactive power which is in essence the background energy movement of energy in an Alternating Current (AC) system arising from the production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Devices which store energy such as cables by virtue of the electric field across the insulation are said to generate reactive or leading power.

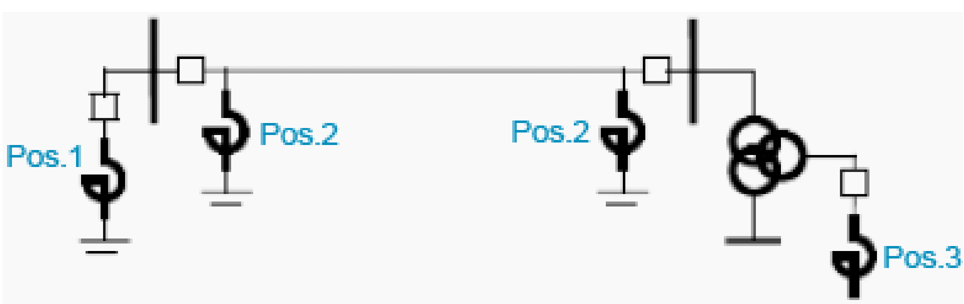
Devices which store energy as virtue of a magnetic field such as inductors produced by a flow of current are said to absorb reactive power. Power flows must thus be controlled in order for a power system to operate within acceptable voltage limits. The flow of reactive power can cause substantial voltage changes across the system therefore a power balance must be maintained between sources that generate reactive power such as cables and source that consume reactive power.

Unlike system frequency which remains relatively constant in a power system, voltages across the power system form a "voltage profile" related to local generation and demand at that instant, affected by prevailing system network arrangements. Voltage and system stability in a power system can be maintained through circuit arrangements; the addition of new facilities and equipment such as lines, generators, and transformers; and the addition of shunt or static compensation.

The addition of the 500-kV cables will add 7.05 µF of capacitance which will draw 767.52 amperes of charging current in each phase when the cables are energized. The flow of the charging current causes a leading reactive power flow of approximately 665 MVAR. This can be compensated at 60 to 70 percent by the addition of reactors totaling approximately 399 to 466 MVA.

For the 500-kV cables, shunt reactors could be placed at one or both ends of the cable groups (Pos. 2) to compensate for the flow of charging current. Alternatively, the reactors could be bus connected (Pos. 1) or connected to transformer tertiaries (Pos. 3) as shown in Figure 14-2 below.

Figure 14-2. Connection of Reactors



However, the optimal location for the addition of shunt reactors should be determined by BPA by conducting studies and simulations at different load conditions and also taking into consideration future system additions. The effect of adding the underground cable would be most significant when the system overall is lightly loaded which will cause voltages to rise in substations at the end of the line. To compensate fully for the addition of the 500-kV cables, shunt reactors totaling approximately 665 MVAR would need to be added and this can be done by the addition of reactors in the transition stations. Figure 14-3 shows bus connected single-phase high-voltage shunt reactor in a substation.

Figure 14-3. High-Voltage Single Phase Shunt Reactor

14.3 Reactive Power and Compensation for 230-kV Cables

The addition of the 230-kV cables will add 1.98 µF of capacitance per phase which will cause 99.0 A of charging current to flow. The flow of the charging current causes a leading reactive power flow of approximately 39.5 MVAR.

15.0 EMF ANALYSIS

15.1 EMF from UG Cables

The term EMF refers to electric and magnetic fields that are coupled together at power and high frequencies. Voltages on conductors produce an electric field around the conductor. For underground cables, the electrical field exists only within the insulation and terminates at the cable metallic shield and no field exists outside of the cable. For overhead lines, the air around the conductor is the dielectric medium which acts as the insulation and therefore electrical fields are created between conductors and between the conductors and earth. The strength of electrical fields is high in the immediate vicinity of the conductor and decreases rapidly with increasing distance.

In correlation, currents flowing in an insulated conductor or a wire generate a magnetic field in the area around the wire. The magnetic field surrounding the conductor or wire decreases rapidly with increasing distance from the conductor. The magnetic profile that will exist over the underground transmission cables at any one time will be a function of the geometry of the installation and on the current flowing through the conductors at that time. The current is directly proportional to the magnetic field so the field will be strongest at full load.

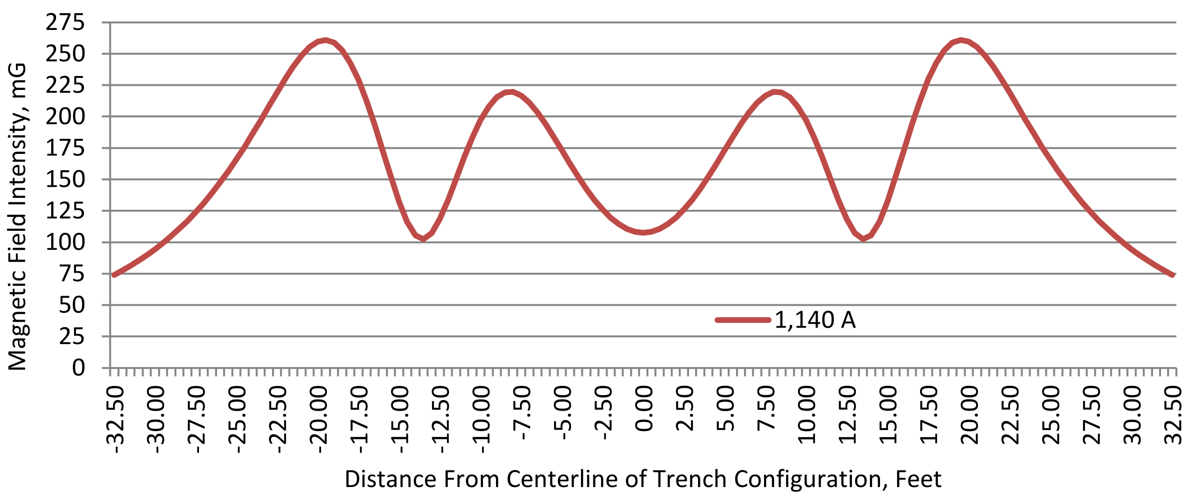
The magnetic field intensity is expressed in milligauss (mG) or microtesla (µT) where 10 mG equals 1 µT.

The International Commission on Non-Ionizing Radiation Protection Guidelines for Limiting Exposure to Time-Varying Electrical and Magnetic Fields (1 Hz – 100 kHz) published in Health Physics 99(6):818-836 in 2010 provides a threshold value of 200 µT or 2,000 mG at 60 Hertz.

15.2 EMF from 500-kV Cables for Scenarios 1 and 2

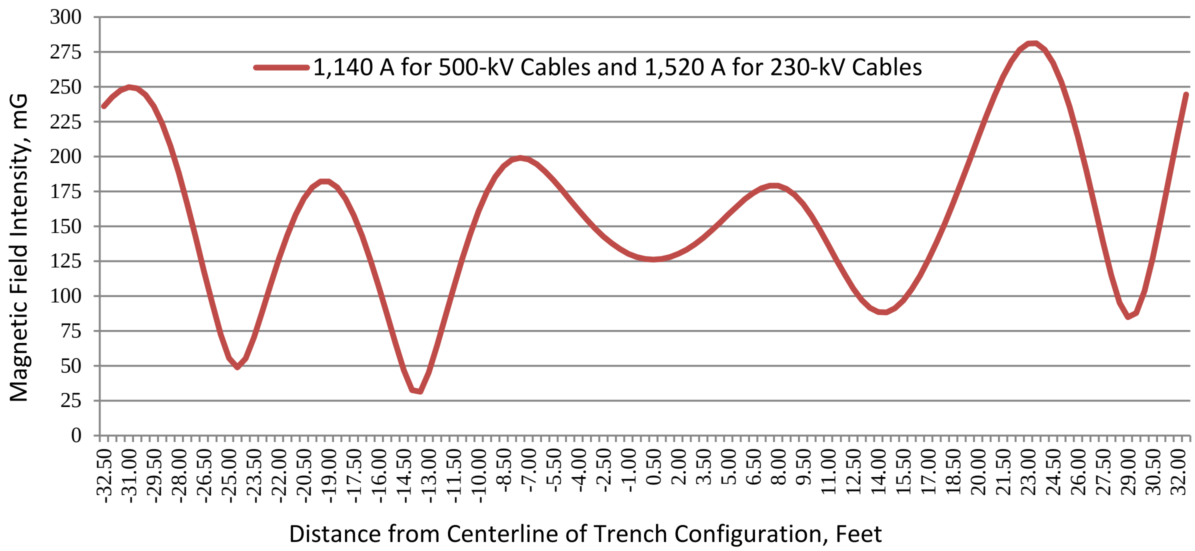
The magnetic field intensity for the four trench configurations and all cables carrying full load is measured at 1 meter above ground and shown in Figure 15-1 for Scenario 1 and Figure 15-2 for Scenario 2 at various distances from the center of the trench configurations. The magnetic field intensity for the 500-kV and two 230-kV cables in deep bores for the Washougal River crossing in Scenario 2 with all cables carrying full load is shown in Figure 15-3.

Figure 15-1. Magnetic Field from Cables in Trenches (Scenario 1)



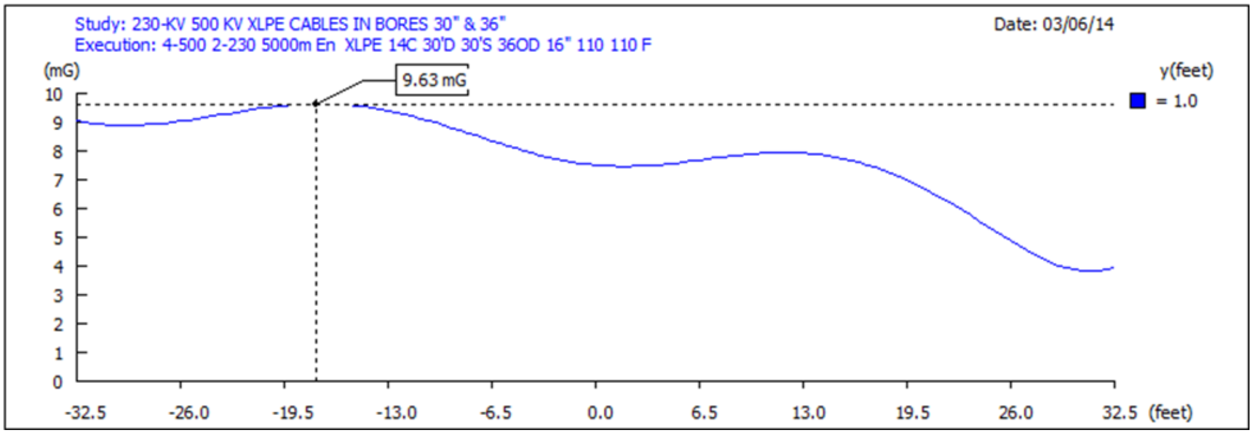
Four Groups of 500-kV Cables carrying 1,140 A

Figure 15-2. Magnetic Field from Cables in Trenches (Scenario 2)



Four Groups of 500-kV Cables carrying 1,140 A and 2 Groups of 230-kV Cables carrying 1,520 A

Figure 15-3. Magnetic Field from Cables in 30-foot Deep Bores (Scenario 2)



Four Groups of 500-kV Cables carrying 1,140 A and 2 Groups of 230-kV Cables carrying 1,520 A

16.0 CIRCUIT AVAILABILITY AND REPAIR

16.1 Circuit Availability

As described in Section 5.0, the majority of outages on high voltage cables are caused by third party damage. However, other factors such as installation problems, manufacturing defects, and aging also contribute to circuit outages.

Circuit outages can be extensive depending on the type of fault, involved equipment, and extent of damage. Repair times depend on availability of spare parts, availability of specialized equipment and availability of trained and skilled personnel to make the repair. Repairs may be extensive depending on the type of fault or problem and may require significant repair time.

16.2 Spare Material for Fault Repair

In order to minimize repair times, it is recommended to keep spare material in stock as part of inventory which has been a long utility practice. It is recommended that the following material be purchased and kept in stock for both the 500-kV and 230-kV cables:

- Cables: The practice is to keep six reels in stock for the longest cable span on the circuit. This is necessary to allow for the replacement of six spans of cable in the event of a manhole fire which damages all six cable phases.
- Joints: Normally, three full jointing kits should be kept in stock. For EHV cables, perishable materials in the kits such as premolded joint bodies or stress cones which have a limited shelf life of about three years should be replaced accordingly.
- Terminations: Normally, two full cable termination kits should be kept in stock. Perishable materials in the kits such as stress cones which have a limited shelf life of around three years should be replaced accordingly.

16.3 Special Tools Required for Repairs

The installation of high voltage joints and terminations requires the use of special tools, which must be available to make the repair. It is suggested that one kit be purchased from the cable supplier and be kept with the spare stock for repair purposes. The special tool kit contains the following equipment and tools:

- Slide Rail System: Used for the installation of heavy premolded or prefabricated components onto the cable ends during the splicing process.
- Presses and Dies: Needed for the pressing of the splice connector.
- Insulation Shield and Insulation Strippers: Needed for removal of the semiconductive insulation shield and of the insulation from the conductor.
- Heating Tapes and Controllers: Needed for heating the cable ends to straighten the cables for joint installation requirements.

Table 16-1 provides a list and picture of special tools which should be kept in stock for repairs

Table 16-1. Special Repair Equipment

Item	Description	Picture	Specification
1	Temperature Controller		Rated Voltage : 220V For all of the XLPE Cable
2	Tool for Removing XLPE		For cutting a groove around the insulation of extra high voltage cable

Table 16-1. Special Repair Equipment

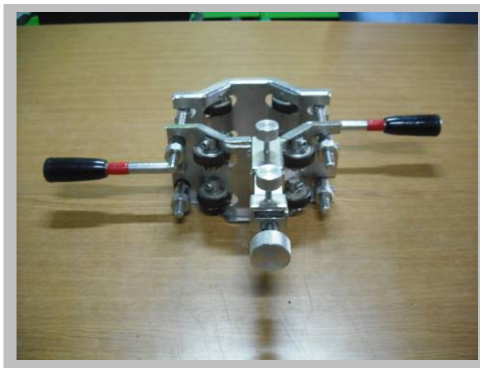
Item	Description	Picture	Specification
3	Pullers		6in-s-5ton
4	XLPE Shaver		For peeling the extruded semicon layer of extra high voltage cable
5	Pressure Pump		
6	Pressure Holder		

Table 16-1. Special Repair Equipment

Item	Description	Picture	Specification
7	Hexagonal Dies		Pressure Holder: EP-200W

16.4 Repair Times

The failure rates for high-voltage cables are low but repair times can be long and depend on the type of fault. In the event of a cable failure, the following steps would be required:

1. Fault location and site assessment
2. Assess extent of damage and engineer repair
3. Mobilize personnel and equipment and assemble needed spare part
4. Prepare all necessary repair drawings and instructions such as jointing and testing instructions
5. Obtain all necessary permits
6. Transport new cable reel and joint kits to repair site
7. Undo two joints at end of faulted cables
8. Remove the faulted cable
9. Install the replacement cable
10. Assemble two joints at end of new cable
11. Assemble cross-bonding cable connections
12. Perform electrical tests such as an AC high voltage test with a RTS
13. If a RTS is not available, conduct a 24-hour "soak" test
14. Conduct PD testing on the replacement joints
15. Test SVLs in link boxes
16. Reinstate area

It is estimated that this process may take in excess of 30 days for the 500-kV cables assuming spare materials and skilled jointers are readily available.

17.0 CIRCUIT MAINTENANCE

The safe and reliable operation of both the 500-kV and 230-kV system will depend to an extent on preventive maintenance and inspections which are good practices for any utility operator of such facilities. Although there is a cost associated with rigorous maintenance and inspection, this a prudent practice and will more than offset this cost through the scheduled repair of equipment before they turn into forced outages which will also limit system availability.

A maintenance schedule must be developed and followed. A typical schedule is described below.

17.1 Underground Cable Routes Patrols

- Frequency: Weekly
- Visually inspect for any fresh excavations near the cable alignments.
- Visually inspect for any excavations in progress.
- Verify that all route and cable markers and warning signs are in place and visible.

17.2 Manholes, Joints, Link Boxes and Steel Supports

- Frequency: Yearly

17.2.1 Manholes and Support Hardware

- Visually inspect walls and ceilings for cracks and concrete spalling.
- If water is present, pump all water out.
- Inspect steel cable and joint supports for sign of corrosion and repair/replace as needed.
- Inspect cable and joint clamps for sign of loosening or corrosion.
- Check for the legibility of tags on cables and splices.

17.2.2 Cables in Manholes

- Visually inspect jackets for any sign of cracking or deterioration.
- Verify that cables are not moving or slipping through clamps or other restraining devices as a result of expansion with loading or elevation differences along the route.

17.2.3 Joints in Manholes

- Visually inspect jacketing material on the joints.
- Check location of joints for movement.
- Inspect any fiber splicing boxes at joints.
- Visually inspect the bonding cables connections at the joints.

17.3 Sheath Bonding and Grounding System

- Frequency: Yearly
- Remove and/or rearrange links in link boxes.
- Conduct jacket test for each cable section by applying 5-kV for one minute to check integrity of the jacket.
- Ground other cable sections which are not under test.
- If high leakage currents are found, it will be necessary to locate the damage point.
- Test each individual SVL in the link boxes and measure the resistance.

17.4 Cable Terminations

- Frequency: Yearly
- Inspect support insulators.
- Inspect main porcelain or composite bushing for any sign of damage.
- Inspect for oil leaks.
- Test any pressure alarm system associated with the oil system.
- Conduct dissolved gas analysis (DGA) if valves are available for oil sampling.

17.5 Estimated Yearly Maintenance Costs

Table 17-1 below describes the anticipated maintenance requirements in terms of person days/year.

Table 17-1. Maintenance Requirements and Associated Time

Description	Scenario 1 (Days/Cable Group)	Scenario 2 (Days/Cable Group)	No. Persons/ Crew	Person Days/ Year
Weekly Patrols			1	56
Perform DC Jacket Tests	1	1	2	8
Conduct Tests for SVLs, Link Boxes, and grounding	2	2	2	32
Inspect Cable Terminations	0.25	0.25	2	4
Inspect Manholes	2	2	2	32
Total				132

Based on these numbers, the total cost for the inspection program would be: 132 person-days/year x \$50/hour x 8 hour/day = \$52,800/year, which does not include any repair costs.

18.0 COST ESTIMATE

This section provides estimated capital costs for the 500-kV cables and the 230-kV cables. The estimated capital costs for Scenarios 1 and 2 were calculated based on budgetary prices received in 2013 and 2014 from manufacturers for the cable system, installation and testing and in conjunction with costs for the civil work based on other projects and researched information.

18.1 Scenarios 1 and 2 Cable System Supply, Installation and Testing

Data obtained from manufacturers for the cable system supply and installation was compiled and averages were calculated. The estimate for the supply, installation and testing of the cable systems are based on the following:

1. Average costs for the cable components
2. Average cost of installing cable, joints and terminations
3. Average cost of final testing

The sampling of data however was small and data furnished by four manufacturers was used to calculated averages for the 500-kV system and two manufacturers for the 230-kV system.

18.2 Scenarios 1 and 2 Conduit System Installation

The conduit and manhole system installation costs were estimated based on typical costs from other projects for trench excavation and laying and backfilling of conduits; typical costs for jack and bore; and typical costs of horizontal directional drilling.

18.3 Cumulative or End to End Project Costs

The end to end cumulative costs include the following:

1. The installation of the 500-kV underground system for Scenario 1
2. The installation of the 500-kV underground system for Scenario 2
3. The installation of the 230-kV underground portion of Line 1 for Scenario 2
4. The installation of the underground portions of Line 2 for Scenario 2
5. Installation of 500-kV transition stations for Scenario 1
6. Installation of 500-kV transitions stations for Scenario 2

Table 18-1 shows the estimated costs for the 500-kV system for Scenarios 1 and 2, the 230-kV system for Line 1 and Line 2 in Scenario 2, and the costs for the transition stations.

Table 18-1 and Figure 18-1 shows that the total installation costs are as follows:

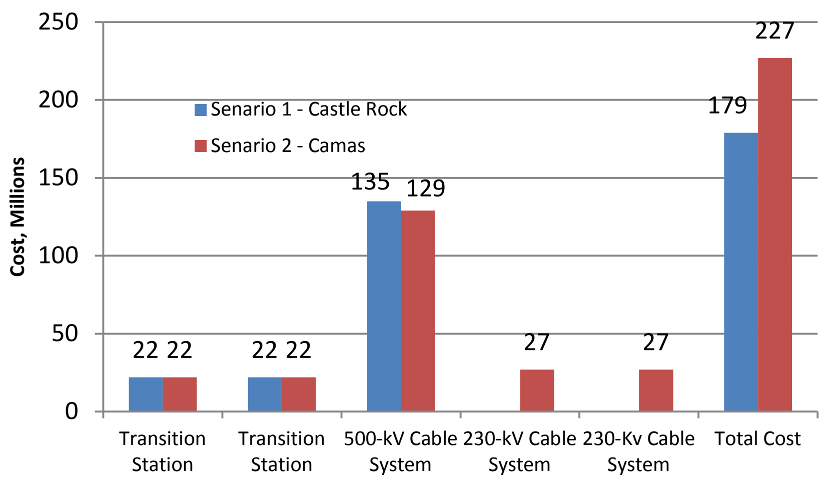
- Scenario 1: $179M for 500-kV cable system and transition stations
- Scenario 2: $173M for 500-kV cable system and transition stations

- Scenario 2: $54M for 230-kV cable systems
- Total: $406M

Table 18-1. Estimated Costs for 500-kV and 230-kV Cable Installations

Scenario	Voltage (kV)	Number of Circuits	Transition Station Cost ($M)	Transition Station Cost ($M)	Cable System Cost ($M)	Total Cost ($M)
1	500	1	22	22	135	179
2	500	1	22	22	129	173
2	230	2			54	54
Total			44	44	318	406

Figure 18-1. Estimated Capital Costs for Scenarios 1 and 2



The basis for the estimated costs, including assumptions and inclusions, are listed in Appendix F.

19.0 SCHEDULE

Table 19-1 below provides the major activities construction time requirements for the installation of the underground cable systems for Scenarios 1 and 2. This estimate assumes that the work would to be done in a serial approach. Work would progress from start to finish for each cable system: 500-kV in Scenario 1, 500-kV in Scenario 2, and 230-kV in Scenario 2. Construction work on all three cable systems would occur at one time. Based on these assumptions, it is estimated that the construction of the underground transmission system would take about 3.0 years as activities can be carried out in parallel. This schedule does not include the time necessary for permitting and design and does not include sequencing outages on existing transmission lines.

Table 19-1. Installation Time Estimate

		Scenario 1	Scenario 2	
Description	**Units**	**500-kV**	**500-kV**	**230-kV**
Conduit Installation	LF	57,000	53,000	26,400
Production - 2 Crews	300 LF per day	190	176	88
Manhole Installation	EA	28	24	12
Production - 1 Crew	1 per 4 days	112	96	48
Cable Installation	Spans	96	84	42
Production	2 Spans per day	48	42	21
Splice Installation	EA	84	96	36
Production - 2 Crews	3 per 15 days	420	360	180
Production - 4 Crews	6 per 15 days	210	180	90
Termination Installation	EA	24	24	12
Production - 2 Crews	3 per 15 days	120	120	60
Commissioning		30	30	30
Total with 2 Splicing Crews				
Days		920	824	427
Months	20 day / month	46.0	41.2	21.4
Years		3.8	3.4	1.8
Total with 4 Splicing Crews				
Days		710	644	337
Months	20 day / month	35.5	32.2	16.9
Years		3.0	2.7	1.4

20.0 OVERHEAD TO UNDERGROUND TRANSITION STATIONS

This section describes the stations needed to transition the 500-kV overhead line to underground cables and the singular pole structures to transition the 230-kV overhead lines to underground cables.

20.1 500-kV Transition Stations

Transition stations will be required for the 500-kV line to transition from overhead to the underground cables. Figure 20-1 shows a 400-kV transition station in Spain with six 400-kV cable terminations in the foreground and the A-frame structure and the overhead conductors in the background.

Figure 20-1. 400-kV Transition Station

A total of four transition stations would be required. Two stations would be required to transition from overhead to underground and from underground back to overhead for Scenario 1. Two transition stations would also be required for Scenario 2. Table 20-1 summarizes the number of stations, locations, and area requirements for stations that have shunt reactors.

Table 20-1. Location and Size of Transition Stations with Shunt Reactors

	Number Required	Proposed Location	Proposed Location	Approximate Length (Feet)	Approximate Width (Feet)	Area (Acre)
Scenario 1	2	Near Tower F-10	Near Tower F-22	380	520	1.85
Scenario 2	2	Near Tower 51-10	Near Tower 52-13	380	520	1.85

The final layout and size of the station will need to be determined by the number and type of required equipment for installation. Two layout drawings of the transition stations were developed and are provided in Appendix E. One station layout includes three single-phase 500-kV reactors for shunt compensation while the other layout eliminates the reactors.

