Paper No.
C2024-20826

ANNUAL CONFERENCE + EXPO
MARCH 3-7, 2024 | NEW ORLEANS, LOUISIANA

Condition Assessment of 66 kV Underground Transmission Lines in Concrete Vaults

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ABSTRACT

This paper focuses on assessing the condition of steel pipe cable sections within concrete vaults, serving as protective covers for conductors transmitting up to 66,000 volts. To prevent internal corrosion and short circuits, these cables are filled with pressurized oil. However, water accumulation during storms frequently submerges the cables in water in the concrete vaults, presenting significant challenges for external corrosion protection. Through condition assessment, it was determined that the coating on the 6-5/8" (16.8 cm) diameter steel carrier pipe remained in satisfactory condition. However, the coating on the 14" (35.56 cm) diameter steel casing exhibited poor condition and no longer provided adequate corrosion protection.

This paper investigates the underlying causes of premature coating failure and proposes a recommended coating system considering the elevated temperatures experienced by the pipe cables. The findings contribute to enhancing the durability and effectiveness of coatings for submerged steel pipe cables, addressing the challenges posed by water submersion and ensuring long-term corrosion protection. Also, we discuss the temperature and corrosion monitoring by wireless Sensor.

Keywords: Pipe Cables, Inspection, Condition Assessment, Underground Transmission Lines, Cathodic Protection (CP), Coatings, Water Analysis, Concrete Condition Assessment, Scanning Electron Microcopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDS)

INTRODUCTION

Pipe type cables (or carrier pipe) serve as steel shields for conductors that can carry up to 140,000 volts. To counteract internal corrosion and potential short circuits, these pipe type cables are filled with pressurized oil. Although predominantly underground, these pipe type cables occasionally pass through below-ground concrete vaults. For oil filled pipe type cables, these vaults offer entry points for oil inspection and sampling through valves. Access to these vaults is facilitated by manholes. Due to stormwater accumulation, these cables are often submerged. Given this situation, the external corrosion protection of the pipe type cables presents a myriad of challenges. These include restricted accessibility, confined areas, regular immersion, elevated humidity levels, and compromised visibility. The protective coatings if present on the pipe type cables will degrade prematurely if not maintained properly.[1]

An assessment was conducted on an underground pipe type cables situated within six distinct concrete vaults. Each of these vaults has dimensions of 8 feet (2.44 m) in width, 22 feet (6.71 m) in length, and 9 feet 4 inches (2.86 m) in height, furnished with two 36-inch (91.44 cm) manholes. These vaults encompass a network comprising six pipes, each spanning a collective distance of around 13 miles. Specifically, the carrier pipes have a diameter of 6-5/8 inches (16.8 cm) with a wall thickness of 0.250 inches (6.35 mm) and are coated externally with 60 mil (1.52 mm) polypropylene and internally with Endcor† 745 epoxy. The steel casing, mastic coated, is 14 inches (35.56 cm) in diameter with a 0.375 inches (9.52 mm) wall thickness. The carrier pipe and the steel casing operate at a temperature up to 105℃ (221℉) in service.

It is worth mentioning that when polypropylene coating on the carrier pipe is disbonded at defects, such as pinholes or holidays, CP current can be shielded, either fully or partially, especially at the crevice bottom. As a result, the CP could not protect the area that is in a corrosive environment. The other possibility of CP shielding is the disbondment of a defect-free coating due to either an inadequate coating application process or the lost adhesion of the coating to the steel substrate during service. Figures 1 - 4 show the behavior of the “shielding” and so called “non-shielding” coatings.[3]

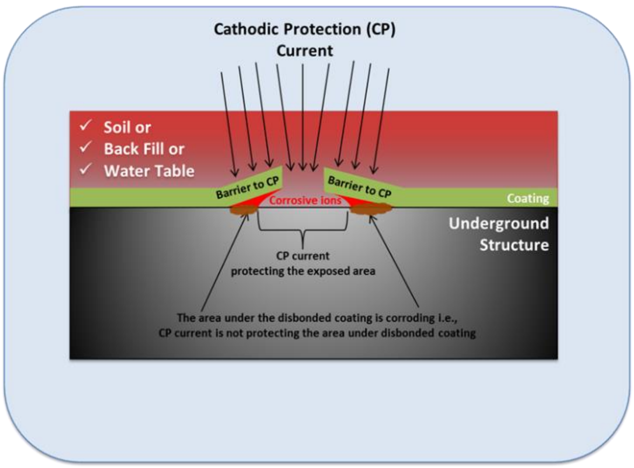


Figure 1: Schematic showing CP Shielding coating behavior at Cathodic Disbondment with holiday.