The reactor station requires a width of 380 feet and a length of 520 feet or 1.85 acres. The station would contain the following equipment:

- Three single-phase 500-kV reactors
- One 500-kV breaker to allow switching of the reactor for different operational requirements
- One 500-kV breaker to allow switching of the four cable groups
- Four 500-kV manual disconnects to disconnect individual cable groups for repair or maintenance

- One A-frame type terminal tower structure to dead end the overhead conductors and for jumper connections to the cable terminations
- Twelve 500-kV surge arresters for the cables for switching and lighting surge suppression

While reactive compensation could be installed in other substations, the optimal location is at the ends of the cable sections. By placing the reactors at the ends of the cable sections, the reactors will help in bleeding off the cables' capacitive charge. The layout of the station would consist of an A-Frame placed at one end of the station and the three reactors placed at the other end of the station. Breakers are placed between the A-frame and the reactors to isolate the reactors or the cables in the event of fault. Manual disconnects are placed in series with the cable terminations so that the individual cable groups can be isolated for repair or maintenance.

The non-reactor station configuration eliminates the reactors and the reactor breakers and requires a width of 250 feet and a length of 648 feet. The station would contain the following equipment:

- One 500-kV breaker to allow switching of the four cable groups
- Four 500-kV manual disconnects to disconnect individual cable groups for repair or maintenance
- One A-frame type terminal tower structure to dead end the overhead conductors and for jumper connections to the cable terminations
- Twelve 500-kV surge arresters for the cables for switching and lighting surge suppression

As an alternative, for either station configuration, a ring-bus scheme could be considered to allow each cable group to have their own 500-kV breaker in addition to the manual disconnect. In addition, cable groups could be individually disconnected while leaving the others in service to provide for flexibility of operation. The ring-bus scheme would also eliminate the need for an outage of the entire line in order to isolate individual cable groups which would require manual operation by personnel. With the automatic opening of a cable group via a breaker, the line would continue to operate with three cable groups in service at reduced capacity. Lastly, placing the reactors in the transition station would allow for the cable capacitive charge stored in the cables' insulation to discharge through the breaker quickly.

20.2 230-kV Transition

Terminal poles will be required for the 230-kV lines to transition from overhead to the underground cables. Figure 20-2 shows a terminal pole with six 230-kV cable terminations at the top of the pole. This arrangement would require two terminal poles for the lines. However, for flexibility of operation each overhead line can transition to underground cables at dedicated terminal poles, therefore, four poles would be required or two per line.

Figure 20-2. Terminal Pole with Cable Terminations

21.0 RECOMMENDATIONS GOING FORWARD

This report provides an initial assessment for undergrounding two sections of an 80-mile long 500-kV transmission line and to underground sections of two 230-kV overhead transmission lines. The next steps recommended going forward for the project implementation are as described in this section.

21.1 Route Interfering Substructures Surveys

Conduct a survey of interfering substructures as follows:

- Identify existing buried substructures from existing substructure maps
- Conduct potholing to determine depth of the substructures
- Determine how the cables would cross either above, below or splitting of the conduits
- Determine the impact on ampacity if the depth of trenches must be increased past 10 foot depth in order to cross underneath substructures
- Determine the impact on ampacity if there is interference heating from substructures such as existing cable systems, steam lines, or pipelines that carry fluids at temperatures above ambient
- Determine if additional jack and bore of horizontal directional drilling is required to cross underneath substructures and the impact on ampacity
- Notify and obtain necessary permits and method of crossing from owners of the substructures

21.2 Plan and Profile Drawings

Develop plan and profile conduit and manhole drawings of the 500-kV installations at Castle Rock for Scenario 1 and of the 500-kV and 230-kV installations at Camas.

21.3 Geotechnical Analysis

Based on the plan and profile drawings, conduct geotechnical studies using soil borings and determine the soil composition and other considerations for the cable system installation such as directional drilling for crossing of the rivers and jack and bore to cross highways. The railroad company owners may also require soil borings and soil analysis for crossing under the railroad tracks.

21.4 Thermal Resistivity Analysis

Based on the plan and profile, conduct a thermal resistivity testing and analysis of the soil along the route as described in Section 2.3.2.

21.5 Temperature Analysis

Based on plan and profile, conduct an earth temperature analysis of the route as described in Section 2.3.3.

21.6 Additional Ampacity Calculations

Based on the plan and profile, thermal resistivity and temperature analysis, perform ampacity analysis for steady state conditions based on the data collected. Also, determine the actual load factor for the summer months for use in the ampacity calculations. Following these analyses, the system design can be optimized to possibly reduce the number of trenches for the 500-kV cables from 4 to 3 by eliminating one cable group and, to reduce the conductor size, and to possibly reduce the overall width of ROW required for the cables.

21.7 Additional Information Requests

Contact cable manufacturers and request additional technical information, data on service experience and test data for 500-kV cable systems including type and PQ testing. Additionally, contact Southern California Edison and obtain information including PQ testing, type testing and design characteristics for the 500-kV, 3.7-mile long, CHUG project which will be in a duct and manhole system similar to the one proposed in this study.

21.8 500-kV Installation Visits

Visit the CHUG project during installation and, if possible, visit 500-kV cable installations in Japan or China which are in tunnels and have cable joints.

21.9 Factory Audits and Visits

Visit cable factories in Japan, Europe, or the US that are prequalified to manufacture 500-kV cables in order to evaluate the manufacturing and quality control processes.

21.10 Additional Testing and Evaluations

Additional testing and evaluations for the project include funding a of a long term PQ test for a 500-kV cable system specific to this project.

21.11 Develop Strategy for Cable Supply and Installation

To minimize risks of the same cause of failure, the possibility of sourcing 500-kV cable and accessories from more than one manufacturer should be investigates but this will require to keep spare material from more than one supplier.

21.12 Reactive Compensation Studies

Study the need to add reactive compensation at the beginning and end of the 500-kV line to compensate for the leading MVAR flow from the underground cable sections under different operating conditions.

22.0 References

Bureau of Land Management. 2013. Technical Working Group Report for the SunZia Transmission Line Project. August 2013.

Johnson, Dennis. 2011. Underground Route Study, January 21, 2011.

Furumasu B and Hosman W, Environmental Impacts Associated with Overhead and Underground 500-kV Transmission Line Construction, Operation and Maintenance Activities, January 21, 2011

Mirebeau P, Ros, H, and Gahungu F, Modern 500kV AC Insulated Cable Transmission System Laid in a Gallery

D. Dubois, 'Shibo 500 kV Cable Project – Shanghai – China', IEEE Insulated Conductors Committee Meeting, Fall 2007, Scottsdale, AZ

Mirebeau P, Ros, H, and Gahungu F, Modern 500kV AC Insulated Cable Transmission System Laid in a Gallery, CEPSI, 2010, Taipei

Taihan Electric Wire Co., LTD, '500kV AC XLPE Cable Project in Russia'

Mirebeau P, Recent 500 kV Cable Systems', IEEE Insulated Conductors Committee Meeting, Spring 2009

Vogelsang R, Sekuda O, Nyffenegger H, and Weissenberg W, 'Long-Term Experience with XLPE Cable Systems up to 550 kV', Konferenca Slovenskih Elektroenergetikov, 2009, Kranjska Gora 2009, CIGRE SC B1

Yongquan H, Ishibashi T, Yamamoto K, Abe K, and Yoneda Y, '500kV Aluminum-Sheathed XLPE Cable in a 96m Vertical Shaft', Hitachi Cable Review No. 18, October 1999

Jiang Y, Jiang X, and Wang Z, '500KV feed Cable Project for Expo Substation, 8th International Conference on Insulated Power Cables, Paper A.3.1

Yonemoto N, Muneta Y, Yamanouchi H, Seo S, Kumada Y, Itoh M, Kunimura S, Nakumura S, Fujii Y, and shii, M, 'Tokyo Electric Power Company, Inc., and VISCAS Corporation, "Construction of the World's First Long-Distance 500kV XLPE Cable Line" Dec 2002.

Southern California Edison, 'Southern California Edison Company's Preliminary Underground Testimony in Response to the Assigned Commissioner's Scoping Memos and Rulings on the Tehachapi Renewable Transmission Project (TRTP)', December 3 2012

Gregory, B and Williams, A, 'Feasibility study for 500 KV AC underground cables for use in the Edmonton region of Alberta, Canada Report # ER 381, February 2010.

Gregory, B and Williams, A, 'Non-Technical Summary Feasibility study for 500 KV AC Underground Cables for Use in the Edmonton Region of Alberta, Cable Consulting International, www.cableconsulting.net

The AESO Commissioned 500 kV Underground Transmission Feasibility Study, Edmonton, Alberta, February 24 2010 Presentation

Gregory, B and Williams, A, Presentation for Feasibility Study for 500 kV AC Underground Cables for Use in the Edmonton Region of Alberta Canada for AESO, presentation by Cable Consulting International, 2010

AESO, Technical Information Section, Underground Transmission Lines, September 18, 2009

Expert Witness Testimony of Simon Allen on behalf of RETA in Relation to Inquiry into the Proposed Heartland 500-kV Transmission Power Line, February 27 2011.

Everglades National Park 500 KV Underground Feasibility Study" Part 1 of 2 dated March 23 2010 prepared for United States Department of the Interior National Park Service by Patrick engineering, Lisle, IL.

Everglades National Park 500 KV Underground Feasibility Study" Part 2 of 2 (Attachments) dated March 23 2010 prepared for United States Department of the Interior National Park Service by Patrick engineering, Lisle, IL.

Public Service Commission of Wisconsin, "Underground Electric Transmission Lines," undated, Website: http://psc.wi.gov.

Evaluating of Underground Electric Transmission Lines in Virginia, House Document No. 87, 2006

http://www.s258888288.websitehome.co.uk/Underground/GIL.html - Gas Insulated Lines

Koch, H, "Experience with 2nd Generation Gas-Insulated Transmission Lines GIL", Siemens AG

Riedl J and Hillers T, "Gas-Insulated Transmission Lines, IEEE Power Engineering Review, September 2000

Poehler S, Rudenko P, "Directly Buried Gas-Insulated Transmission Lines (GIL)" Siemens AG, IEEE 2012

Schoffner G, Kunze D, and Smith I, "Gas Insulated Transmission Lines – Successful Underground Bulk Power Transmission for More than 30 Years", Siemens PTD, Germany

Schlumberger A, "HV XLPE Cable Design and Manufacturing", IEEE Insulated Conductors Committee, Fall 2003, Dallas, Texas

Hampton N, Hartlien R, Orton H, Ramachandran R, "Long-Life Insulated Power Cable", Jicable 20078

Vogelsan R, "Long term Experience with XLPE Cable Systems up to 550-kV

Boone W, De Wild F, HV Power Cables Installed in Multi Purpose Tunnels, A Challengeable Option!, JiCable 2007

Ruiz Riba J. R, Morera Alabern X, "Effects of the Circulating Sheath Currents in the Magnetic Field Generated by an Underground Power Line, Department d' Enginyeria Electrica, UPC

Analysis of Parameters Affecting Costs of Horizontal Directional Drilling Projects in the United States for Municipal Infrastructure By Emmania Claudyne Vilfrant, Arizona State University, December 2010.

Boyle E and MacDonald E, Presentation "Horizontal Directional Drilling", CGA Engineering Conference, 2009

New Bedford Supply Cables Relocation Estimates and Schedules by COM/Electric, March 18 1998 Meeting for EPA Region 1 for Acushnet River Crossing

Barlas A, "Overview of Horizontal Directional Drilling for Utility Construction" Master's Report Presented to the Graduate Committee of the Department of Civil Engineering for the Fulfillment of the Master Degree for the Degree of Master of Engineering, University of Florida, Summer 1999

City of Rochester Public Utilities, "Consideration of Bids for Bids for Directional Boring and Miscellaneous Excavations", Board Action March 27 2012

Hashash Y and Javier J, "Evaluation of Horizontal Directional Drilling (HDD)", for Illinois Center for Transportation Series No 11-095, University of Illinois at Urbana-Champaign, November 2011

Sarireh M, "Cyclic Productivity for Horizontal Directional Drilling (HDD) Operation", International Journal of Construction Engineering and Management 2013, 2(3): 46-52

Appendix B, Cost Estimate for Bonding Submittals, Town of Easton Department of Public Works, January 2011

Typical Jack and Bore Construction, Spec Services Figure 5-2, December 10 2003

ftp://ftp.dot.state.fl.us/LTS/CO/Specifications/SpecBook/2004Book/D556.doc.pdf , Section 556 Jack and Bore

http://brprojects.com/SSOProgram/Documents/Design/specs/Section_817_Jacked_and_Bored_Pipe_Casing.pdf, Section 817 Jacked and Bored Pipe Casings Specs

Kent H and Brucea G, "Report Hauauru ma raki Waikato Wind Farm, Connection to Main Grid Underground Study Attachment 1 of the Consolidated Report", Prepared for Contact Energy by Energy Action Pty Ltd.

http://mn.gov/commerce/energyfacilities/documents/25731/FEIS Appendix D River Crossing.pdf CapX Hampton-Rochester – La Cross 345 kV Project, prepared by Power Engineers for XCEL Energy, December 30,2009

Argaut, P and Damsgaard M, " New 400-kV Underground Cable System Project in Jutland (Denmark), Jicable 2003

De Leon, F "Calculation of Underground Cable Ampacity" CYME International T&D, 2005

Mirebeau P, "Advances in EHV Extruded Cables", Insulated Conductors Committee of IEEE, Spring 2009

ECOFYS Germany GmbH, “Study on the Comparative Methods of Overhead Electricity Transmission Versus Underground Cables”, by order of Department of Communications, Energy and Natural Resources, Ireland, Golder Associates, May 2008

EPRI Report 1001846, “Cable System Technology Review of XLPE EHV Cables, 220-kV to 500-kV”

EPRI Report TR-109205, “Deep Cable Ampacities Guidelines for Calculating Ampacities of Cables Installed by Guided Boring, December 1997”

CIGRE Working Group B1.07, Document 338, “Statistics of AC Underground Cables in Power Networks”, December 2007

CIGRE Working Group B1.10, Technical Brochure 379 Update of Service Experience of HV Underground and Submarine Cable Systems”, April 2009

National Grid, “Undergrounding High Voltage Electricity Transmission, Technical Issues” August 2008

The Highland Council, Cairngorms National Park Authority and Scottish Heritage Undergrounding of Extra High Voltage Transmission Lines”

Neher J H, McGrath M H, “The Calculation of the Temperature Rise and Load Capability of Cable Systems”, AIEE, Pages 752-772, October 1957

IEC 62067, Power Cables with Extruded Insulation and Their Accessories for Rated Voltages 150 kV up to 500 kV

AEIC CS9, “Specifications for Extruded Insulation Power Cables and Their Accessories Rated 46 kV through 345 kV AC.

McKelvie S, “Tunnel Technologies Emerging Technologies – Pump Stations and Pipelines”, Presentation at W8G Conference, September 2008

Curtis R, “Borehole Design Charts and Thermal Conductivity”, GSPH Association, Technical Seminar, Homerton College, Cambridge, November 16 2011.

http://electrical-engineering-portal.com/ehvhv-underground-cable-sheath-earthing-part-22

Daily News, “CPUC Approves Undergrounding Through Chino Hills”, July 10, 2013, http://www.dailybulletin.com/general-news/20130711/puc-approves-undergrounding-through-chino-hills

California Public Utility Commission, “CPUC Approves Undergrounding of the Tehachapi Transmission Line Through City of Chino Hills” Press Release, July 11, 2013, Docket No.: A.07-06-031

Appendix A. 500-kV Cable System Technical Assessment

A.1 INTRODUCTION

Installation conditions have been previously descried in the main body of the report.

A.2 MAIN SYSTEM CHARACTERISTICS

The electrical, laying, environmental, and operating data were specified or assumed as described in Sections 3 to 12 of this Appendix.

A.3 ELECTRICAL DATA

- Nominal rated voltage (specified) 500 kV
- Power frequency (known) 60 Hz
- Phase to phase short circuit 21 kA for 5 cycles
- Phase to earth short circuit 16 kA for 5 cycles
- Continuous conductor temperature 90°C
- Continuous current ratings 4,560 A
- Emergency conductor temperature 105°C
- Emergency current ratings None

A.4 INSTALLATION CONDITIONS

Installation conditions are assumed to be as follows:

- Depth to top of conduit bank: 48 Inches
- Maximum ground temp. at 4-foot depth: 20°C
- Depth to top of bores by HDD: 360 Inches
- Maximum ground temp. at 30-foot depth: 14°C
- Thermal resistivity of concrete encasement: 85°C.m/W
- Thermal resistivity of grout backfill for bores: 110°C.m/W
- Thermal resistivity of earth for trenches: 110°C.m/W
- Thermal resistivity of earth for deep bores: 110°C.m/W

A.5 500-kV CABLE DESIGN

There are several cable manufacturers worldwide that can supply the cable for this project. A typical cable cross-section is provided in Section A.12. The significant features of the cables would be as follows:

Conductor

Copper, 5 or 6 segment construction, complying with the requirements of ASTM B8 or IEC 60228 Class 2 with enamel coated wires to reduce the skin and proximity effects.

Conductor Binder

A combination of non-swellable and water swellable tape semi-conductive tapes applied directly over the conductor.

Conductor Shield

An extruded semi-conducting cross-linked layer, 30 mil in thickness, applied in a triple extrusion process and bonded to the insulation.

Insulation

Extruded cross-linked polyethylene (XLPE), 1260 mil (32 mm) wall thickness and extruded simultaneously with the semi-conductive conductor and insulation shield.

Insulation Shield

An extruded semi-conducting cross-linked layer, 60-mil minimum thickness, applied in the same operation as the insulation and bonded to the insulation.

Inner Bedding Tapes

One or more swellable semi-conductive tapes applied directly over the insulation. The bedding tapes' thickness shall compensate for the radial expansion of the insulation and to act as a cushioning layer for the shielding wires.

Stainless Steel Tubes

Two 70-mil stainless steel tubes applied helically and each containing two single-mode and two-multi mode optical fibers.

Shielding Wires

Sixty copper wires applied helically to provide a fault duty of 30-kA for 0.5 second in conjunction with the lead sheath. An equalizing copper tape shall be applied over the copper wires.

Outer Bedding Tapes

One or more swellable semi-conductive tapes applied directly over the shielding wires and optical fibers stainless steel tubes.

Metallic Sheath and Moisture Barrier

An extruded lead alloy sheath having 120-mil thickness for durability and to provide a moisture impervious layer.

Jacket

A medium density polyethylene of not less than 180 mil thick to provide physical and corrosion protection for the cables with an outer semiconductive layer, 20-mil in thickness, extruded over the jacket to allow for jacket DC hipot testing.

A.6 CABLE TERMINATION

Cable termination shall be premolded with EPDM or silicon rubber stress cone or paper roll condenser cone construction, oil-filled, with polymer or porcelain bushing for outdoor installation. Drawings of typical outdoor terminations are shown at the end of this document.

A.7 CABLE JOINTS

One-piece premolded or three-piece prefabricated construction, sectionalizing (shield break) type with external copper casing. Drawings of typical joints are provided at the end of this section.

A.8 REQUIRED CABLE SIZES AND INSTALLATION

- Scenario 1 – One Circuit: 3,950 MVA
- Scenario 2 – One Circuit: 3,950 MVA
- Cables Per Phase: 4
- Number of Cable Groups per Circuit: 4
- Rating of Each Cable Group: 987 MVA

Each cable group will be rated for 1,140 A or equivalent to 987 MVA. The cables will have a 5,000 Kcmil segmental or Milliken conductors to meet this rating and would be configured in a triangular formation in 8-inch concrete encased PVC conduits with 15 inch spacing between cables.

River Crossing and Other Crossings at Increased Depths

For the crossing of rivers, each 500-kV cable group would be installed in 36-inch casing at a depth of 30 feet below the river bed and at a spacing of 30 feet.

For the crossing of other large obstructions such as railroad tracks and freeways, each cable group would be installed in 30 inch casings at a depth of 5.5 to 15 feet below the obstruction at spacing of 10 to 12 feet.

A.9 LOSSES

The circuit losses in conductor, metallic sheath and copper wires, and insulation are given below

Scenario 1 – 500-kV 3950 MVA Cable Circuit

The conductor current would be 1,140 A and the losses for the first circuit would be:

- Conductor losses: 44,380 W/Kft
- Sheath losses: 2,680 W/Kft
- Dielectric losses: 24,210 W/Kft

- Total Losses: 71,270 W/Kft

Scenario 2 – 500-kV 3950 MVA Cable Circuit

The conductor temperature would be 90ºC and the losses for the first circuit would be:

- Conductor losses: 44,380 W/Kft
- Sheath losses: 2,680 W/Kft
- Dielectric losses: 24,210 W/Kft
- Total Losses: 71,270 W/Kft

Total 500-kV Loss for Scenarios 1 and 2

Total losses (Two Circuits) 142,540 W/Kft

A.10 SECTION LENGTHS AND SCHEDULE OF QUANTITIES

The number of sections and section lengths will and will need to be determined at final design.

Item	Detail	Unit	CASTLE ROCK	CAMAS
500-kV cable	5000 Kcmil	EA	96 x 1,800 Feet	84 x 1,900 Feet
Terminations	Outdoor Type	EA	24	24
Joints	Sectionalized	EA	84	72
Link box	3-way single point bonding	EA	8	4
Link box	3-way solid bonding at terminations	EA	--	4
Link box	3-way solid bonding at joints	EA	12	8
Link box	3-way cross bonding	EA	16	16
Bonding leads	Single Core 500-kcmil	FT	2,000	1,600
Bonding leads	Concentric 500-kcmil	FT	1,600	1,600
Continuity Conductor	Single Core 500-kcmil	FT	15,000	7,700

A.11 CABLE REEL SIZES AND WEIGHT

Scenario 1

- 5,000 Kcmil Copper cable 37.0 Lb/ft
- 1,800 ft of cable 33.3 tons
- Drum weight 2.5 tons
- Gross mass of cable and drum 35.8 tons

Scenario 2

- 5,000 Kcmil Copper cable 37.0 Lb/ft

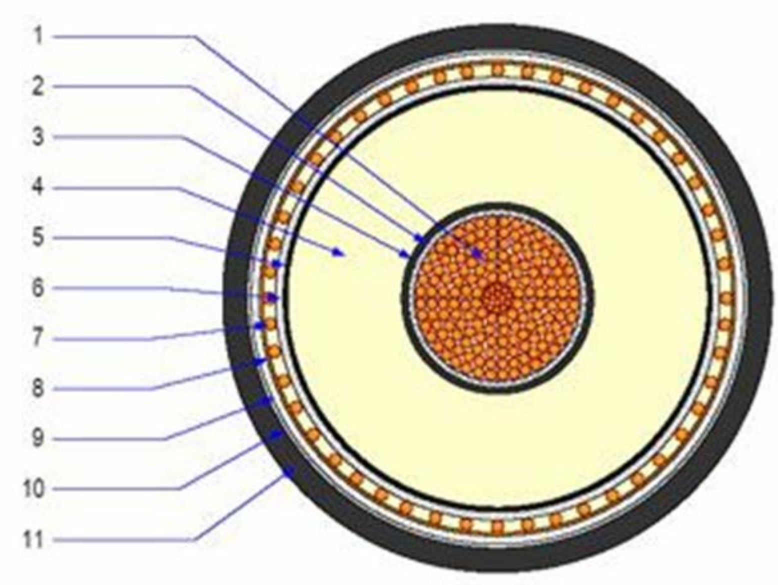
- 1,900 ft of cable 35.2 tons
- Drum weight 2.5 tons
- Gross mass of cable and drum 37.7 tons

A.12 DRAWINGS

500-kV Cable

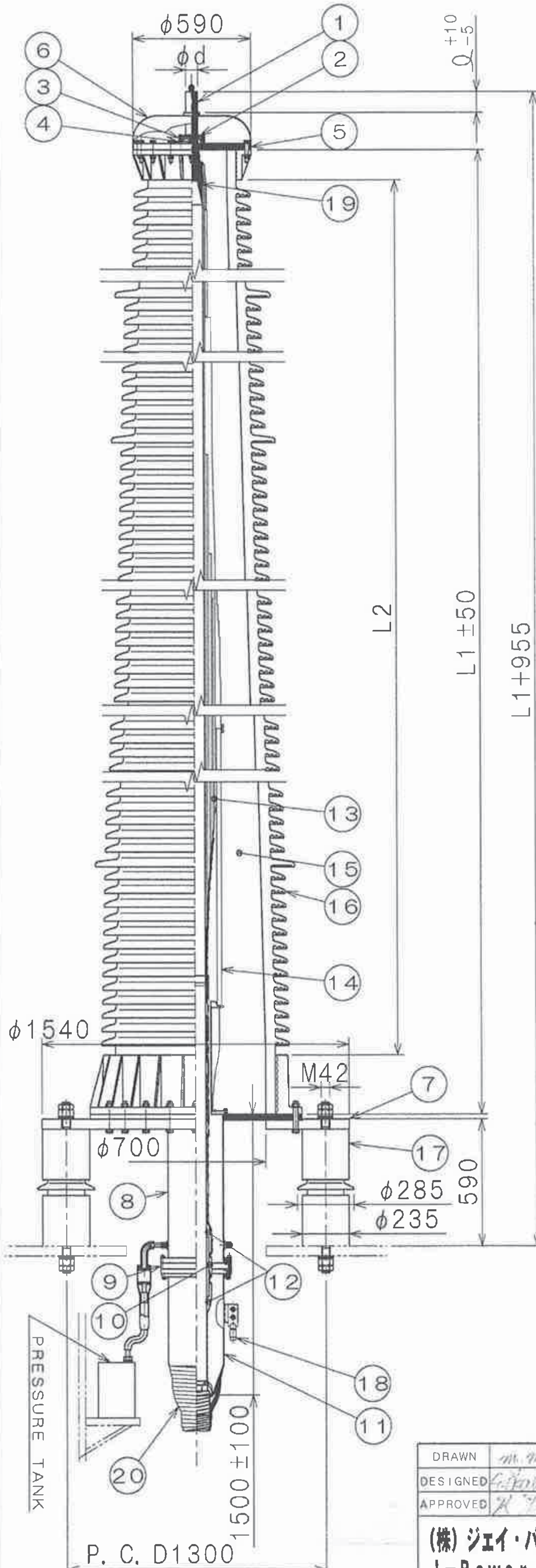
This drawing shows a cross-section of a cable with a 5,000 mm segmental conductor.

Voltage	Conductor Size	Insulation	Max. Stress	Fault Current
500-kV	5,000 Kcmil	XLPE	12.9 KV/mm	30 kA for 0.5 cycles



		Nominal Thickness (In)	Description	Nominal Diameter (In)
1	Conductor		Copper Milliken	2.5
2	Binder	0.02	Water Swellable Tapes	
3	Conductor Screen	0.08	Semiconducting Compound	2.625
4	Insulation	1.260	XLPE	5.14
5	Insulation Screen	0.02	Semiconducting Compound	3.70
6	Insulation Bedding		Water Swellable Tapes	
7	Wires	0.07	60 Copper Wires	
8	Equalizing Tape		Copper	
9	Waterblocking Tape		Semiconductive Tape	5.55
10	Metallic Sheath	0.13	Lead	5.81
11	Jacket w/Semi-Conductive Layer	0.20	MDPE or HDPE	6.17 or 6.21

REV.	DESCRIPTION	DATE	DESIGNED	APPROVED
A	ORIGINAL ISSUE	2003. 10. 29	G. OKAMOTO	K. FUDAMOTO
B	ADDED OF "COLOR PORCELAIN"	2004. 08. 26	–	–



No.	DESCRIPTION
1	CONNECTOR
2	LOCK NUT
3	FIXING PLATE
4	TIGHTENING PLATE
5	TOP PLATE
6	SHIELD
7	FITTING METAL
8	CASE (A)
9	FLANGE
10	MOLDING METAL
11	CASE (B)
12	MOLDING
13	REINFORCING INSULATION PAPER
14	CONDENSER CONE
15	SILICONE OIL
16	PORCELAIN BUSHING
17	PORCELAIN SUPPORTER
18	EARTHING TERMINAL
19	MOLDING
20	WATER PROOF LAYER

CONDUCTOR SIZE (mm²)	DIMENSION (mm)	
	d	ℓ
less than 1000	45	80
1200~2000	60	105
2500~3000	70	105

PORCELAIN BUSHING TYPE	L1 (mm)	L2 (mm)	CREEPAGE DISTANCE (mm)	APPROX. WEIGHT (kg)
B-5003	5400	4950	15850	4500
B-5022	6700	6250	20400	5250
B-5023	8000	7550	25300	6000

COLOR OF PORCELAIN
BROWN
WHITE
LIGHT GRAY

DRAWN	M. Miyake		
DESIGNED	[illegible]	SCALE	
APPROVED	[illegible]	–/–	

(株) ジェイ・パワーシステムズ
J-Power Systems

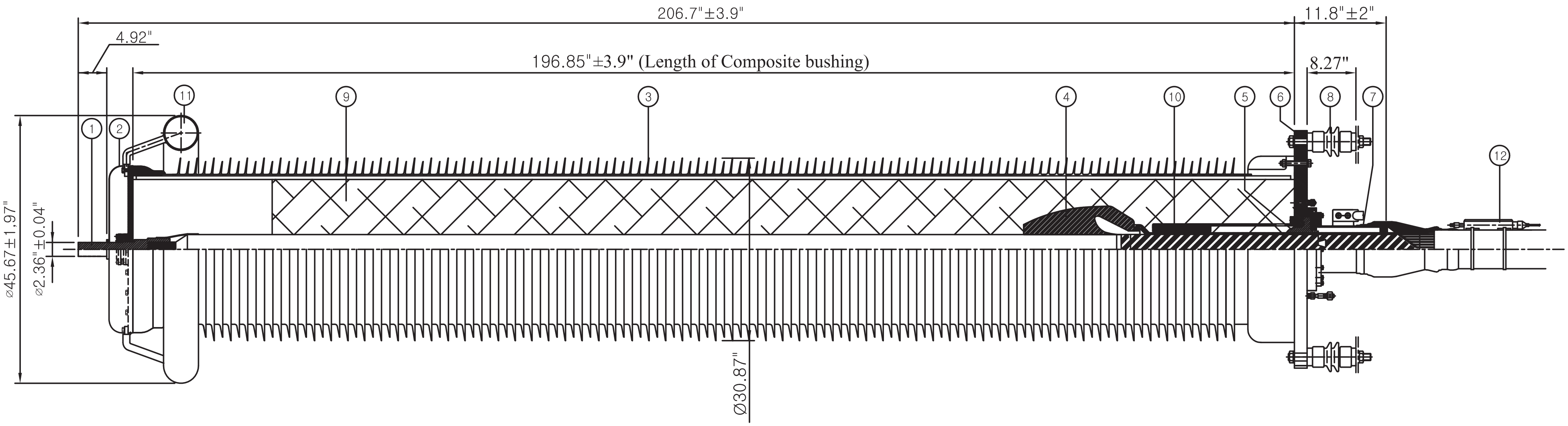
OUTDOOR SEALING END
FOR 345-500kV XLPE CABLE

DRG. No. STA50005 B

unit: mm STA50005B

(TTA50002)

Amendments & Print Issue		Date
0	Original Print Issue	13.May.2013
1	Correction of material of Insulation medium (No.9)	22.Jul.2013



NOTE

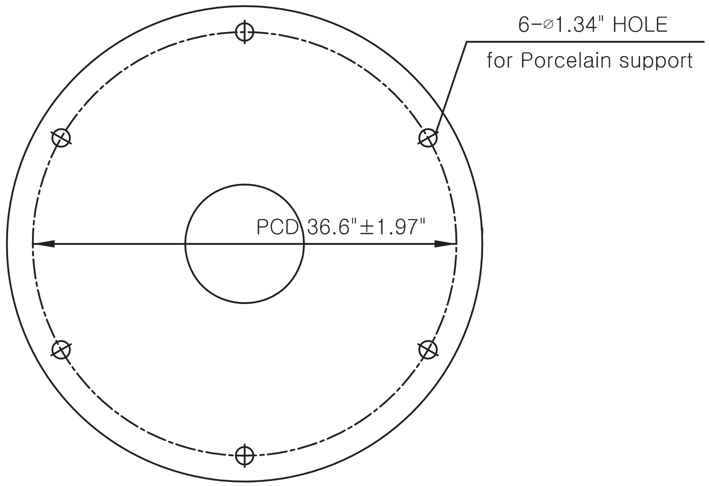
1. All Dimensions are in inch.

PHYSICAL CHARACTERISTICS

1. Creepage Distance : Min. 748inch
2. Pollutiong level (IEC 60815) : Very heavy
3. The termination meets the seismic requirement per IEEE 693, Annex N
4. Color of Composite bushing : Light grey
5. Gross weight : approx. 3527lbs

ELECTRICAL CHARACTERISTICS (IEEE 48)

1. B.I.L : 1550kV
2. B.S.L : 1175kV



UPPER VIEW OF No. 6

No	Name of parts	Material
1	Conductor sleeve	Copper
2	Rain shield	Copper
3	Composite bushing	Silicone & Aluminum alloy
4	Stress cone	Silicone rubber
5	Sealing unit	Silicone rubber
6	Fitting metal	Aluminum
7	Lower metal case	Aluminum
8	Porcelain supporter	Porcelain
9	Insulation medium	Silicone oil
10	Cable center supporter	Aluminum
11	Corona shield ring	Aluminum
12	Optical fiber termination	P.B.T

MANUFACTURER

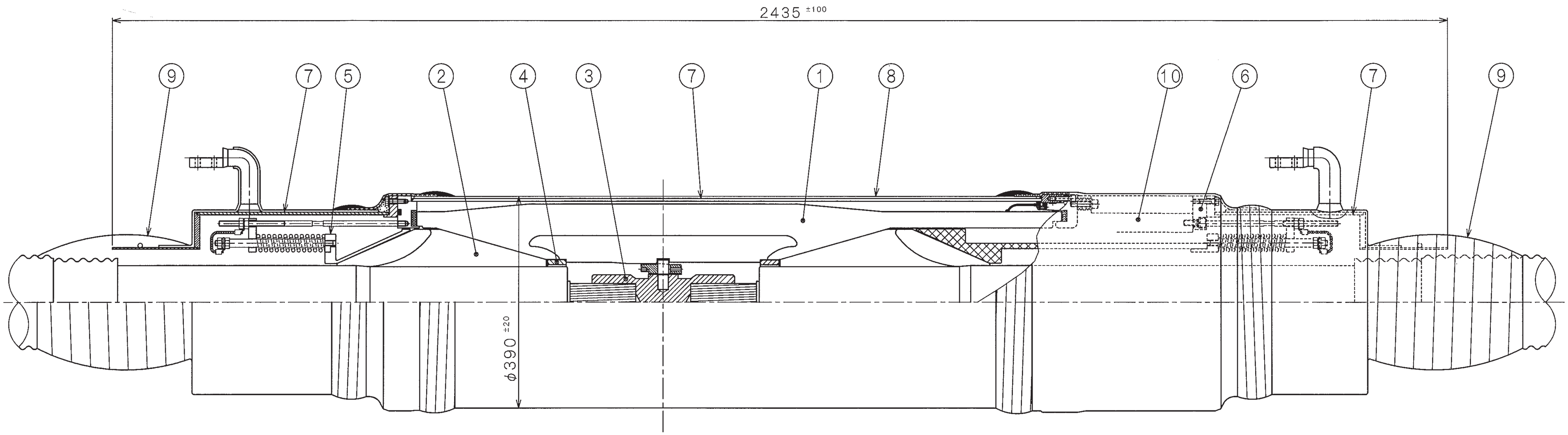
TAIHAN ELECTRIC WIRE CO., LTD.

OUTDOOR TERMINATION
FOR 500kV XLPE CABLE

Chief	H.H.KIM	Drawn	J.H.SONG
Checker	K.Y.KIM	Scale	N.S
Designer	J.H.SONG	Date	13,MAY,2013
Drawing No.	CVC-ACS-5004900S-BD		1
	CAD No.	CVC-ACS-5004900S-BD	

TEC TAIHAN ELECTRIC WIRE CO.,LTD.

REV.	DESCRIPTION	DATE	DESIGNED	APPROVED
A	ORIGINAL ISSUE	2007. 04. 19	W. MURATA	K. FUDAMOTO
B	SOME PORTION ARE AMENDED.	2008. 03. 14	–	–



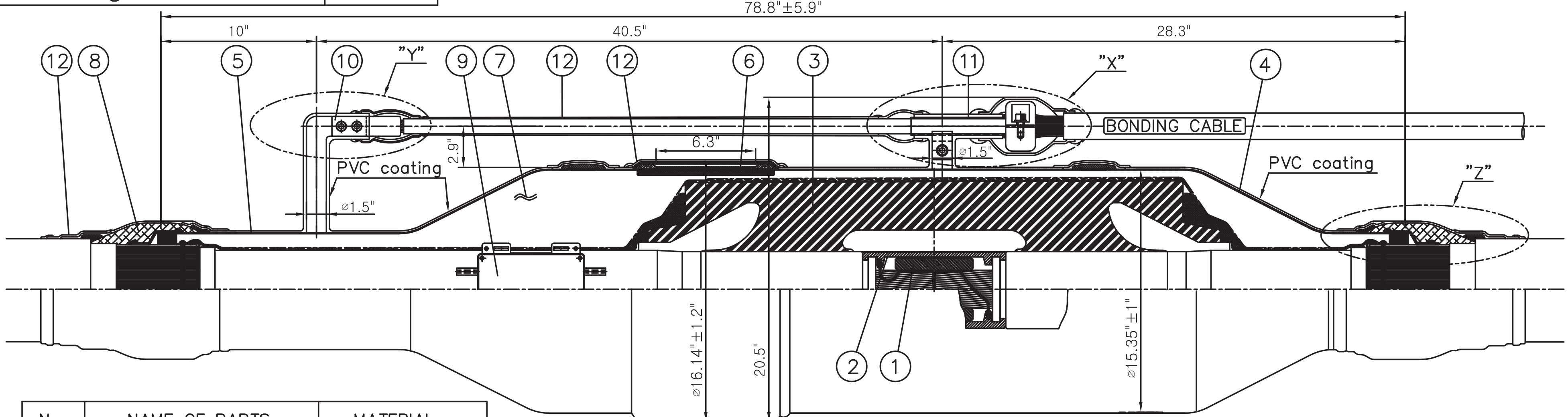
SIGN	NAME OF PART	MATERIAL
1	EPOXY RESIN INSULATION UNIT	EPOXY
2	RUBBER MOLD STERSS CONE	SYNTHETIC RUBBER
3	COMPRESSION TYPE FERRULE	COPPER
4	STOPPER RING	FRP
5	COMPRESSION RING	BRASS & OTHERS
6	FLANGE	BRASS
7	CASING	BRONZE OR COPPER TUBE
8	WATERPROOF LAYER	PVC OR PE
9	WATERPROOF TAPING LAYER	SYNTHETIC RUBBER & OTHERS
10	INSULATOR	EPOXY

DRAWN	J.Hirakawa		PREFABRICATED TYPE
DESIGNED	G.Okamoto	SCALE	INSULATING JOINT
APPROVED	K.F-lt	FREE	UP TO 550kV XLPE CABLE
(株) ジェイ・パワーシステムズ J-Power Systems			DRG. No. STN50015 B

unit:mm STN50015B

(STN50004A)

Amendments & Print Issue		Date	Amendments & Print Issue		Date	Amendments & Print Issue		Date
0	Original Print Issue	13.May.2013	2	Addition of Note 2 (Nominal thickness of PVC coating)	10.Jun.2013	3	Correction of material of heat shrink tube (No.12)	22.Jul.2013
1	Revision of connection method for bonding cable	4.Jun.2013						

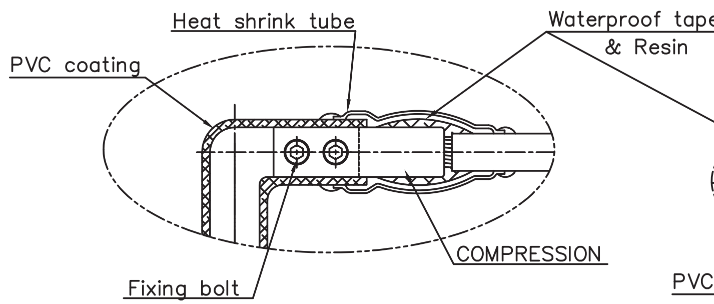


No.	NAME OF PARTS	MATERIAL
1	CONDUCTOR SLEEVE	COPPER
2	CORONA SHIELD	ALUMINUM
3	PREMOULD UNIT	SILICONE
4	CASE (A)	COPPER
5	CASE (B)	COPPER
6	INSULATING FLANGE	P.E
7	WATERPROOF COMPOUND	POLYURETHANE
8	ANTI-CORROSION LAYER	EPOXY PUTTY
9	OPTICAL FIBER JOINT	P.B.T
10	EARTHING TERMINAL (A)	COPPER BAR
11	EARTHING TERMINAL (B)	COPPER BAR
12	HEAT SHRINK TUBE	SYNTHETIC RESIN

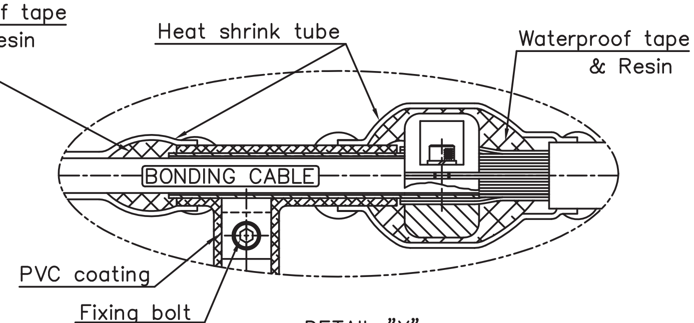
NOTE:
1. All Dimensions are in inches.
2. Nominal thickness of PVC coating : 0.2"

MANUFACTURER
TAIHAN ELECTRIC WIRE CO.,LTD.

PHYSICAL CHARACTERISTICS
Gross Weiht: Approx. 353lbs



DETAIL "Y"



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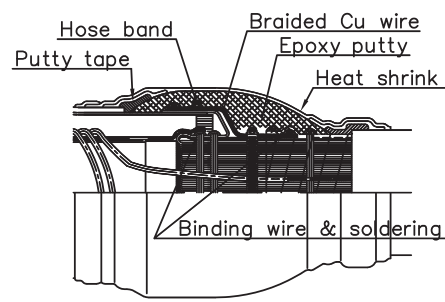
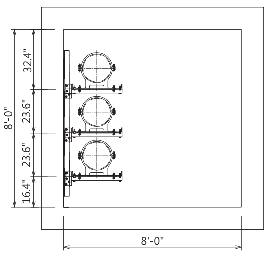


DETAIL "Z"

INSULATING JOINT for 500kV 1C 5000kcmil XLPE CABLE			
Chief	D.Y.KIM	Drawn	J.H.SONG
Checker	K.Y.KIM	Scale	N.S
Designer	J.H.SONG	Date	13.MAY.2013
Drawing No.	XM-5025-FI00		3
	CAD No.	XM-5025-FI00	

TAIHAN ELECTRIC WIRE CO.,LTD.



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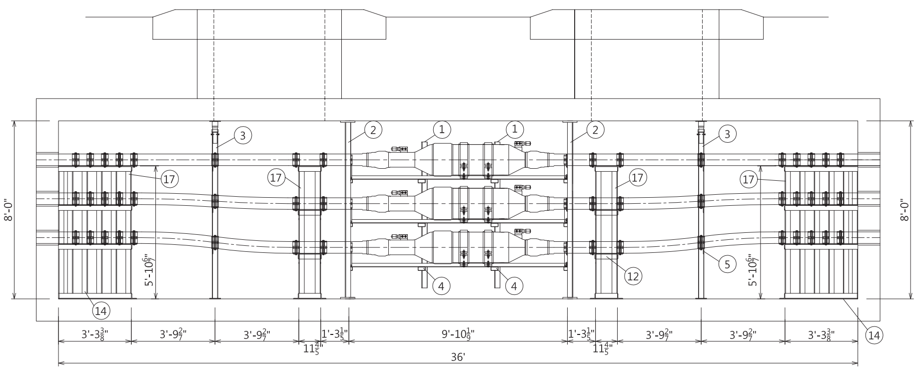

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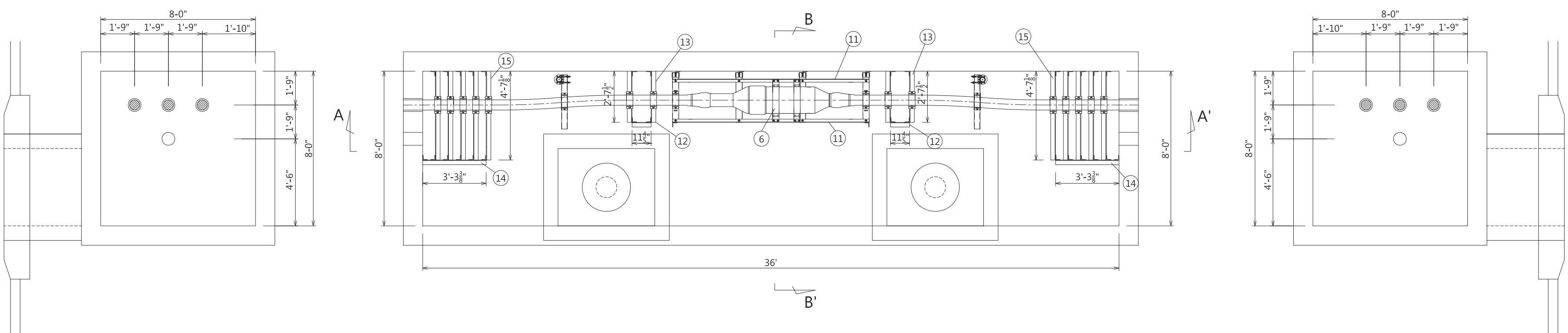


Plane Figure

* Material list for 1 Circuit

No.	Description	Spec(Unit/mm)	Unit	Q'ty	Remarks
1	Angle Support	L=2000	EA	4	Stainless
2	Angle Support	L=2440	EA	2	Stainless
3	Cylinder Support	L=2300	EA	2	Stainless
4	"ㅁ"-Type Hanger	ASN-695	EA	12	Stainless
5	"ㅁ"-Type Hanger	CSNV-710	EA	6	Stainless
6	PLATE	100*9t*656L	EA	6	Stainless
7	Bolt&Nut	M12 * 35	EA	12	Stainless
8	Bolt&Nut	M12 * 90	EA	24	Stainless
9	Bolt&Nut	M16 * 50	EA	152	Stainless
10	Set Anchor	1/2"*100	EA	90	Stainless
11	"ㄱ"-Type Angle	50*50*6t*3000L	EA	6	Stainless
12	"ㄱ"-Type Angle	75*75*9t*300L	EA	8	Stainless
13	"ㄱ"-Type Angle	75*75*9t*800L	EA	16	Stainless
14	"ㄱ"-Type Angle	75*75*9t*1000L	EA	8	Stainless
15	"ㄱ"-Type Angle	75*75*9t*1400L	EA	32	Stainless
16	"ㄱ"-Type Angle	75*75*9t*1800L	EA	30	Stainless

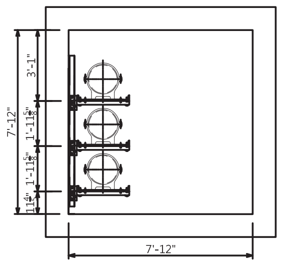
No.	DATE	DESCRIPTION	DRN	DGN	CK	APP
A	'12.12	ISSUED FOR APPROVAL				

TAIHAN ELECTRIC WIRE CO.,LTD

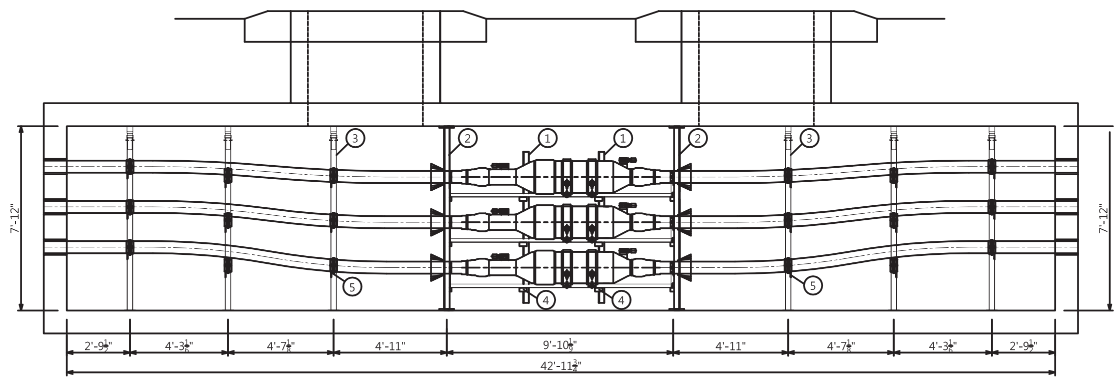
TITLE: SPLICE M/H Cable Racking System

CONTRACTOR DWG. No.: TC-SCE-1212-001

MULTI UNITS	SCALE	PRJ.CODE	DOCUMENT No.	M.F.No.	TYPE	REV.
	1/50					A



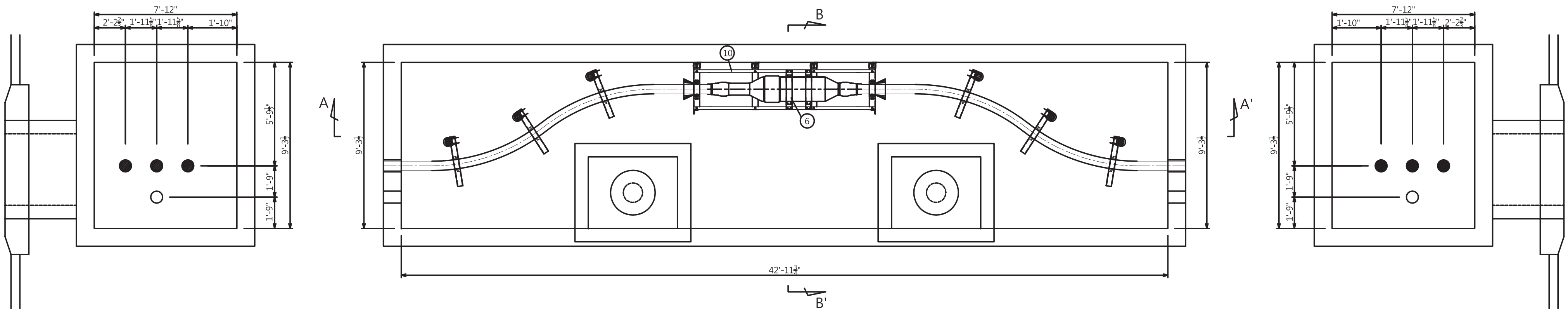
Section B-B'



Section A-A'

* Material list for 1 Circuit

No.	Description	Spec(Unit/mm)	Unit	Q'ty	Remarks
1	Angle Support	L=2000	EA	4	Stainless
2	Angle Support	L=2440	EA	2	Stainless
3	Cylinder Support	L=2300	EA	6	Stainless
4	"ㅁ"-Type Hanger	ASN-695	EA	12	Stainless
5	"ㅁ"-Type Hanger	CSNV-710	EA	18	Stainless
6	PLATE	100*9t*656L	EA	6	Stainless
7	Bolt&Nut	M12 * 35	EA	12	Stainless
8	Bolt&Nut	M12 * 90	EA	24	Stainless
9	Set Anchor	1/2"*100	EA	90	Stainless
10	"ㄱ"-Type Angle	50*50*6t*3000L	EA	6	Stainless



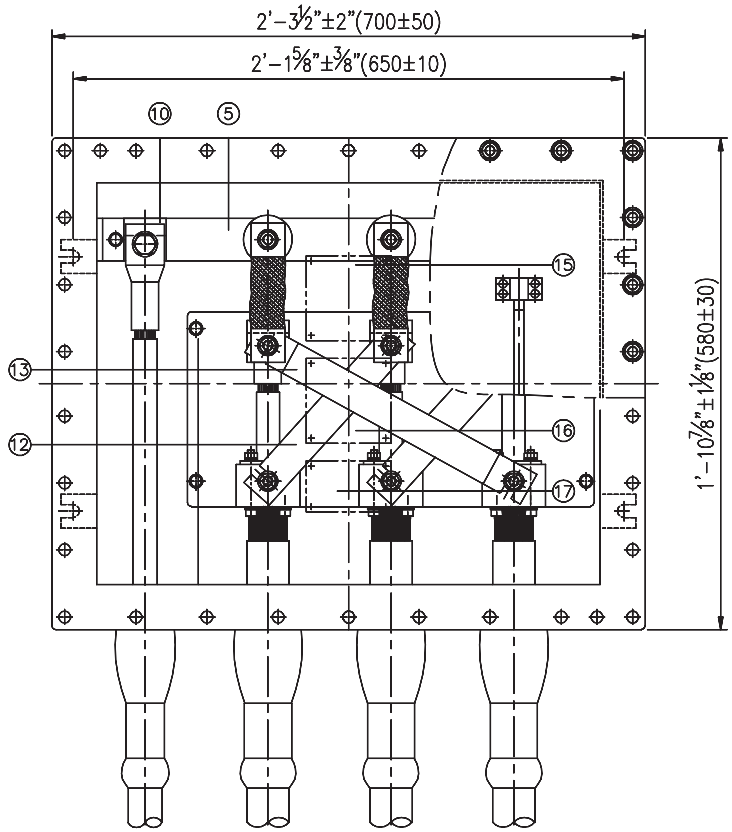
Plane Figure

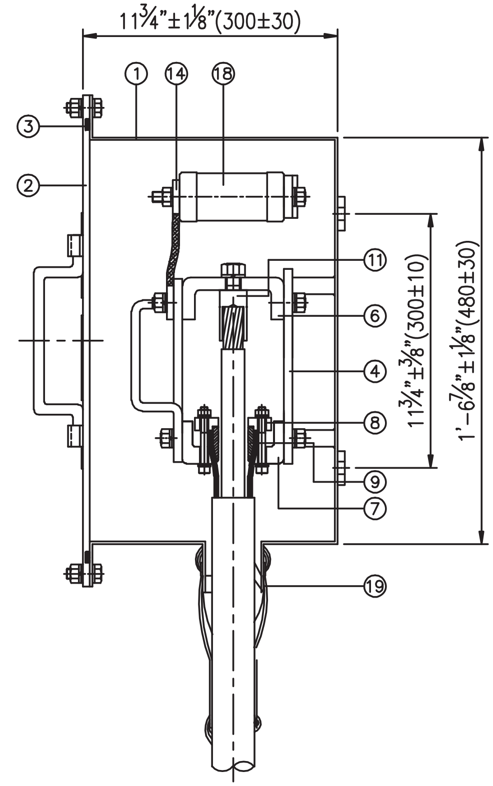
No.	DATE	DESCRIPTION	DRN	DGN	CK	APP
A	'12.12	ISSUED FOR BIDDING				

TAIHAN ELECTRIC WIRE CO.,LTD

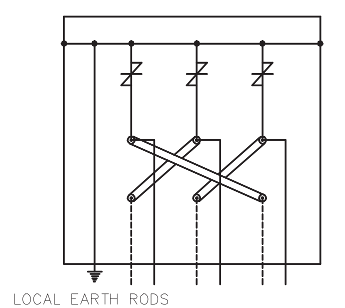
TITLE	Preliminary offset system design
CONTRACTOR DWG. No.	TC-SCE-1212-001

MULTI UNITS	SCALE	PRJ.CODE	DOCUMENT No.	M.F.No	TYPE	REV.
	1/50					A





ITEM	DESCRIPTION	MATERIAL
1	CASING	STAINLESS STEEL
2	LID	STAINLESS STEEL
3	GASKET	NBR
4	INSULATING PLATE	EPOXY RESIN
5	SUPPORT BAR	COPPER
6	TERMINAL BLOCK(A)	COPPER
7	TERMINAL BLOCK(B)	COPPER
8	TERMINAL BLOCK(C)	COPPER
9	TERMINAL BLOCK(D)	STAINLESS STEEL
10	TERMINAL BLOCK(E)	COPPER
11	STALK LUG	COPPER
12	LINK PLATE(A)	COPPER
13	LINK PLATE(B)	COPPER
14	LINK PLATE(C)	COPPER
15	WARNING LABEL	STAINLESS STEEL
16	CIRCUIT DIAGRAM	STAINLESS STEEL
17	NAME PLATE	STAINLESS STEEL
18	SHEATH VOLTAGE LIMITER	ZnO NON LINEAR RESISTOR
19	WATERPROOF LAYER	TAPE & TUBE



CIRCUIT DIAGRAM

NOTE

1. PACKING
   1) MATERIAL : WOOD
   2) SIZE : 1670Lx770Wx485H 250kg (2set/box)
2. GROSS WEIGHT : APPROX. 125kg

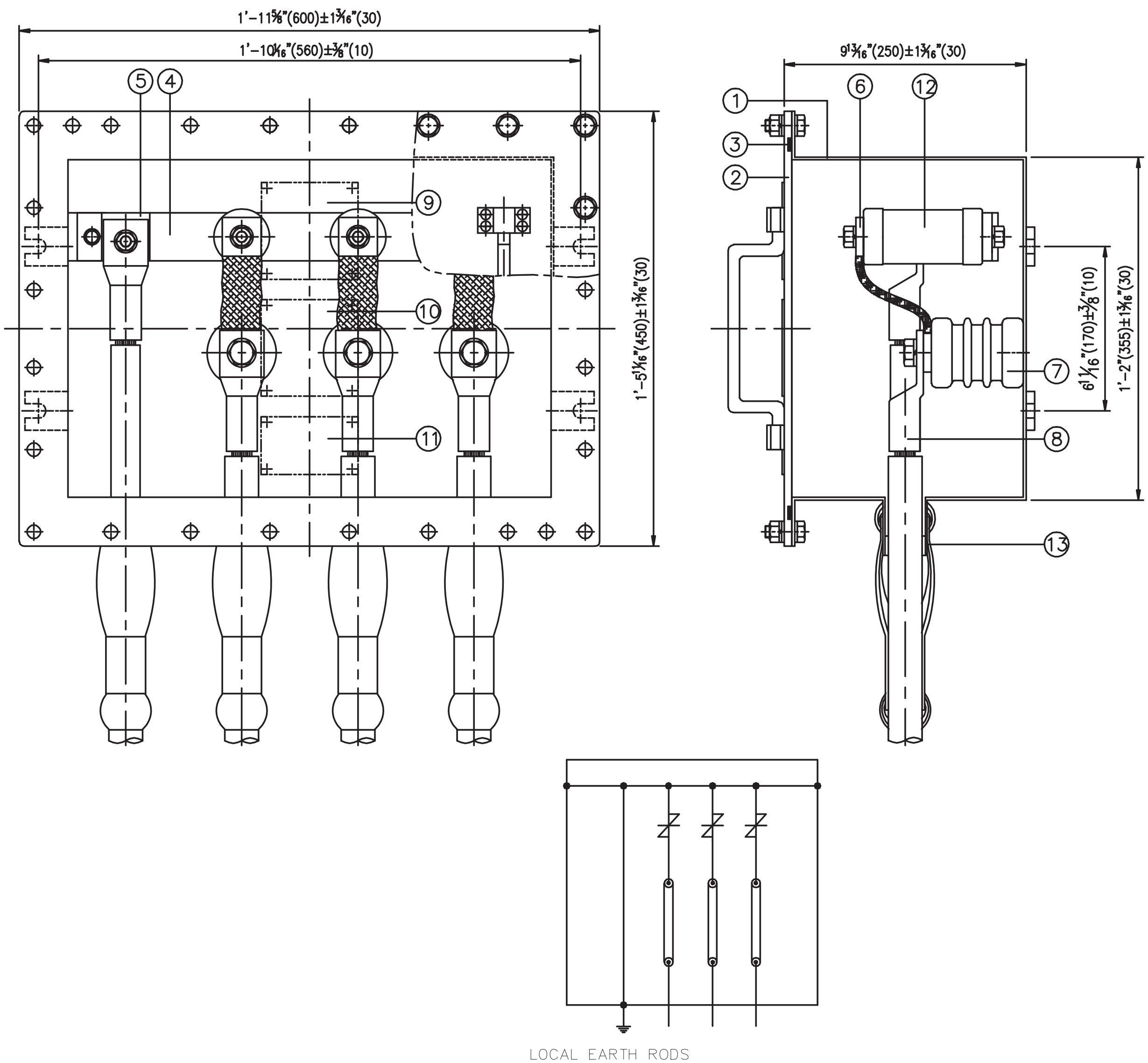
REV. NO.	DATE	DESCRIPTIONS	DGN	CHK	APP
△					
0	Mar.17,2014	FOR BIDDING	H.S.L	S.H.S	K.S.K

LS Cable & System

TITLE
LINK BOX FOR CROSS-BONDING
(3-1 WAY)

DRAWING NO **UEEBX3Q001**

SCALE	UNIT	PROJECT	REV.
NTS	**MM**		**0**



CIRCUIT DIAGRAM

ITEM	DESCRIPTION	MATERIAL
1	CASING	STAINLESS STEEL
2	LID	STAINLESS STEEL
3	GASKET	NBR
4	SUPPORT BAR	COPPER
5	TERMINAL BLOCK	COPPER
6	LINK PLATE	ELECTROLYTIC COPPER
7	EPOXY INSULATOR	EPOXY
8	COPPER LUG	COPPER
9	WARNING LABEL	STAINLESS STEEL
10	CIRCUIT DIAGRAM	STAINLESS STEEL
11	NAME PLATE	STAINLESS STEEL
12	SHEATH VOLTAGE LIMITER	ZnO NON LINEAR RESISTOR
13	WATERPROOF LAYER	TAPE & TUBE

NOTE

1. PACKING
   1) MATERIAL : WOOD
   2) SIZE : 5'-5¾"Lx2'-6 5/16"Wx1'-7⅛"H
      [1670Lx770Wx485H] 200kg (2set/box)
2. GROSS WEIGHT : APPROX. 100kg/set

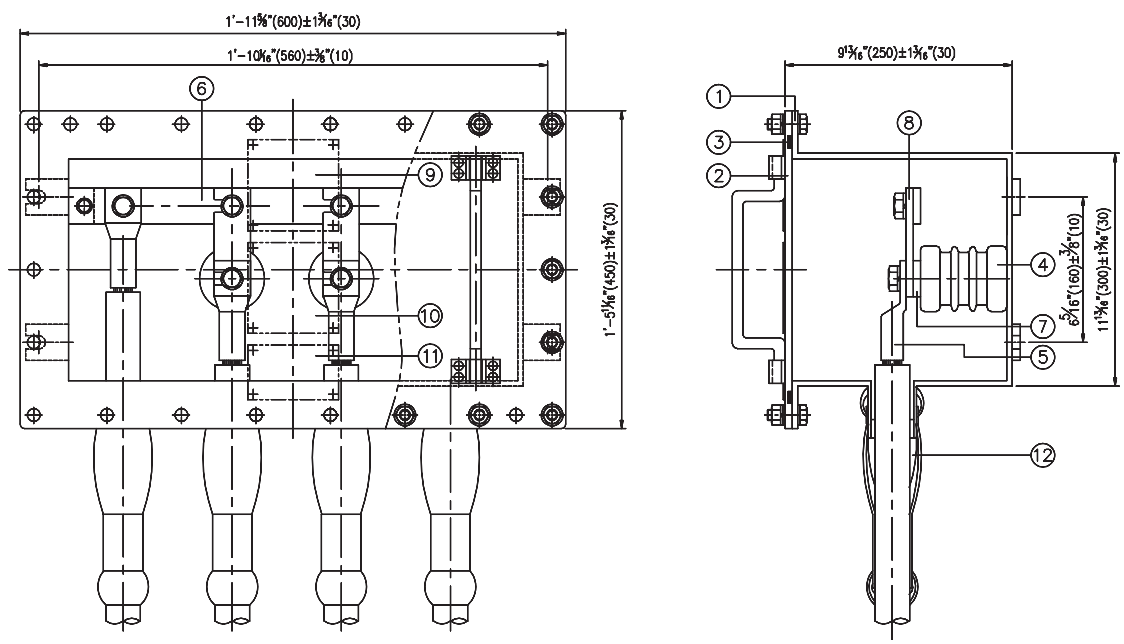
REV. NO.	DATE	DESCRIPTIONS	DGN	CHK	APP
△					
0	Jan.16,2014	FOR BIDDING	H.S.L	S.H.S	K.S.K

LS Cable & System

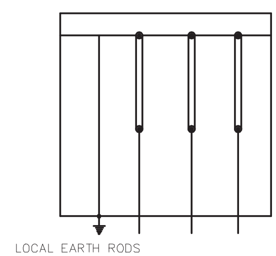
TITLE **LINK BOX WITH SVL (3-1 WAY)**

DRAWING NO **UEEBS3Q002**

SCALE	UNIT	PROJECT	REV.
NTS	**MM**		**0**



ITEM	DESCRIPTION	MATERIAL
1	CASING	STAINLESS STEEL
2	LID	STAINLESS STEEL
3	GASKET	NBR
4	EPOXY INSULATOR	EPOXY
5	COPPER LUG	ELECTROLYTIC COPPER
6	LINK PLATE(A)	TINNED COPPER
7	LINK PLATE(B)	MN NYLON
8	LINK PLATE(C)	TINNED COPPER
9	WARNING LABEL	STAINLESS STEEL
10	CIRCUIT DIAGRAM	STAINLESS STEEL
11	NAME PLATE	STAINLESS STEEL
12	WATER-PROOF LAYER	TAPE & TUBE



CIRCUIT DIAGRAM

NOTE

1. PACKING
   1) MATERIAL : WOOD
   2) SIZE: 4'-7⅛"Lx2'-2¹⁵⁄₁₆"Wx1'-5½"H
      [1400Lx685Wx445H] 150kg (2set/box)
2. GROSS WEIGHT : APPROX. 75kg/set

REV. NO.	DATE	DESCRIPTIONS	DGN	CHK	APP
△					
0	Jan.16,2014	FOR BIDDING	H.S.L	S.H.S	K.S.K

LS Cable & System

TITLE
LINK BOX FOR EARTHING
(3-1 WAY)

DRAWING NO **UEEBE3Q002**

SCALE	UNIT	PROJECT	REV.
NTS	**MM**		**0**

Appendix B. 230-kV Cable System Technical Assessment

B.1 INTRODUCTION

Installation conditions have been previously descried in the main body of the report.

B.2 MAIN CABLE SYSTEM CHARACTERISTICS

The electrical, laying, environmental, and operating data were specified or assumed as described in Section 3 to 12 of this Appendix.

B.3 ELECTRICAL DATA

- Nominal rated voltage (specified): 230 kV
- Power frequency (known): 60 Hz
- Phase to phase short circuit: 31.4 kA for 6 cycles
- Phase to earth short circuit: 28.1 kA for 6 cycles
- Continuous conductor temperature: 90°C
- Continuous current ratings: 1,520 A
- Emergency conductor temperature: 105°C
- Emergency current ratings: None

B.4 INSTALLATION CONDITIONS

Installation conditions are assumed as follows:

- Depth to top of conduit bank: 48 Inches
- Maximum ground temperature at 4 feet depth: 20°C
- Depth to top of bores by HDD: 360 Inches
- Maximum ground temperature at 30-foot depth: 14°C
- Thermal resistivity of concrete encasement: 85°C.m/W
- Thermal resistivity of grout backfill for bores: 110°C.m/W
- Thermal resistivity of earth for trenches: 110°C.m/W
- Thermal resistivity of earth for deep bores: 110°C.m/W

B.5 230-kV CABLE DESIGN

There are several cable manufacturers worldwide that can supply the cable for this project. A typical cross-section is provided in Section B.12.

The significant features of the cables would be as follows:

Conductor

Copper, 4 or 5 segment construction, complying with the requirements of ASTM B8 or IEC 60228 Class 2 with coated wires to reduce the skin and proximity effects.

Conductor Binder

A combination of non-swellable and water swellable semi-conductive tapes applied directly over the conductor.

Conductor Shield

Extruded semi-conducting cross-linked compound, minimum 30 mil thickness applied in a triple extrusion process and bonded to the insulation.

Insulation

Extruded cross-linked polyethylene (XLPE), 1,060 mil (27 mm) wall thickness, extruded simultaneously with the semi conductive conductor and insulation shield.

Insulation Shield

Extruded semi-conducting cross-linked compound, 60-mil minimum thickness, applied in the same operation as the insulation and bonded to the insulation.

Inner Bedding Tapes

One or more swellable semi-conductive tapes applied directly over the insulation. The thickness of the bedding tapes shall compensate for the radial expansion of the insulation and act as a cushioning layer for the shielding wires.

Stainless Steel Tubes

Two70-mil stainless steel tubes applied helically and each containing two single-mode and two-multi mode fibers.

5.8 Shielding Wires

Sixty copper wires applied helically to provide a fault duty of 30-kA for 0.5 second in conjunction with the lead sheath. A copper equalizing tape shall be applied over the copper wire.

Outer Bedding Tapes

One or more swellable semi-conductive tapes applied directly over the insulation. The thickness of the bedding tapes shall compensate for the radial expansion of the insulation and act as a cushioning layer for the shielding wires.

Metallic Sheath

An extruded lead alloy sheath having a 120-mil thickness.

Jacket

A medium density polyethylene of not less than 180 mil thick to provide physical and corrosion protection for the cables with an outer semiconductive layer, 20-mil thickness, extruded over the jacket to allow for jacket DC hipot testing.

B.6 CABLE TERMINATION

Cable termination shall be premolded or prefabricated type, oil-filled, with porcelain or polymer bushing for outdoor installation. A drawing of a typical outdoor termination, with a polymeric insulator, is shown at the end of this document.

B.7 CABLE JOINTS

The cable joints shall be premolded one-piece or three-piece prefabricated construction, sectionalizing (shield break) type with external copper casing. Drawings of typical joints are shown at the end of this document.

B.8 REQUIRED CABLE SIZES AND INSTALLATION

- North-Bonneville-Troutdale 1: 605 MVA
- North-Bonneville-Troutdale 2: 605 MVA
- Cable Per Phase: 1
- Number of Cable Groups per Circuit: 1

The cables will have a 5,000 Kcmil segmental or Milliken conductors and would be configured in a triangular formation in 8-inch concrete encased PVC conduits with 15 inch spacing between cables.

River Crossing and Other Crossings at Increased Depths

For the crossing of rivers, each 230-kV cable group would be installed in 36-inch casing at a depth of 30 feet below the river bed and at spacing of 30 feet.

For the crossing of other large obstructions such as railroad tracks and freeways, each cable group would be installed in casings at a depth of 5.5 to 15 feet below the obstruction at spacing of 10 to 12 feet.

B.9 LOSSES

The circuit losses in conductor, sheath and wires, and insulation are given below.

North Bonneville-Troutdale 1: 605MVA

The conductor temperature would be 90ºC and the losses for the first circuit would be:

- Conductor losses: 19,910 W/Kft
- Sheath losses: 920 W/Kft
- Dielectric losses: 1,500 W/Kft
- Total Losses: 22,330 W/Kft

North Bonneville-Troutdale 2: 605 MVA

The conductor temperature would be 90ºC and the losses for the first circuit would be:

- Conductor losses: 19,910 W/Kft
- Sheath losses: 920 W/Kft
- Dielectric losses: 1,500 W/Kft
- Total Losses: 22,330 W/Kft

Total 230-kV Loss for Two Lines

Total losses (Two Circuits): 44,660W/Kft

B.10 SECTION LENGTHS AND SCHEDULE OF QUANTITIES

The number of sections and section lengths would vary and will need to be determined at final design but for the study a 1,800 foot length was chosen.

Item	Detail	CASTLE ROCK	CAMAS
230-kV cable	5000 Kcmil	21 x 1,900 Feet	21 x 1,900 Feet
Terminations	Outdoor Type	6	6
Joints	Sectionalized	21	21
Link box	3-way single point bonding	1	1
Link box	3-way solid bonding at terminations	1	1
Link box	3-way solid bonding at joints	2	2
Link box	3-way cross bonding	4	4
Bonding leads	Single Core 500-kcmil	400	400
Bonding leads	Concentric 500-kcmil	400	400
Continuity Conductor		1,900	1,900

B.11 CABLE REEL SIZES AND WEIGHT

North Bonneville-Troutdale 1

- 5,000 Kcmil Copper cable 35.0 Lb/ft
- 1,900 ft of cable 33.3 tons
- Drum weight 2.5 tons
- Gross mass of cable and drum 35.7 tons

North Bonneville-Troutdale 2

- 5,000 Kcmil Copper cable 35.0 Lb/ft
- 1,800 ft of cable 33.3 tons

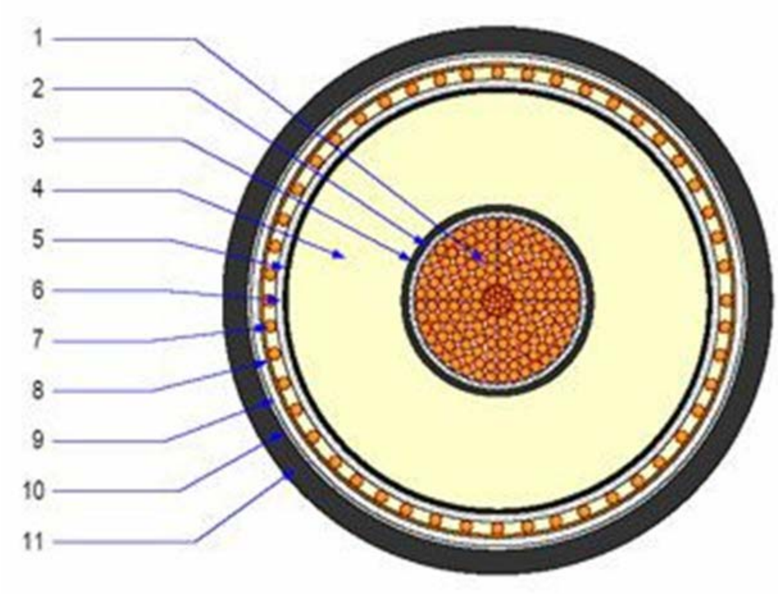
- Drum weight 2.5 tons
- Gross mass of cable and drum 35.7 tons

B.12 DRAWINGS

230-kV Cable

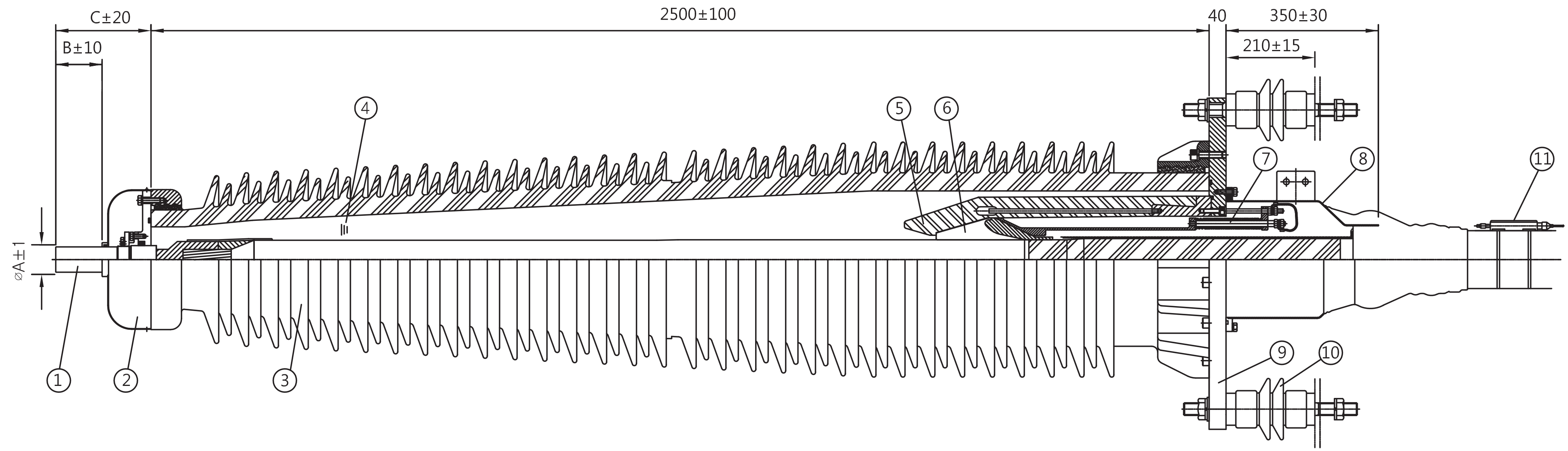
This drawing shows a cross-section of a cable with a 5,000 mm segmental conductor:

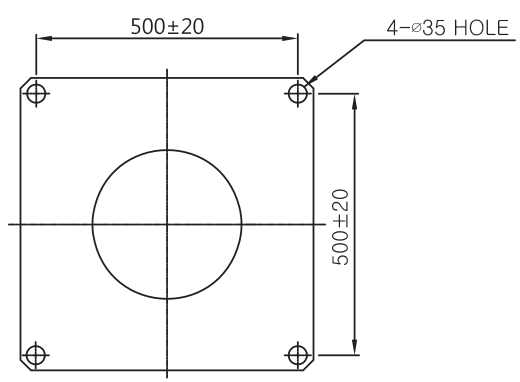
Voltage	Conductor Size	Insulation	Max. Stress	Fault Current
230-kV	5,000 Kcmil	XLPE	6.9 KV/mm	30 kA for 0.5 cycles



		Nominal Thickness (In)		Nominal Diameter (In)
1	Conductor		Copper Milliken	2.50
2	Binder	0.02	Water Swellable Tapes	
3	Conductor Screen	0.06	Semi-Conducting Compound	
4	Insulation	1.062	XLPE	4.88
5	Insulation Screen	0.06	Semi-Conducting Compound	
6	Insulation Bedding		Water Swellable Tapes	
7	Wires	0.09	60 Copper Wires	
8	Equalizing Tape		Copper	
9	Waterblocking Tape		Semi-conductive Tape	
10	Metallic Sheath	0.12	Glued Copper Tape	5.61
11	Oversheath	0.00	HDPE	5.81

Amendments & Print Issue	
A	Original Print Issue





UPPER VIEW OF No. 9

Conductor size(mm²)	Dimension		
	A	B	C
1200 ~ 2500	70	110	225

No	Name of parts	Material
1	Conductor sleeve	Copper
2	Rain shield	Copper
3	Porcelain bushing	Porcelain & Aluminum alloy
4	Compound	Insulation oil
5	Epoxy supporter	Epoxy
6	Stress cone	Rubber
7	Compression ring	Bronze, STS, Brass
8	Lower copper tube	Copper
9	Fitting metal	Aluminum
10	Porcelain supporter	Porcelain
11	Optical fiber joint	PBT

NOTE

1. All Dimensions are in mm.

PHYSICAL CHARACTERISTICS

Creepage Distance : Min. 8,700mm

MANUFACTURER

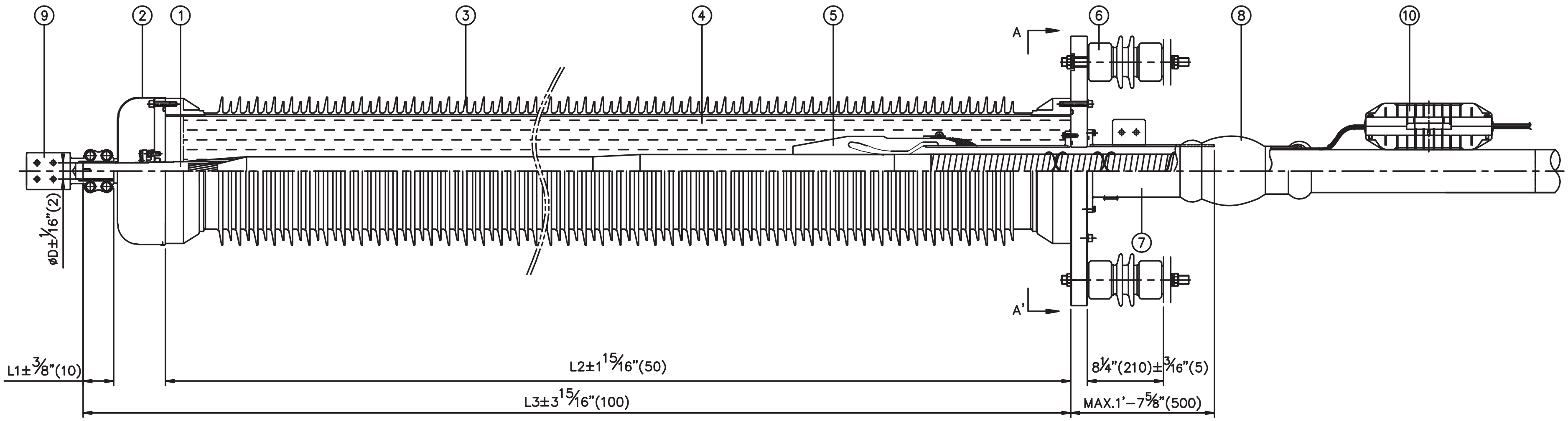
TAIHAN ELECTRIC WIRE CO., LTD.

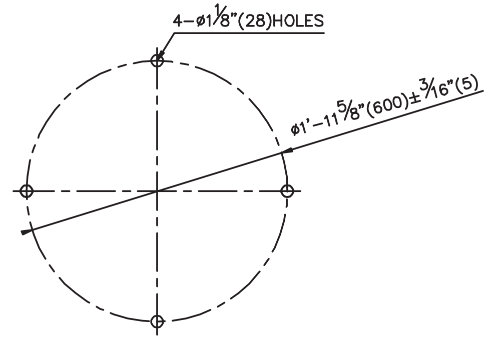
OUTDOOR TERMINATION

FOR 220kV ~ 230kV XLPE CABLE

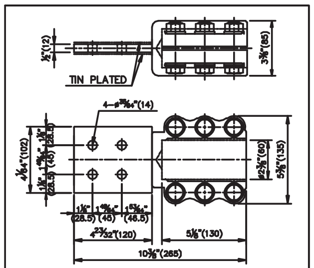
Chief	H.H.KIM	Drawn	D.Y.KIM
Checker	K.Y.KIM	Scale	N.S
Designer	D.Y.KIM	Date	2010. 9
Drawing No.	CVC-APC-2202500F-BD		A
	CAD No.	CVC-APC-2202500F-BD	

TEC TAIHAN ELECTRIC WIRE CO.,LTD.





SECTION=A-A'



DETAIL TERMINAL LUG

CONDUCTOR SIZE[KCMIL(mm²)]	DIMENSION D	DIMENSION L1	DIMENSION L2	DIMENSION L3	CREEPAGE DISTANCE
400(200) - 2000(1000)	1¾"(45)	3⅜"(85)	8'-10" (2692)	9'-6 15⁄16"(2919)	Min : 29'-2⅜" (8900)
▷ 2400(1200) - 5000(2500)	2⅜"(60)	4 5⁄16"(110)		9'-7⅞"(2944)	

COLOR OF COMPOSITE INSULATOR	GRAY

ITEM	DESCRIPTION	MATERIAL
1	LEADING CONDUCTOR	COPPER
2	SHIELDING COVER	COPPER ALLOY
3	COMPOSITE INSULATOR	POLYMER
4	INSULATING COMPOUND	POLYBUTENE OIL
5	TERMINATION SLEEVE	SILICONE RUBBER
6	SUPPORTING INSULATOR	PORCELAIN
7	CASING	ALUMINIUM/COPPER
8	WATER PROOF LAYER	TAPE & TUBE
9	TERMINAL LUG	COPPER/ALUMINUM
10	OPTICAL JOINT BOX	-

NOTE

1. PACKING
   1) MATERIAL : WOOD
   2) SIZE : No.1) 5'-1 7⁄16"Lx3'-4⅜"Wx3'-1⅜"H [1560Lx1025Wx950H] 500kg (3set/box)
      No.2) 4'-0⅜"Lx4'-0⅜"Wx3'-3'-4⅜"H [1230Lx1230Wx1025H] 610kg (3set/pallet)
      No.3) 9'-10⅛"Lx2'-0 13⁄16"Wx2'-2⅜"H [3000Lx630Wx670H] 200kg (1set/box)
2. GROSS WEIGHT : APPROX. 470kg/set

REV. NO.	DATE	DESCRIPTIONS	DGN	CHK	APP
△					
0	Mar.17,2014	FOR BIDDING	H.S.L	S.H.S	K.S.K

LS Cable & System

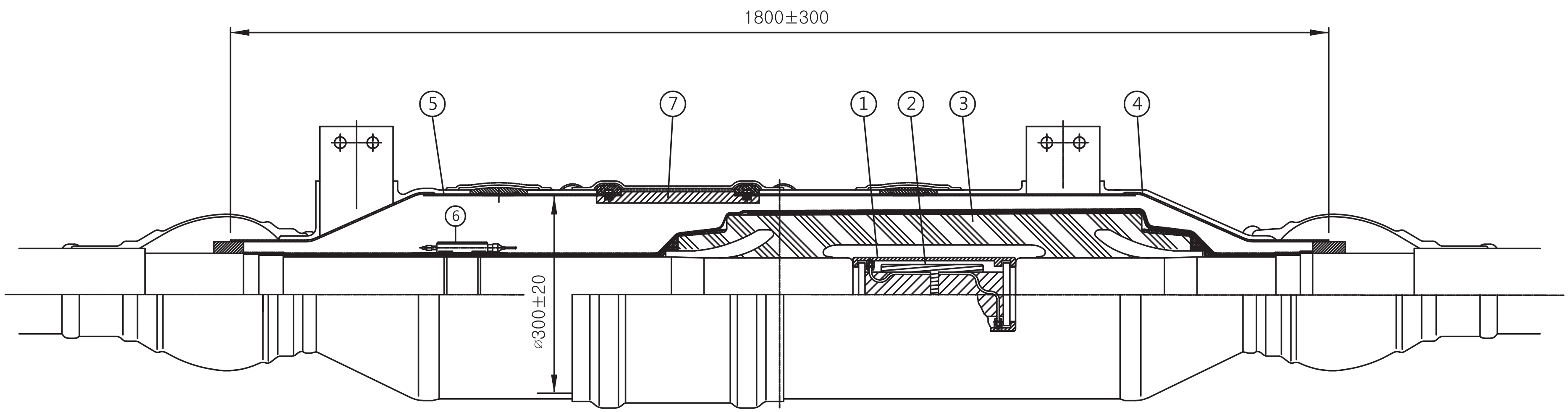
TITLE

OUTDOOR SEALING END
FOR 230kV XLPE CABLE

DRAWING NO **UEMA27Q006**

SCALE	UNIT	PROJECT TITLE	REV.
NTS	MM		0

Amendments & Print Issue	
A	Original Print Issue



No	Name of parts	Material
1	Corona shield	Aluminum
2	Conductor sleeve	Copper
3	PMJ unit	Rubber
4	Outer case (A)	Copper
5	Outer case (B)	Copper
6	Optical fiber joint	PBT
7	Insulator	PE

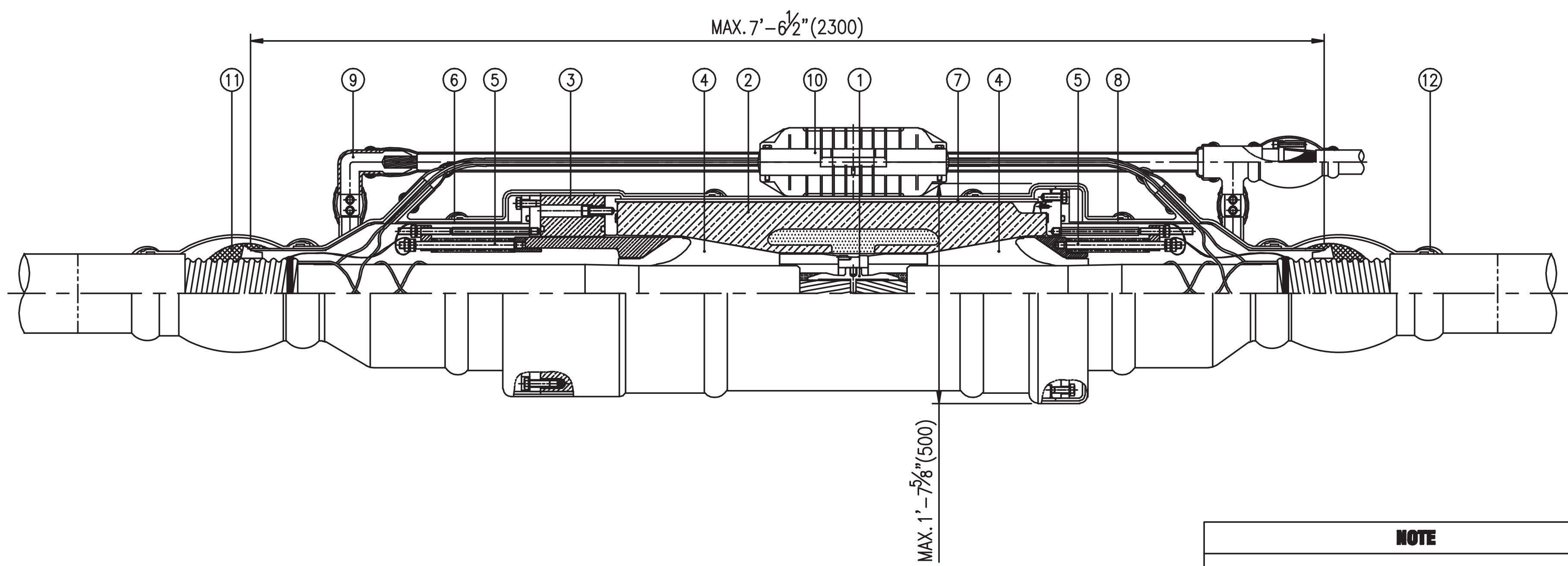
NOTE

1. All Dimensions are in mm.

MANUFACTURER

TAIHAN ELECTRIC WIRE CO., LTD.

PREMOLD INSULATED JOINT FOR 220kV ~ 230kV XLPE CABLE			
Chief	H.H.KIM	Drawn	D.Y.KIM
Checker	K.Y.KIM	Scale	N.S
Designer	D.Y.KIM	Date	2011. 3
Drawing No.	CVC-MIP-220-BD		A
	CAD No.	CVC-MIP-220-BD	
TEC	TAIHAN ELECTRIC WIRE CO.,LTD.		



ITEM	DESCRIPTION	MATERIAL
1	FERRULE	COPPER
2	EPOXY UNIT	EPOXY
3	INSULATING PLATE	EPOXY
4	STRESS RELIFF CONE	EPR
5	SPRING UNIT	BRASS & STAINLESS STEEL
6	CASING(1)	COPPER ALLOY
7	CASING(2)	COPPER ALLOY
8	CASING(3)	COPPER ALLOY
9	EARTHING TERMINAL	COPPER ALLOY
10	OPTICAL JOINT BOX	−
11	WIPED JOINT	LEAD SOLDER
12	WATER PROOF LAYER	SYNTHETIC TUBE & TAPE

NOTE

1. PACKING
   1) MATERIAL : WOOD
   2) SIZE : No.1) 7'−10½"Lx4'−7⅛"Wx3'−3⅜"H [2400Lx1400Wx1000H] 1400kg (3set/1Box)
      No.2) 4'−11"Lx33'−3⅜"Wx1'−11⅝"H [1500Lx1000Wx600H] 500kg (3set/1Box)
2. GROSS WEIGHT : APPROX. 600kg/set

REV. NO.	DATE	DESCRIPTIONS	DGN	CHK	APP
△					
0	Mar.17,2014	FOR BIDDING	H.S.L	S.H.S	K.S.K

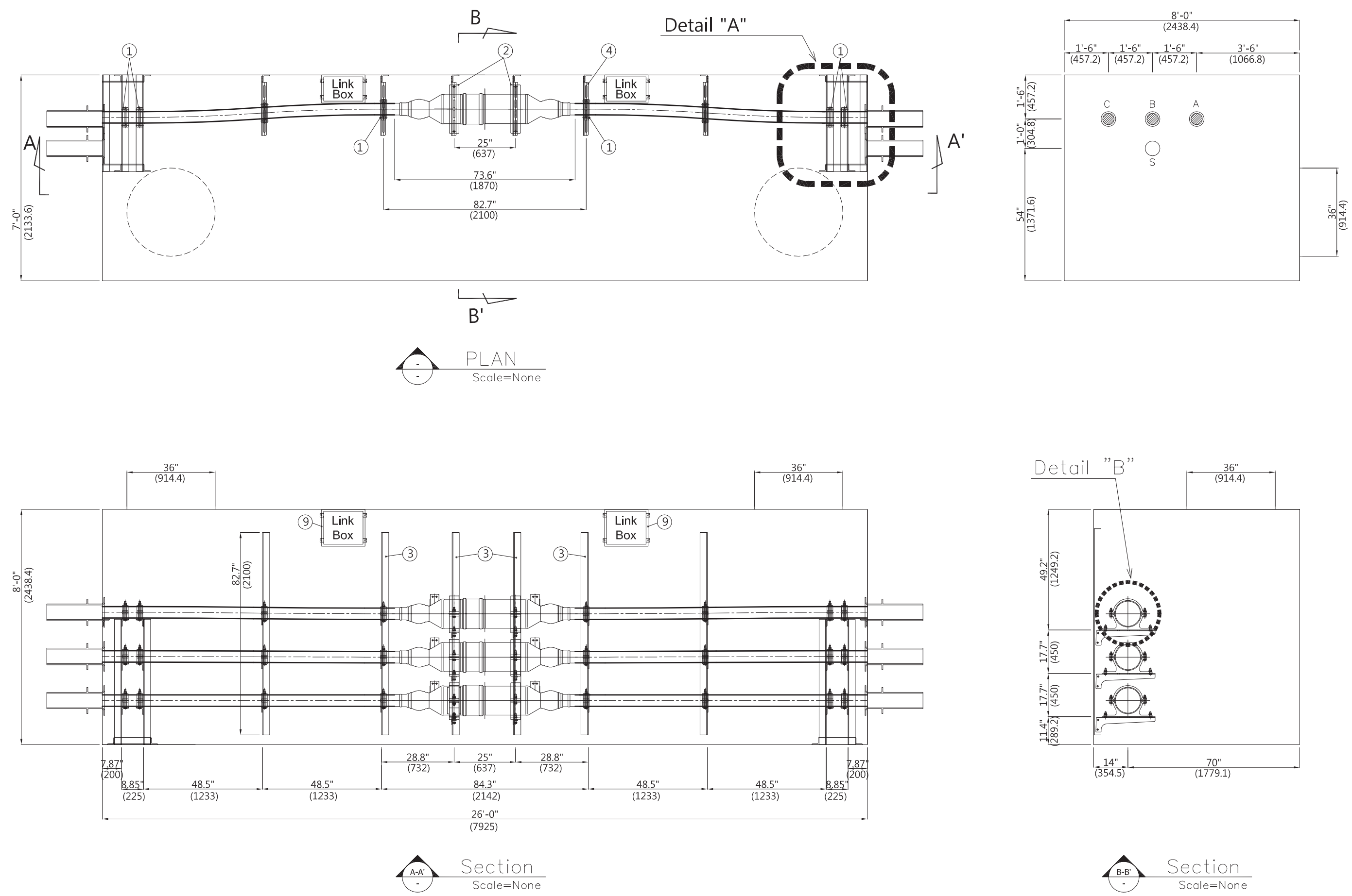
LS Cable & System

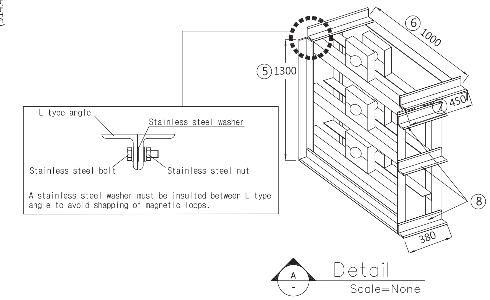
TITLE

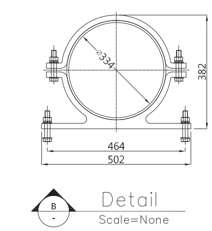
INSULATION JOINT
FOR 230kV XLPE CABLE

DRAWING NO **UEPK27Q001_0P**

SCALE	UNIT	PROJECT	REV.
NTS	MM		0







※ Material List

NO.	Description	Spec(Unitm/m)	Unit	Q'ty	Remarks
1.	Cable Clamp	Single A type	EA	24	
2.		Single C type		6	
3.	Angle Support	L=2100		6	
4.	"L" Type Hanger	ASL-550		18	
5.	(Detail A) "L" Type Angle	75*75*9t*1300		8	
6.		75*75*9t*1000		18	
7.		75*75*9t*450		4	
8.		75*75*9t*380		6	
9.	Link Box Type1	3AB		1	
10.	Link Box Type2	3B		1	
11.	Stainless Bolt & Nut	M16*50		60	
12.	C-Sleeve	SGW2525		5	
13.	Earthing Wire	250SQmm(500kcmil)	m	40	
14.	Earthing Lug	250SQmm(1Hole)	EA	2	
15.	C-Channel	L=100		15	
16.	Pipe Clamp	⌀28		15	
17.	Set Anchor	1/2"*100		70	
18.		1/4"*50		15	

No.	DATE	DESCRIPTION	DRN	DGN	CK	CK	APP
B	12.02.08	ISSUED FOR APPROVAL	HJY	KSC	CSH	KSC	WSC
A	11.11.25	ISSUED FOR APPROVAL	HJY	KSC	CSH	KSC	WSC

TAIHAN ELECTRIC WIRE CO.,LTD

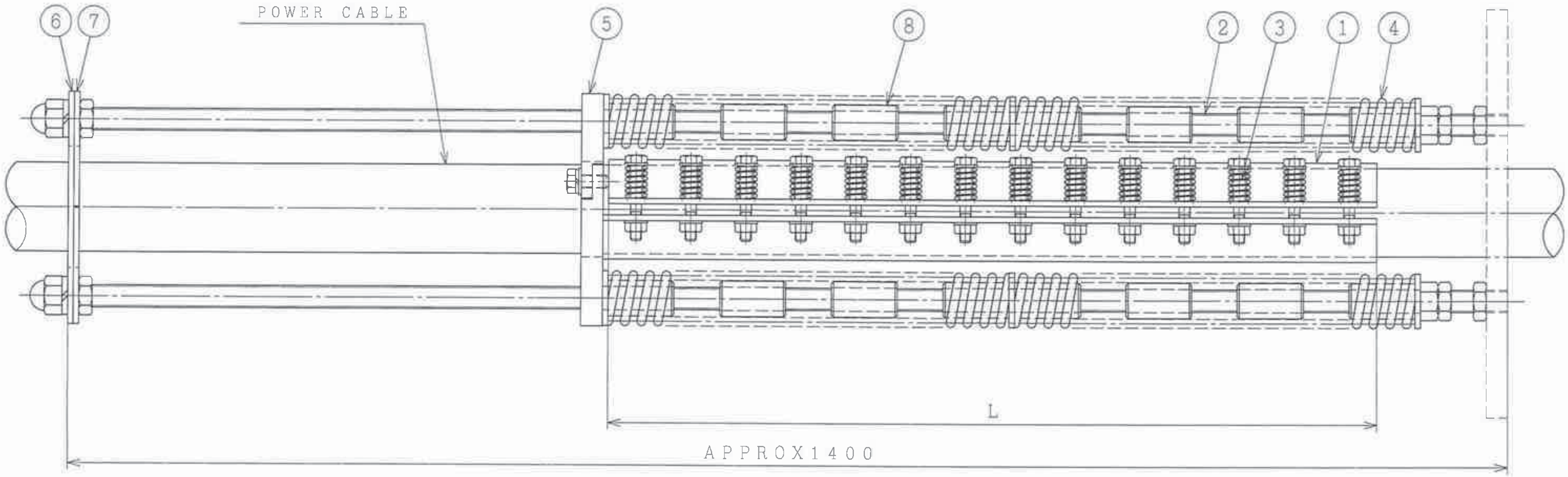
TITLE Burns & Mc Donnell
230kV Cable & Accessories Supply

CONTRACTOR DWG. No. RS-230C2500IXNWZ-C120208

MULTI UNITS	SCALE	PRJ.CODE	DOCUMENT No.	M.F.No.	TYPE	REV.
	NONE					B

Appendix C. Cable Restraining System in Manholes

REV.	DESCRIPTION	DATE	DESIGNED	APPROVED
A	ORIGINAL ISSUE	2014.02.06	–	–
B				



No.	ITEM	MATERIAL
1	CLEAT	STAINLESS STEEL
2	GUIDE BOLT	STAINLESS STEEL
3	SPRING(1)	STAINLESS STEEL
4	SPRING(2)	STAINLESS STEEL
5	FIXING PLATE(1)	STAINLESS STEEL
6	FIXING PLATE(2)	STAINLESS STEEL
7	FIXING PLATE(3)	STAINLESS STEEL
8	SPUPPORTING METAL FOR SPRING	STAINLESS STEEL

CLAMPING FORCE	LENGTH OF CLEAT
200～600kg	300mm
600～1000kg	500mm
1000～1400kg	700mm

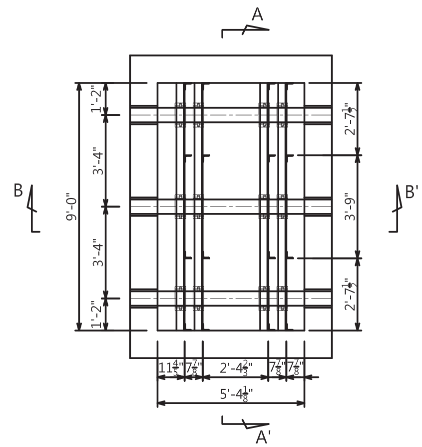
DRAWN	T. Kyama	
DESIGNED	T. Kyama	SCALE
APPROVED		1/4

(株)ジェイ・パワーシステムズ
J-Power Systems

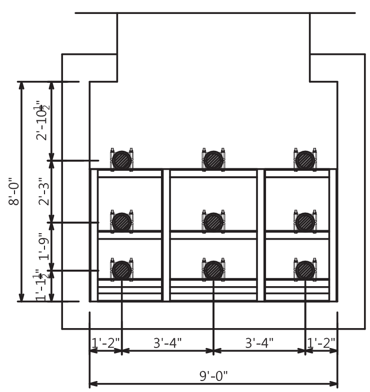
RATCHET DEVICE

DRG.No. SYZ2200 A

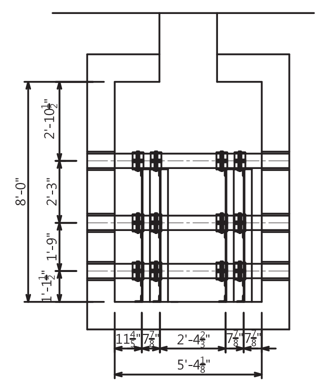
unit:mm SYZ2200



Plane Figure



Section A-A'



Section B-B'

No.	DATE	DESCRIPTION	DRN	DGN	CK	CK	APP
A	'12.12	ISSUED FOR APPROVAL					

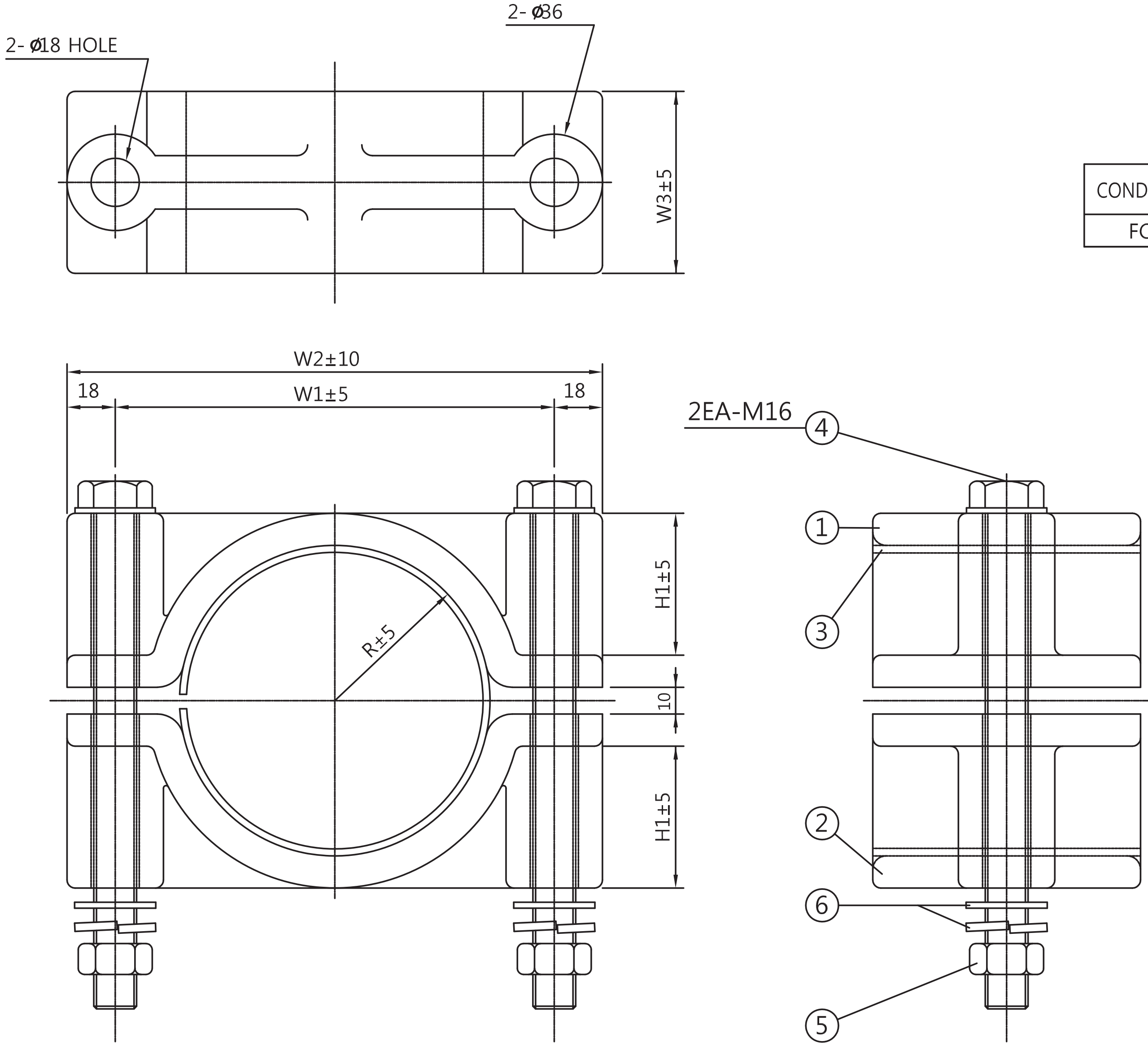
TAIHAN ELECTRIC WIRE CO.,LTD

TITLE RESTRAINT M/H Cable Racking System (Option B or D) S/V#1~S/V#2, S/V#2~S/V#3

CONTRACTOR DWG. No.	TC-SCE-1212-001				
SCALE	PRJ.CODE	DOCUMENT No.	M.F.No	TYPE	REV.
1/50					A

MULTI UNITS

Amendments & print Issue	
A	Original Print Issue



CONDUCTOR SIZE	W1	W2	W3	H1	R	BOLT SIZE
FCR-81	242	278	80	76.5	81	M16x240L

No.	NAME OF PARTS	MATERIAL
1	UPPER BODY	ALUMINUM ALLOY
2	LOWER BODY	ALUMINUM ALLOY
3	RUBBER PLATE	RUBBER
4	HEX BOLT	STAINLESS STEEL
5	NUT	STAINLESS STEEL
6	WASHERS	STAINLESS STEEL

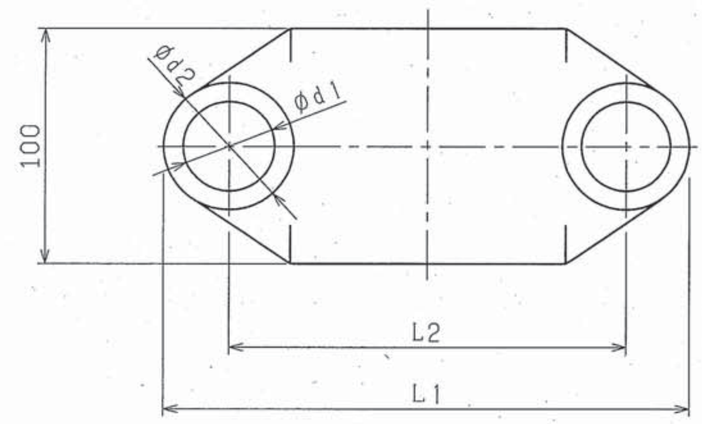
NOTE

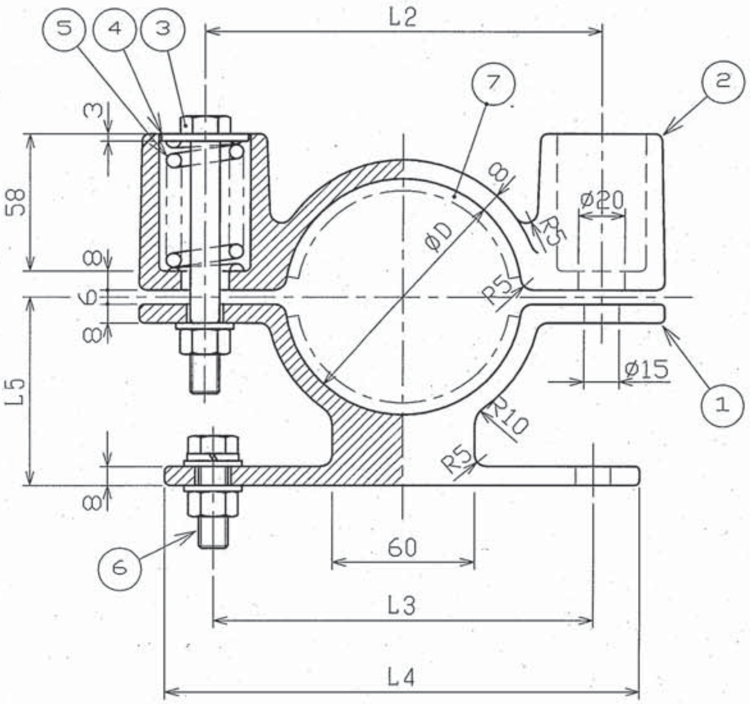
1. ALL DIMENSIONS ARE IN mm
2. EPOXY PAINTING : MUNSELL N/7 COLOR

SINGLE TYPE FIXING CLEAT
for 230kV 1CX5000MCM XLPE CABLE

Chief		Drawn	M.O.CHOI
Checker		Scale	N.S
Designer	S.H.JEONG	Date	'07. 7.
Drawing No.	KA-MAFCR81-01		A
	CAD No.		

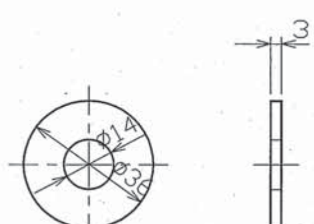
TAIHAN ELECTRIC WIRE CO.,LTD.





SIZE	Dimension(mm)								
	D	L1	L2	L3	L4	L5	L6	d1	d2
D 60	60	174	122	120	160	60	58	38	52
D 70	70	190	137	120	160	60	58	38	53
D 80	80	201	147	120	160	60	58	38	54
D 90	90	211	157	120	160	60	58	38	54
D100	100	221	167	160	200	80	58	38	54
D110	110	231	177	160	200	80	58	38	54
D120	120	241	187	160	200	80	58	38	54
D130	130	251	197	160	200	80	58	38	54
D140	140	261	207	160	200	80	58	38	54
D150	150	271	217	160	200	80	58	38	54
D160	160	281	227	160	200	80	58	38	54

REFERENCE ONLY



4 Detail of washer

No.	Description	Quantity	Material	remark
7	Spacer	2	Rubber	
6	Bolt & Nut	2	SUS304	
5	Spring	2	SUS304	
4	Washer	2	SUS304	
3	Bolt & Nut	2	SUS304	
2	CAST ALUMINUM ALLOY	1	AC7A	
1	CAST ALUMINUM ALLOY	1	AC7A	

FOR			
APPD BY	K.HIROISHI	DESIGNER	Y.SAITO
CHECKER	K.HIROISHI	SCALE	N.T.S
TRACER	Y.SAITO	DATE	Feb.10 2004

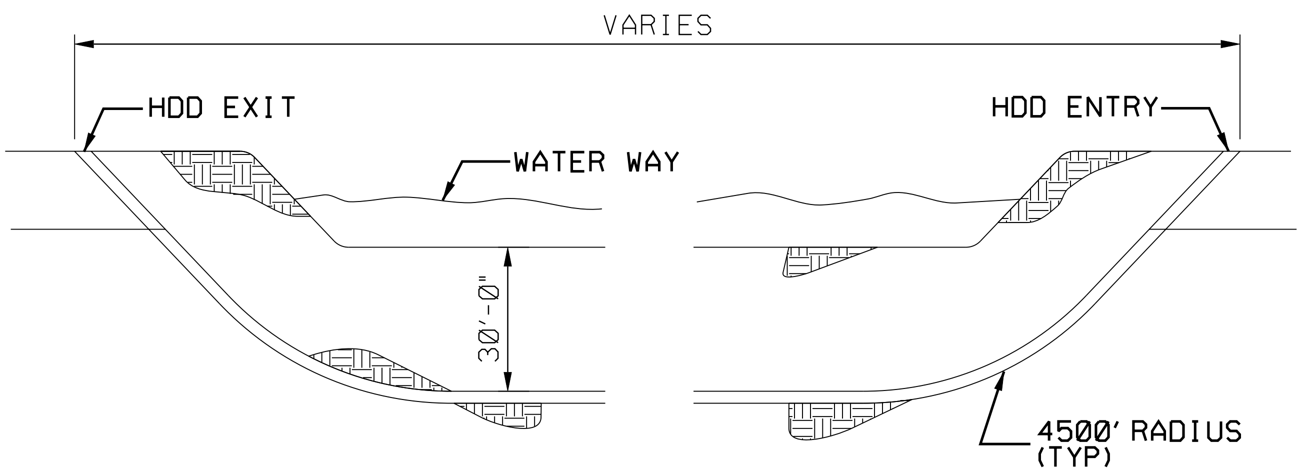
TITLE
SPRING ALUMINUM CLEAT
(Single type)

VISCAS Corporation
POWER CABLE ALLIANCE OF FURUKAWA AND FUJIKURA, JAPAN

DRAWING NO. KEDG-04019

REV

Appendix D. Civil Drawings



TYPICAL WATERWAY CROSSING PROFILE BY HORIZONTAL DIRECTIONAL DRILL

CASTLE ROCK & CAMAS 500KV & 230KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

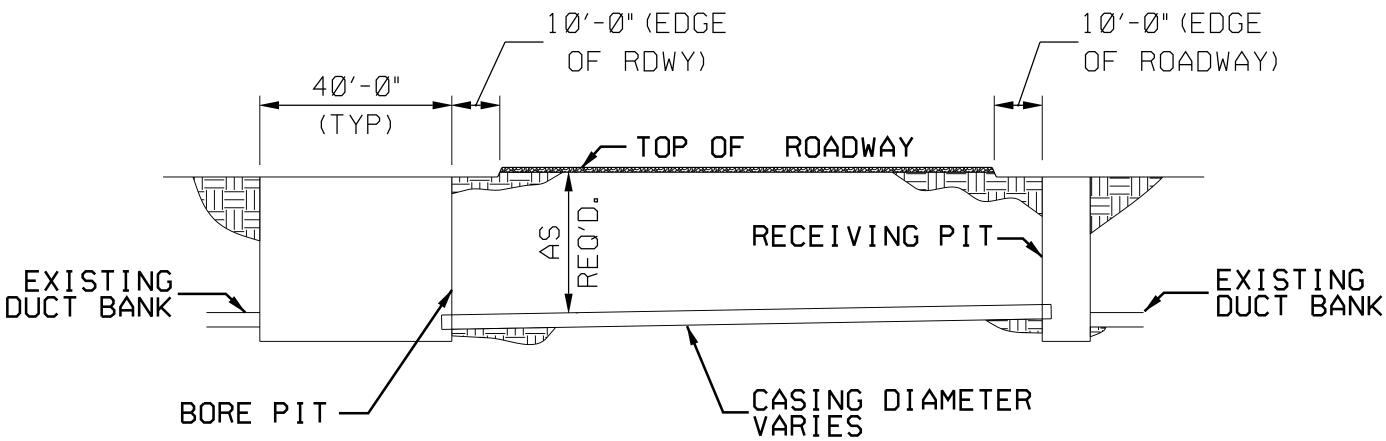
C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED	
COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT PROFILES

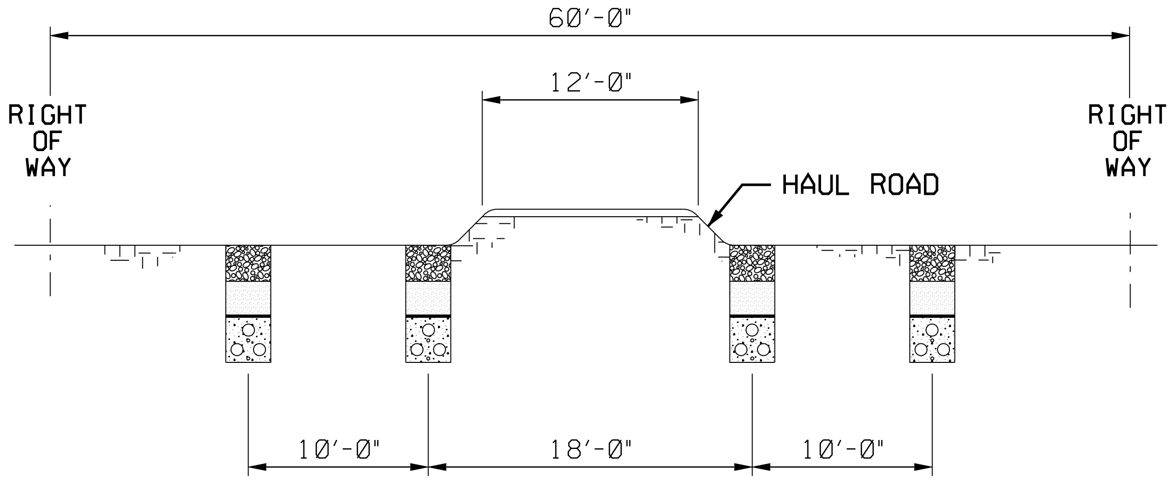
SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	1 OF 10	0



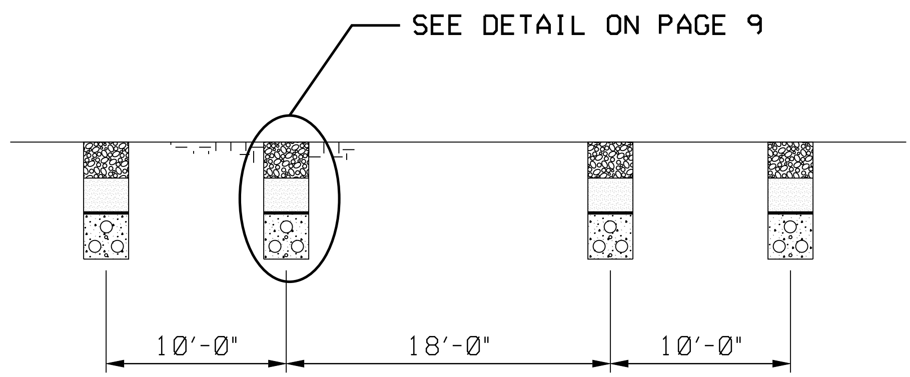
TYPICAL JACK & BORE PROFILE
CASTLE ROCK & CAMAS 500KV & 230KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED
C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#						

APPROVED		
COMPILED	XXXXXXXX	UNITED STATES DEPARTMENT OF ENERGY BONNEVILLE POWER ADMINISTRATION HEADQUARTERS, PORTLAND, OREGON
DRAWN	XXXXXXXX	SITE DEVELOPMENT PROFILES
CHECKED	XXXXXXXX	
CHECKED	XXXXXXXX	
APPROVED	XXXXXXXX	
DATE	XXXXXXXX	SERIAL ####### / SOURCE LBL / SIZE ANSI A / SHEET 2 OF 10 / REVISION 0



CONSTRUCTION WIDTH MINIMUM REQ.
CASTLE ROCK 500KV CABLES



OPEN CUT TRENCH CONFIGURATIONS
CASTLE ROCK 500KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

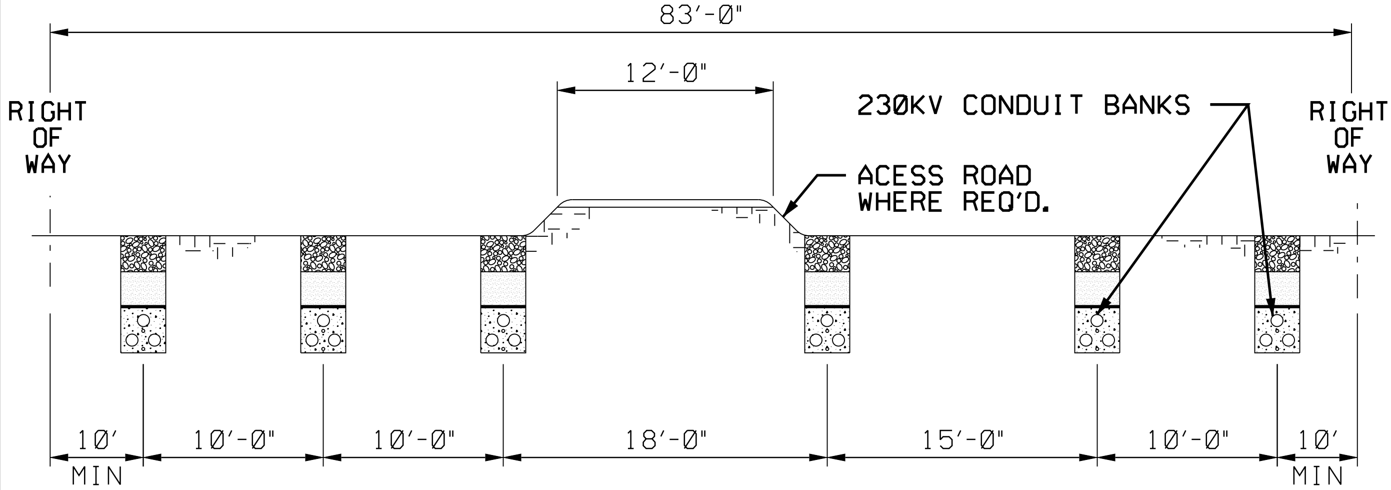
C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED	
COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

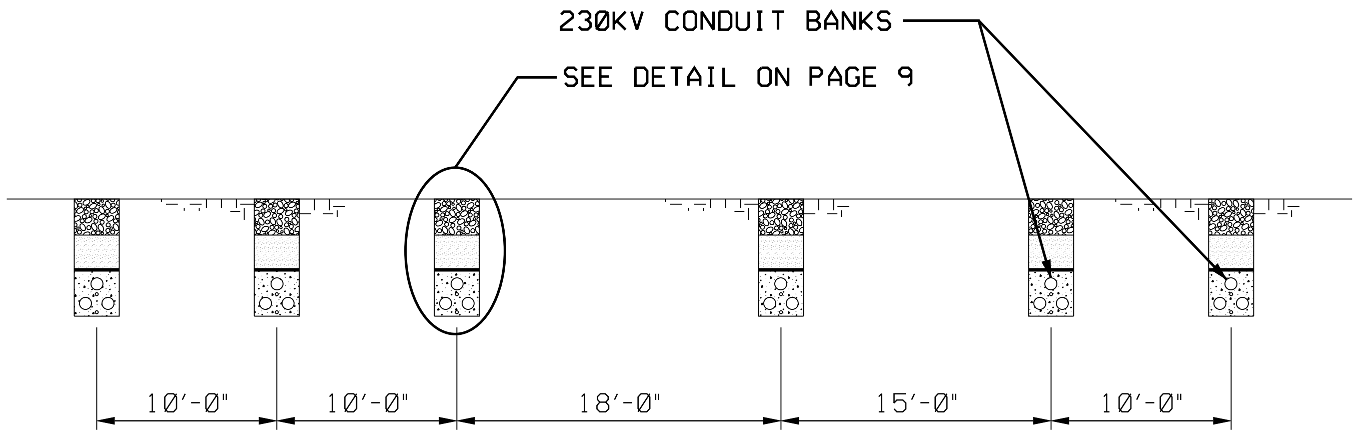
SITE DEVELOPMENT
SECTIONS

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	3 OF 10	0



CONSTRUCTION WIDTH MINIMUM REQ.

CAMAS 500KV & 230KV CABLES



OPEN CUT TRENCH CONFIGURATIONS

CAMAS 500KV & 230KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED

COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT
SECTIONS

SERIAL	SOURCE	SIZE	SHEET	REVISION
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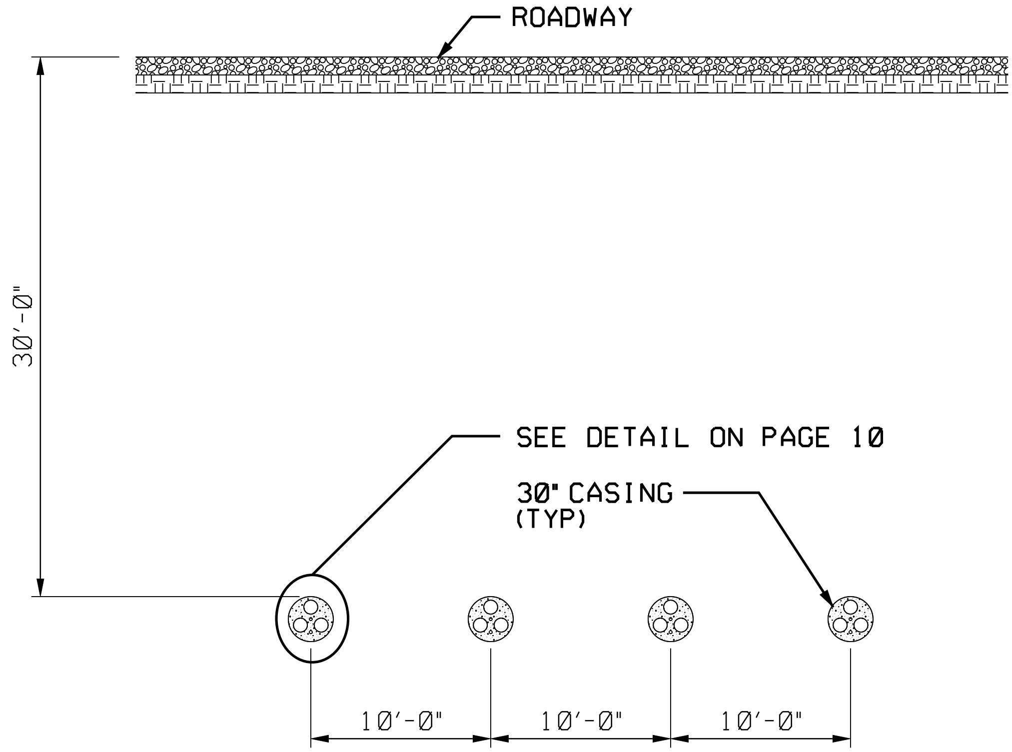


TYP HIGHWAY CROSSING BY JACK & BORE

CASTLE ROCK 500KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

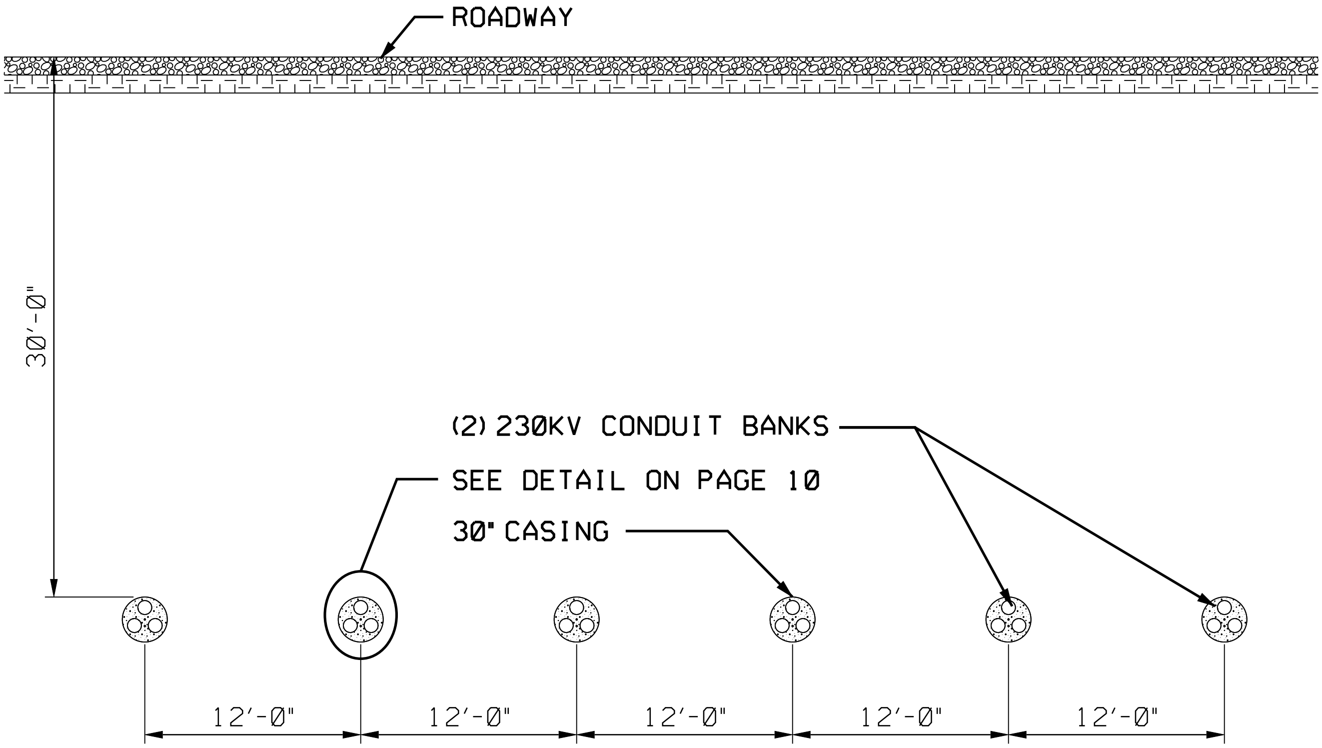
C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED	
COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT
SECTIONS

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	5 OF 10	0



TYP HIGHWAY CROSSING BY JACK & BORE

CAMAS 500KV & 230KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

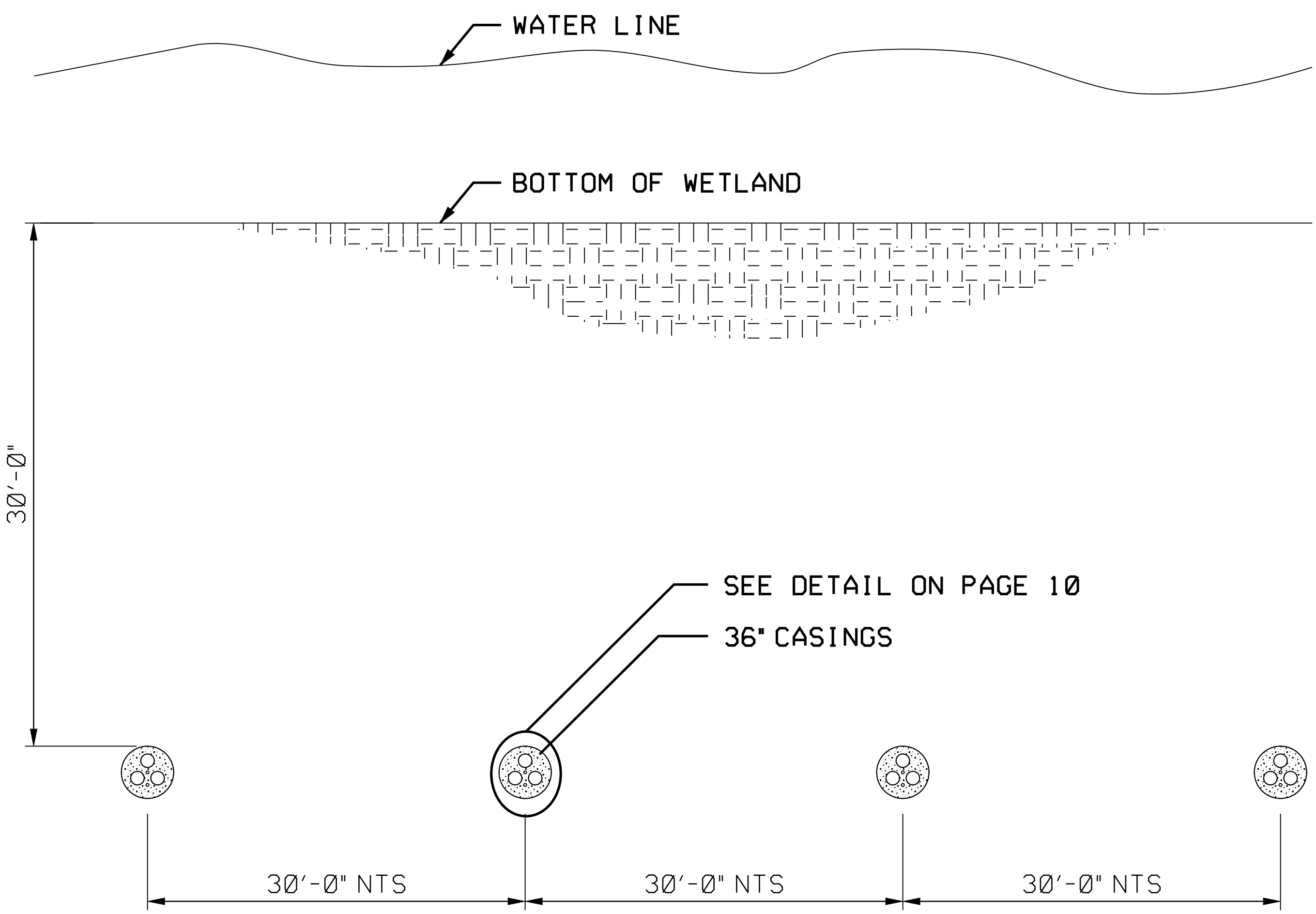
APPROVED

COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT
SECTIONS

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	6 OF 10	0



TYP WATERWAY CROSSING BY HORIZONTAL DIRECTIONAL DRILL

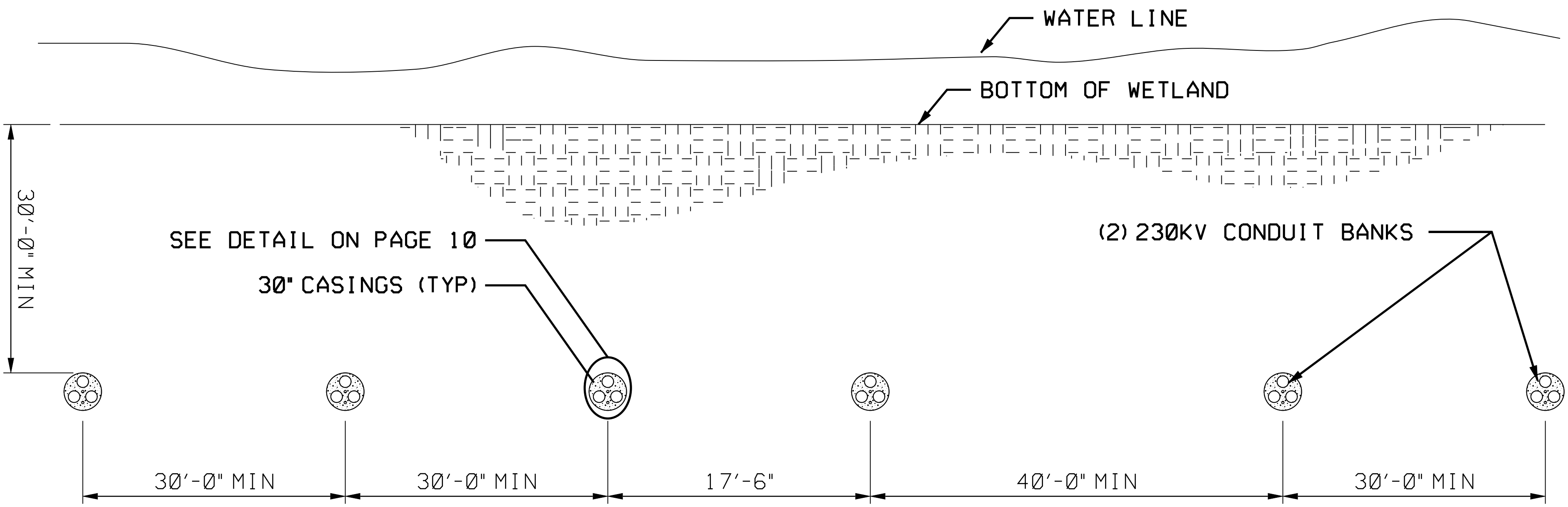
CASTLE ROCK 500KV CABLES

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED		UNITED STATES DEPARTMENT OF ENERGY BONNEVILLE POWER ADMINISTRATION HEADQUARTERS, PORTLAND, OREGON
COMPILED	XXXXXXXX	SITE DEVELOPMENT SECTIONS
DRAWN	XXXXXXXX	
CHECKED	XXXXXXXX	
CHECKED	XXXXXXXX	
APPROVED	XXXXXXXX	
DATE	XXXXXXXX	

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	7 OF 10	0



TYP WATERWAY CROSSING BY HORIZONTAL DIRECTIONAL DRILL

CAMAS 500KV & 230KV CABLES

NO.	WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

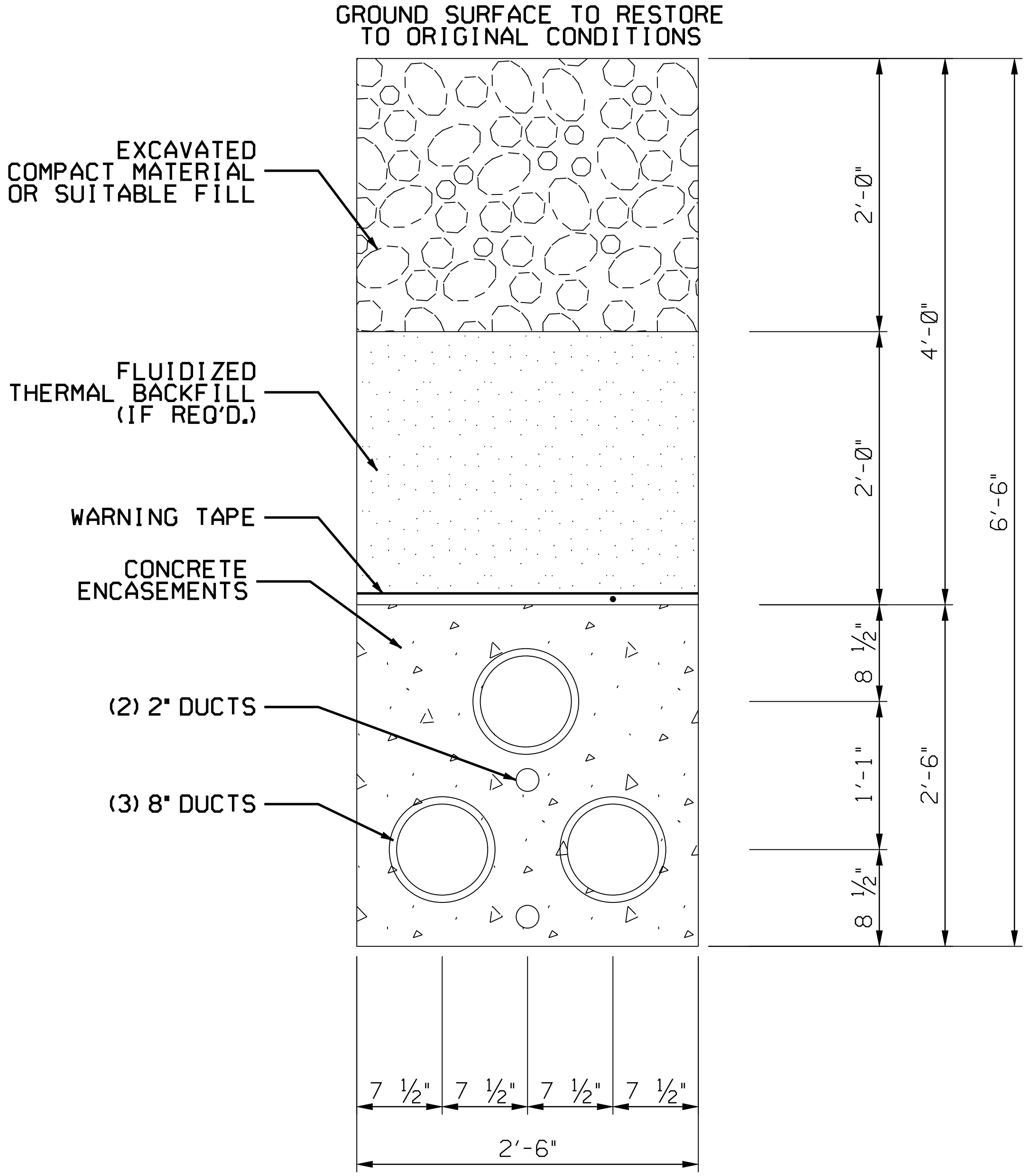
C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED	
COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT SECTIONS

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	8 OF 10	0

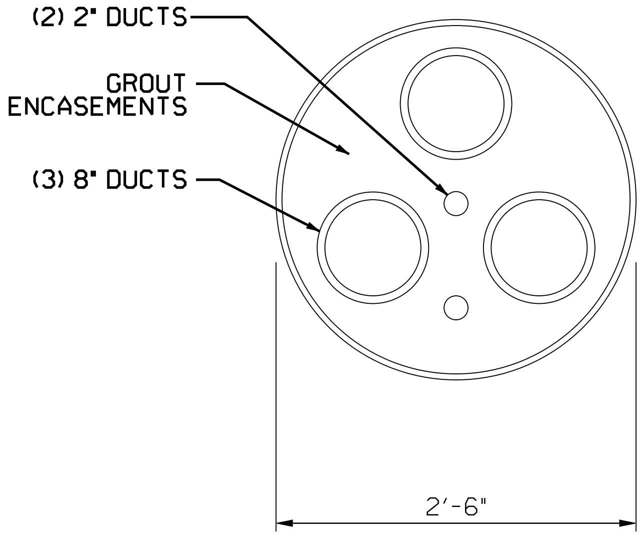


NO.	WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

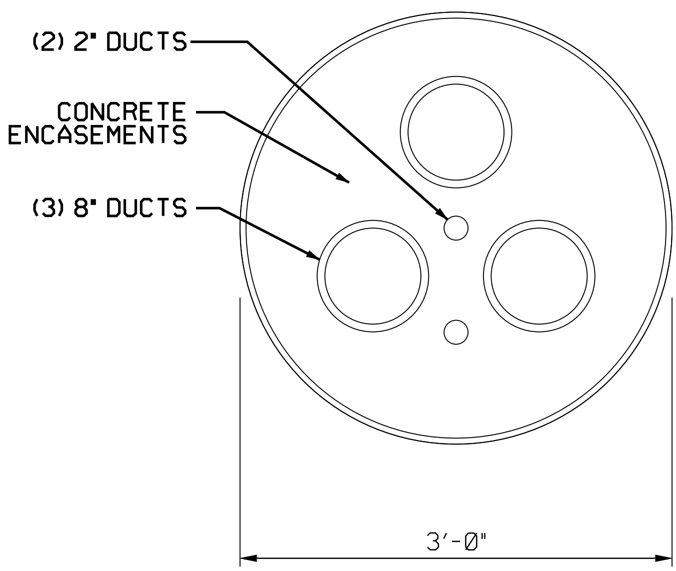
APPROVED		UNITED STATES DEPARTMENT OF ENERGY BONNEVILLE POWER ADMINISTRATION HEADQUARTERS, PORTLAND, OREGON
COMPILED	XXXXXXXX	SITE DEVELOPMENT DETAIL
DRAWN	XXXXXXXX	
CHECKED	XXXXXXXX	
CHECKED	XXXXXXXX	
APPROVED	XXXXXXXX	
DATE	XXXXXXXX	

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	9 OF 10	0



CASING FOR JACK AND BORE

CASTLE ROCK AND CAMAS



CASING FOR HORIZONTAL DIRECTIONAL DRILL

CASTLE ROCK AND CAMAS

NO.		WO	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTR., FA=FORCE ACCOUNT CONSTR., R=RECORD, FILE NAME: ######-#-#

APPROVED	
COMPILED	XXXXXXXX
DRAWN	XXXXXXXX
CHECKED	XXXXXXXX
CHECKED	XXXXXXXX
APPROVED	XXXXXXXX
DATE	XXXXXXXX

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

SITE DEVELOPMENT
DETAIL

SERIAL	SOURCE	SIZE	SHEET	REVISION
#######	LBL	ANSI A	10 OF 10	0

8'–0" x 9'–4" LADWP TRANSMISSION TUNNEL VAULT x 34'–0" LONG

NOTES:

- VAULT DESIGNED IN ACCORDANCE WITH AASHTO H–20–44 TRAFFIC BRIDGE LOADING USING 5,500 PSI [37.92MPa] COMPRESSIVE STRENGTH CONCRETE AND 60,000 PSI [413.2MPa] YIELD STRENGTH ASTM A–706 STEEL REINFORCEMENT PER CALCS. #31893.
- VAULT DESIGNED IN ACCORDANCE WITH LADWP SPEC. 9610 AND SPEC. P178–RS.
- VAULT TO BE PLACED ON 6" BASE OF CRUSHER RUN FOR EASE OF INSTALLATION AND EVEN LOAD DISTRIBUTION.
- LIMIT OF COVER OVER ROOF SECTION IS 1'–0" TO 4'–0".
- CONCRETE MIX USED IN POURING THIS PRODUCT SHALL USE FLY ASH AS AN ADMIXTURE.
- EACH CONCRETE SECTION SHALL BE MARKED ON THE INSIDE & OUTSIDE WITH "JENSEN PRECAST", THE DESIGNATION "DWP/FA.", AND THE DATE OF POUR.
- EACH CONCRETE SECTION SHALL HAVE CAST–IN ON THE INSIDE "JENSEN", THE YEAR, AND THE DESIGNATION "FA".
- NO SHARP OR ROUGH EDGES ON THE TERMINATORS ENTERING THE VAULT.

THE FOLLOWING MATERIAL TO BE SHIPPED WITH VAULT:

(a) 7/8" x 1 3/4" CONSEAL GASKET.
(b) 1 5/8" x 1 5/8" GALVANIZED UNISTRUT x 92" LONG (12) W/(72) 1/2"–13NC x 1 1/2" ROUND HEAD SLOTTED PLATED MACHINE SCREWS & (72) 1/2" PLATED WASHERS (12 REQUIRED).
(c) 1 5/8" x 1 5/8" GALVANIZED UNISTRUT x 36" LONG (6) W/(12) 1/2"–13NC x 1 1/2" ROUND HEAD SLOTTED PLATED MACHINE SCREWS & (12) 1/2" PLATED WASHERS (12 REQUIRED).
(d) 1 5/8" x 1 5/8" GALVANIZED UNISTRUT x 22" LONG (2) W/ 1/2"–13NC x 1 1/2" ROUND HEAD SLOTTED PLATED MACHINE SCREWS & (6) 1/2" PLATED WASHERS (6 REQUIRED).
(e) 1 5/8" x 1 5/8" GALVANIZED UNISTRUT x 68" LONG (12) W/ 1/2"–13NC x 1 1/2" ROUND HEAD SLOTTED PLATED MACHINE SCREWS & (60) 1/2" PLATED WASHERS (60 REQUIRED).
(f) 3/4" x 20" COIL PYD (20 REQUIRED).
(g) 7/8" x 1/2" x 3" WASHER GALVANIZED (40 REQUIRED).
(h) 3/4" HEX COIL NUT PYD (40 REQUIRED).
(i) I–3885 LADDER 11' (2 REQUIRED).

ORDERING INFORMATION:

K894X–TV34–12 FOR ASSEMBLY AS SHOWN.
APPROVED FOR LADWP SPEC. H–240
TOTAL WEIGHT OF ASSEMBLY AS SHOWN IS 231,200 lbs.

GENERAL NOTES:

1. Minimum soil bearing capacity is hereby assumed to be 2000 PSF unless otherwise documented by a geotechnical report that shall be provided to Jensen Precast by the end user. Jensen Precast shall not be held responsible for the soil bearing capacity.
2. Installation of Manholes, Vaults, Handholes, Meter Boxes etc. will be as per Jensen installation procedures.
3. Structural modification to the Jensen line of products is not permitted without prior written approval from Jensen Engineering Department.
4. Do not scale the drawings, verify all dimensions including rough openings, if any discrepancies are found, notify the Jensen Engineer immediately.
5. The Jensen Engineer will interpret the intent of the drawings in case of possible conflict or discrepancy.
6. Permissible Variations:
   Dimensional Tolerances – The length, width, height, or dia. measurements of the structure when measured on the inside surfaces shall not deviate form design dimensions by more than the following:

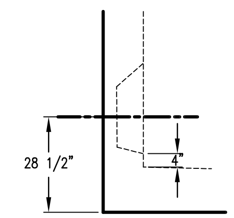
Dimensions:	Tolerance:
0 to 5 Feet	1/4"
5 to 10 Feet	3/8"
10 to 20 Feet as agreed upon between the supplier and purchaser.	

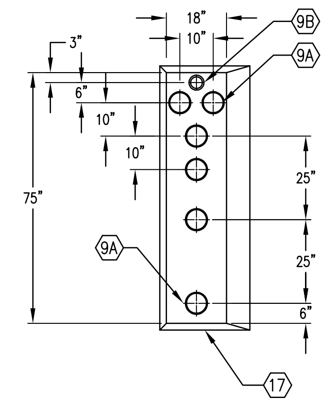
7. Squareness Tolerance:
   The inside of the precast concrete component shall be square as determined by diagonal measurements. The difference between such measurements shall not exceed the following:

Measured Length:	Allowable Difference
0 to 10 Feet	1/2"
10 to 20 Feet	3/4"
20 Feet and over as agreed upon between the supplier and purchaser.	

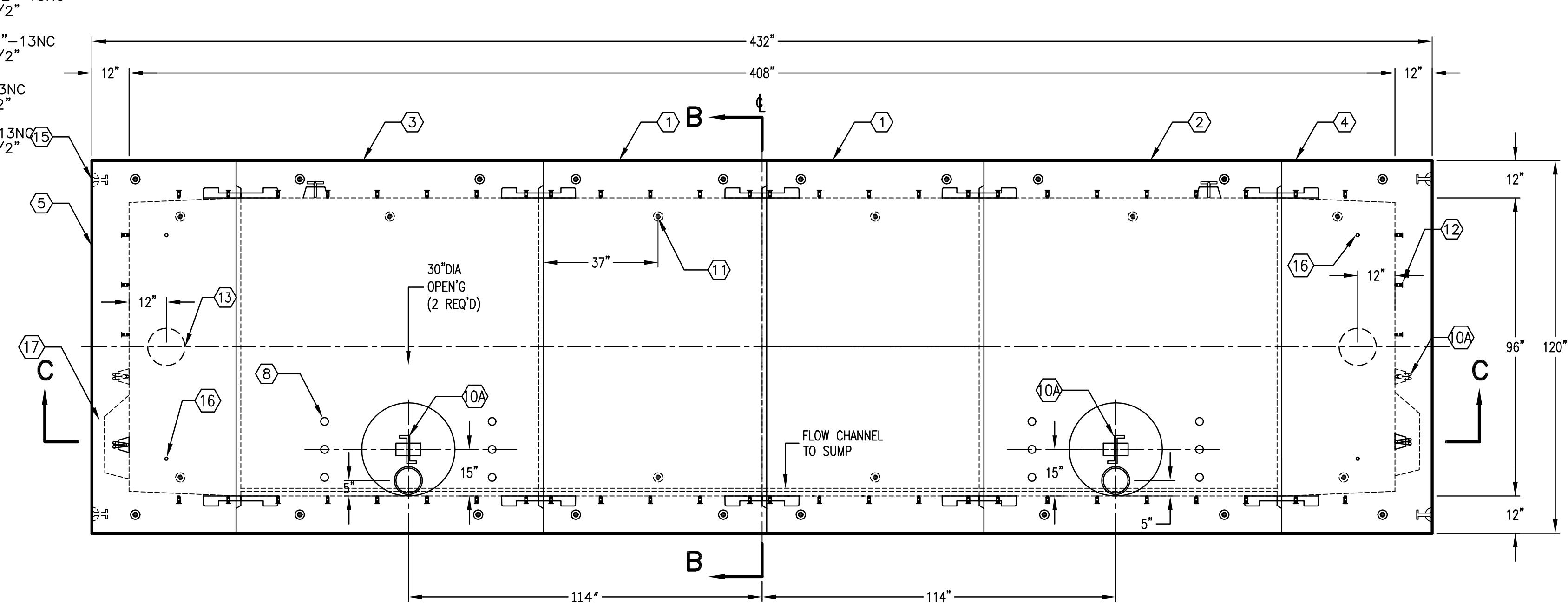
1. (2) TV894X–R72–12, 72" EXTENSION SECTION. WT. 34,800 lbs. EACH
2. TV894X–CR96–12, 96" EXTENSION CENTER SECTION. WT. 46,400 lbs.
3. TV894X–C96–12, 96" CENTER SECTION. WT. 46,400 lbs.
4. TV894X–E36A–12, 36" END SECTION. WT. 34,400 lbs.
5. TV894X–E36B–12, 36" END SECTION. WT. 34,400 lbs.
6. (2) 30" DIA. x 12" HIGH GRADE RING.
7. 8" DIA. x 9" DIA. SUMP x 10" DEEP. LOCATE AS FOLLOWS: CENTER SECTION (1) CORE MTD.; EXTENSION CENTER (1) CORE MTD.
8. 2 1/2" DIA. THROUGH HOLE. LOCATE AS FOLLOWS: CENTER SECTION (6) REQ'D. IN ROOF, EXTENSION CENTER (6) REQ'D. IN ROOF.

9A. 6" DIA. CONTERM. LOCATE AS FOLLOWS: END SECTION (6) EACH SURFACE MTD.
9B. 3" DIA. CONTERM. LOCATE AS FOLLOWS: END SECTION (1) EACH SURFACE MTD.
10. 1 1/4" DIA. x 8 1/2" GALVANIZED PULL IRON WITH LEGS (10,000 lbs.). LOCATE AS FOLLOWS: EXTENSION CENTER SECTION (1) CORE MTD.; CENTER SECTION (1) CORE MTD.
10A. 1 1/4" DIA. x 8 1/2" GALVANIZED PULL IRON WITH LEGS (30,000 lbs.). LOCATE AS FOLLOWS: EXTENSION CENTER SECTION (1) CORE MTD.; CENTER SECTION (1) CORE MTD.; END SECTION (4) CORE MTD.
11. 4 TON x 9 1/2" LONG GALV. RISS PINS. LOCATE AS FOLLOWS IN FLOOR: EXTENSION CENTER SECTION (1) CORE MTD.; CENTER SECTION (1) CORE MTD.; EXTENSION SECTION (2) EA. CORE MTD.; END SECTION (2) EA. CORE MTD.
12. 1/2" PLASTIC INSERT. LOCATE AS FOLLOWS: EXTENSION SECTION (30) EACH CORE MTD.; EXTENSION CENTER SECTION (36) CORE MTD.; CENTER SECTION (36) EACH CORE MTD.; END SECTION (15) EACH CORE MTD.
13. 12" DIA. x 10" DEEP SUMP. LOCATE AS FOLLOWS: END SECTION (1) EACH CORE MTD.
14. 950 BOLT–UP CASTING W/RECESS. LOCATE AS FOLLOWS: CENTER SECTION (4) CORE MTD.; EXTENSION SECTION (4) EACH CORE MTD.; EXTENSION CENTER (4) CORE MTD.; END SECTION (4) EACH CORE MTD.
16. 2" DIA. GROUND ROD SLEEVE W/SEALED TERM. END SECTION (2) EACH CORE MTD.
17. 18" x 75" KNOCKOUT x 8" DEEP. DRAFT AS FOLLOWS: T=2", S1=7", S2=2", B=2". LOCATE AS FOLLOWS: END SECTION (1) EACH CORE MTD.
18. A–3885 ALHAMBRA FOUNDRY LADDER. 16" WIDE x 11'–0" LONG, FLOOR AND WALL MTD.

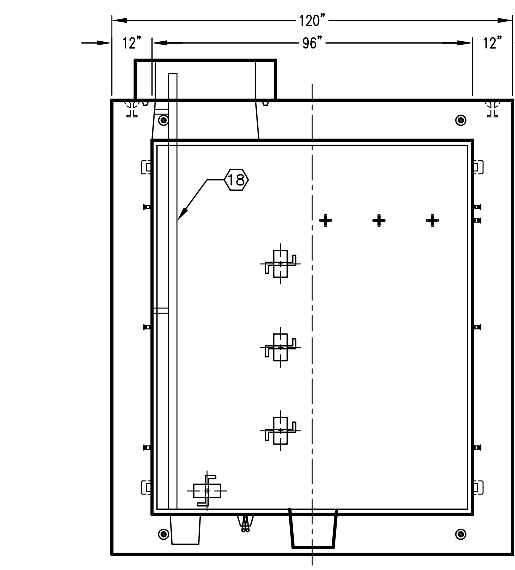




ITEM 17 DETAIL

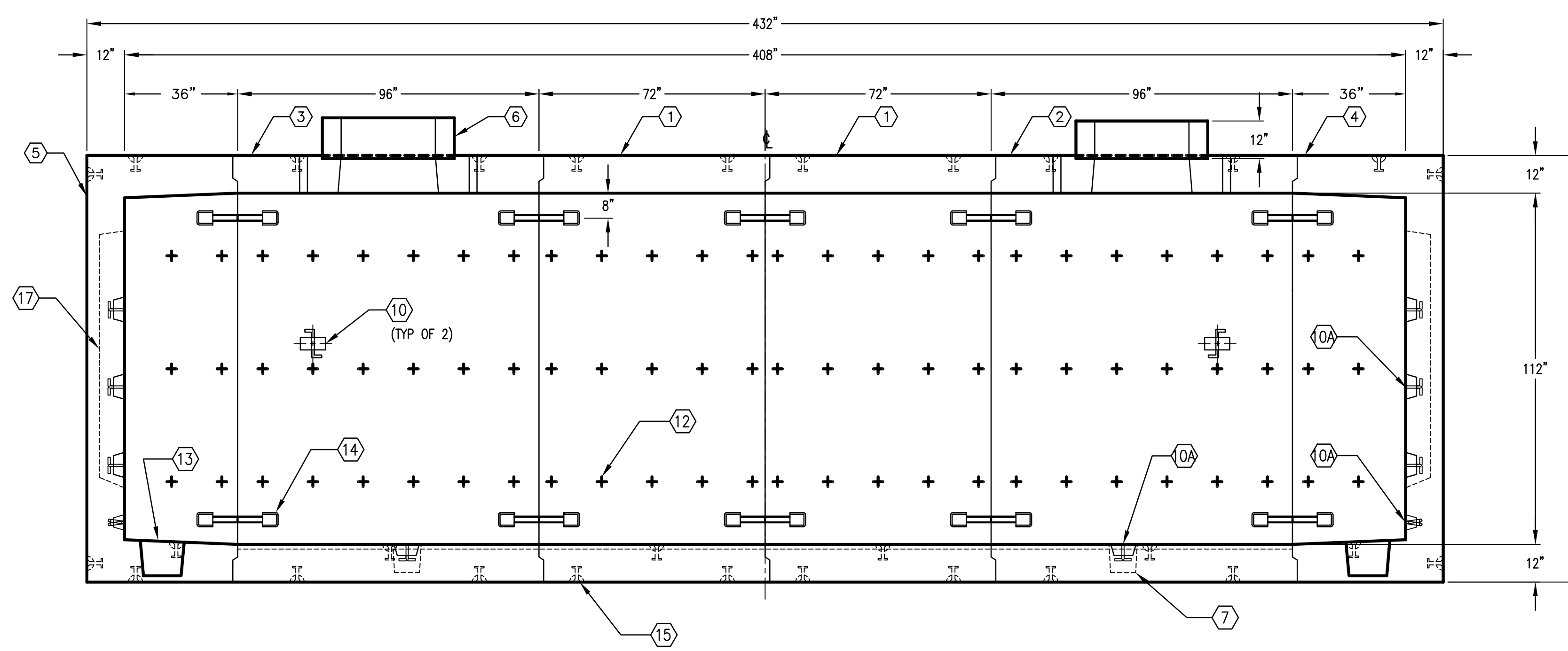


PLAN VIEW



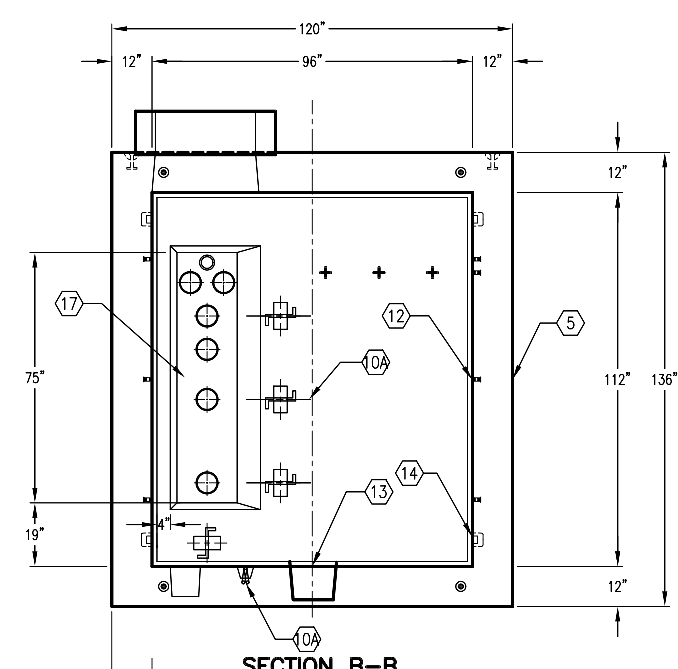
LADDER DETAIL

(KNOCKOUT NOT SHOWN FOR CLARITY)



SECTION C–C

(OPPOSITE SIDE SAME EXCEPT NO PULL IRONS)



SECTION B–B

(OTHER END OPPOSITE HAND)

JENSEN PRECAST®

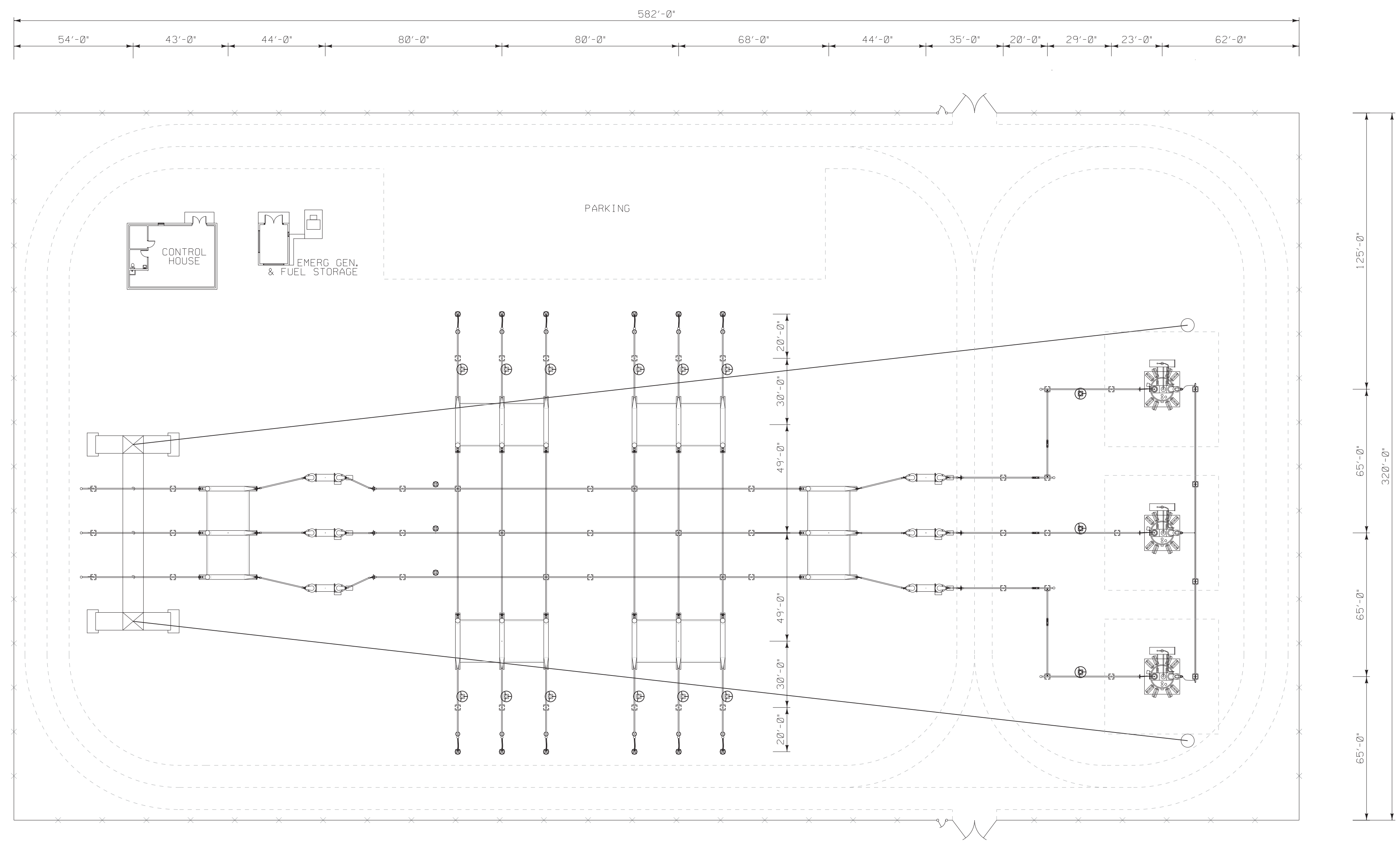
AutoCAD Rel. 14
K894X–TV34–12

#	DATE	DESCRIPTION	BY

K894X–TV34–12

PER L.A.D.W.P. SPEC. H–240 03–01–02

Appendix E. Transition Station Drawings



SCALE 1" = 30'-0" 0 15 30 60 90 FT

NO.	W.O.	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTRUCTION, FA=FORCE ACCOUNT CONSTRUCTION, R=RECORD

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

DSGN
DRWN
CHKD
REVW
CNCR
APPR
DATE

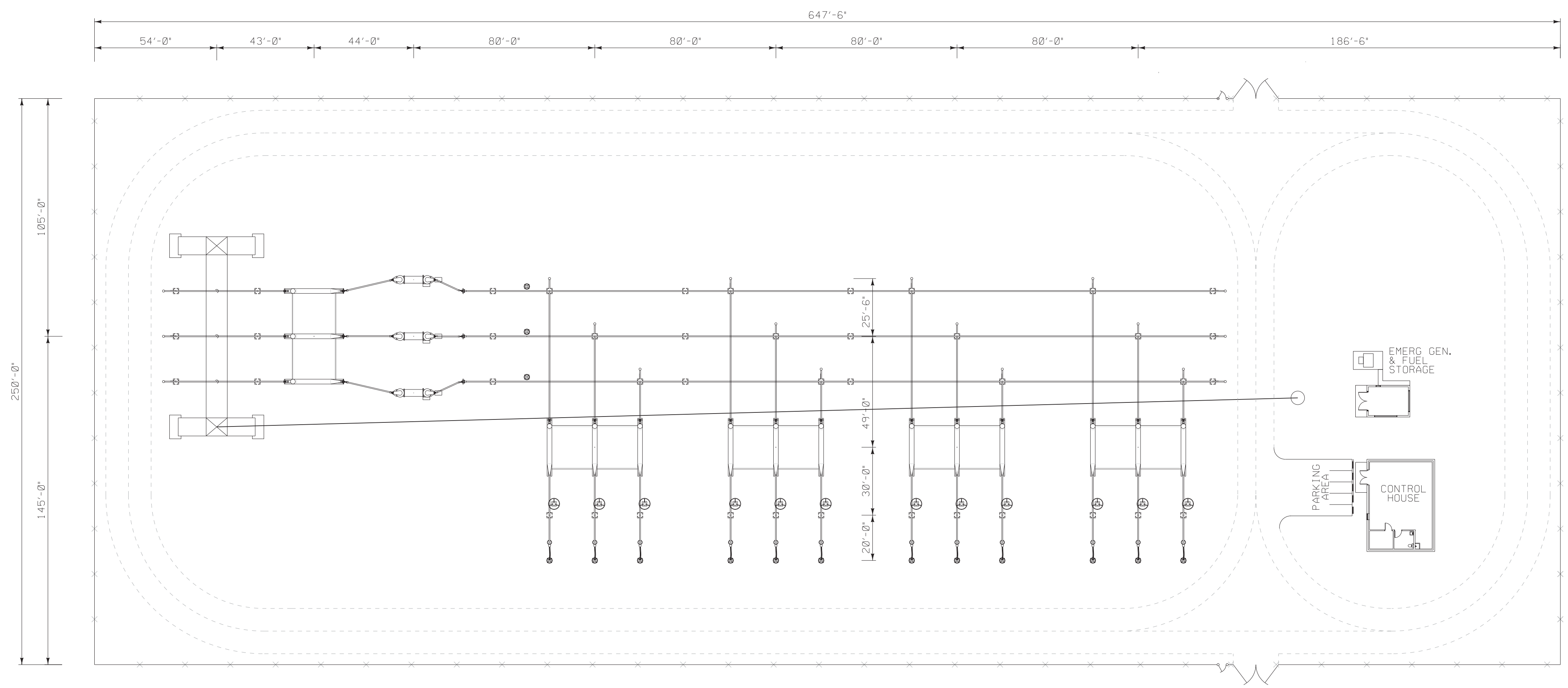
TRANSITION STATION

SERIAL	SOURCE	SIZE	SHEET	REVISION
	SOE	A1		

TRIM LINE

TRIM LINE

DATE



SCALE 1" = 30'-0"

0 15 30 60 90 FT

NO.	W.O.	COMPUTER REVISION ONLY	BY	DATE	APPROVED

C=CONTRACT CONSTRUCTION, FA=FORCE ACCOUNT CONSTRUCTION, R=RECORD

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

DSGN
DRWN
CHKD
REVW
CNCR
APPR

TRANSITION STATION

SERIAL	SOURCE	SIZE	SHEET	REVISION
	SOE	A1		

DATE

TRIM LINE

TRIM LINE

DATE

Appendix F. Preliminary Cost Estimate

F.1 PRELIMARY COSTS FOR 500-KV CABLE SYSTEMS

A breakdown of preliminary costs for the 500-kV cable system installations for Scenarios 1 and 2 is shown in the table below

			SCENARIO 1	SCENARIO 2
MATERIAL				
CABLE SYSTEM TOTAL			$ 52,876,000	$ 49,307,000
CONDUIT SYSTEM TOTAL			$ 4,133,000	$ 3,704,000
SUBTOTAL - MATERIAL			$ 57,009,000	$ 53,011,000
MATERIAL ALLOCATION			$ 5,701,000	$ 5,301,000
TOTAL - MATERIAL			$ 62,710,000	$ 58,312,000
INSTALLATION				
CONDUIT SYSTEM TOTAL			$ 16,874,000	$ 16,325,000
CABLE SYSTEM TOTAL			$ 9,319,000	$ 9,926,000
TOTAL INSTALLATION			$ 26,193,000	$ 26,251,000
ENGINEERING			$ 2,150,000	$ 2,150,000
INDIRECTS	Percent	150	$ 3,225,000	$ 3,225,000
TOTAL - ENGINEERING			$ 5,375,000	$ 5,375,000
CONSTRUCTION MANAGEMENT			$ 420,000	$ 420,000
INDIRECTS	Percent	150	$ 630,000	$ 630,000
TOTAL - CONSTRUCTION MANAGEMENT			$ 1,050,000	$ 1,050,000
TESTING			$ 1,676,000	$ 1,676,000
SUBTOTAL			$ 97,004,000	$ 92,664,000
CONTINGENCY	Percent	30	$ 29,101,000	$ 27,799,000
SUBTOTAL			$ 126,105,000	$ 120,463,000
AFUDC	Percent	7	$ 8,827,000	$ 8,432,000
OVERALL TOTAL			**$ 134,933,000**	**$ 128,896,000**
COST PER MILE			$ 14,055,000	$ 11,935,000
COST PER FOOT			$ 2,660	$ 2,260

F.2 PRELIMARY COSTS FOR 230-KV CABLE SYSTEMS

A breakdown of preliminary costs for the 230-kV cable system installations for Scenario 2 is shown in the table below.

			SCENARIO 1	SCENARIO 2
MATERIAL				
CABLE SYSTEM TOTAL			N/A	$ 8,388,000
CONDUIT SYSTEM TOTAL			N/A	$ 897,000
SUBTOTAL - MATERIAL			N/A	$ 9,285,000
MATERIAL ALLOCATION			N/A	$ 929,000
TOTAL - MATERIAL			N/A	$ 10,214,000
INSTALLATION				
CONDUIT SYSTEM TOTAL			N/A	$ 4,078,000
CABLE SYSTEM TOTAL			N/A	$ 2,339,000
TOTAL INSTALLATION			N/A	$ 6,417,000
ENGINEERING			N/A	$ 1,350,000
INDIRECTS	Percent	150	N/A	$ 2,025,000
TOTAL - ENGINEERING			N/A	$ 3,375,000
CONSTRUCTION MANAGEMENT			N/A	$ 420,000
INDIRECTS	Percent	150	N/A	$ 630,000
TOTAL - CONSTRUCTION MANAGEMENT			N/A	$ 1,050,000
TESTING			N/A	$ 325,000
SUBTOTAL			N/A	$ 21,381,000
CONTINGENCY	Percent	20	N/A	$ 4,276,000
SUBTOTAL			N/A	$ 25,657,000
AFUDC	Percent	7	N/A	$ 1,796,000
OVERALL TOTAL			N/A	**$ 27,453,000**
COST PER LINEAR MILE			N/A	$ 10,168,000
COST PER LINEAR FOOT			N/A	$ 1,930

F.3 BASIS OF PRELIMINARY ESTIMATES FOR 500-kV and 230-kV CABLE SYSTEMS

1. Estimates are ±30 percent
2. Pricing for the cable system materials is based on average or prices received from manufacturers
3. Pricing for cable system installation is based on average of pricing received from manufacturers
4. Material costs include a 10 percent handling charge
5. Engineering costs include indirects
6. Costs do not include any sales tax
7. Installation costs for conduit and manhole system are contractor costs and would include contractor's direct and indirect costs.
8. Costs are in 2014 dollars and no escalation is included.
9. Cost do not include environmental studies or work
10. Costs do not include local, state, and federal permits required for the project.
11. Costs do not include any acquisition of land for transition station or ROW.
12. Cost of spare material consisting of additional cable, 2 joints and 1 terminations is included in the estimate
13. A 30% contingency has been added to material and labor costs.
14. Costs do not include construction of access roads needed for construction.
15. Costs do not include any vegetation clearing needed for construction.