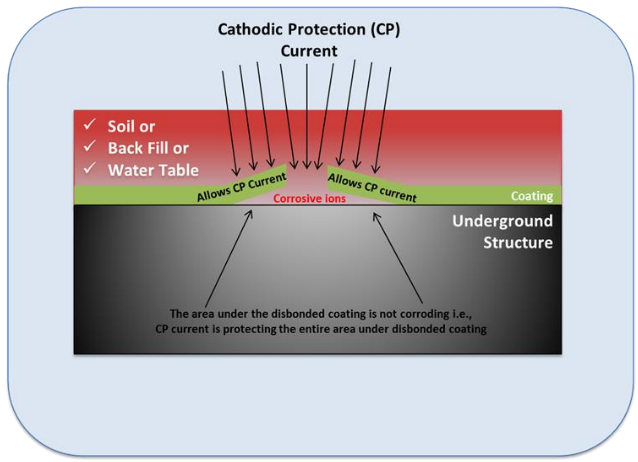


Figure 2: Schematic showing CP Non-Shielding coating behavior at Cathodic Disbondment with holiday.

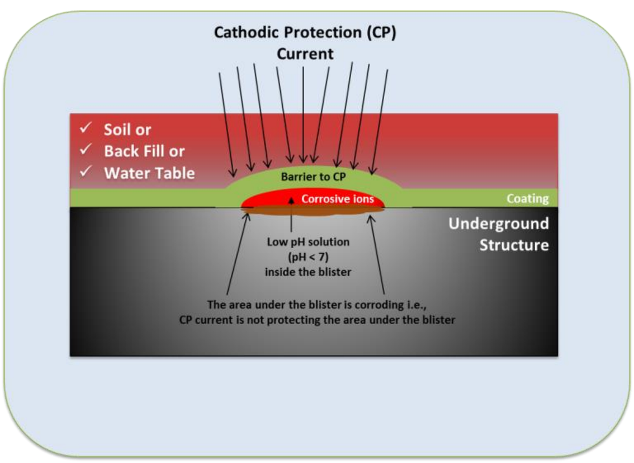


Figure 3: Schematic showing CP Shielding Coating behavior at Cathodic Disbondment without holiday.

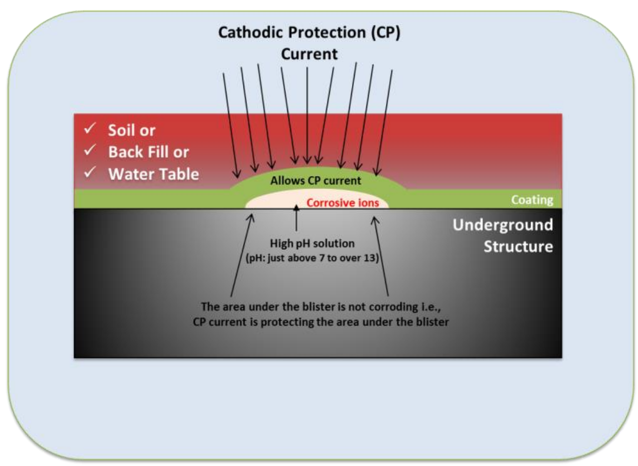


Figure 4: Schematic showing CP Non-Shielding Coating behavior at Cathodic Disbondment without holiday.

† Trade Name

CONDITION ASSESSMENT

Overview

The pipe type cable was installed in the year 1970 and was in service for more than 50 years. The pipe type cable is under cathodic protection (CP). One end of the CP cables is connected to the negative terminal of the rectifier via junction box, and the other end of the CP cables are Cad welded to the steel pipe casing. During the condition assessment, various non-destructive techniques were utilized to inspect the underground pipes within the vaults. The inspection sought to identify potential issues such as pitting corrosion, crevice corrosion, microbiologically influenced corrosion (MIC), galvanic corrosion, and stray current corrosion.

Test Results

Visual Examination

As a part of initial assessment, the condition of the coating on the below ground piping in the vaults was assessed. A visual assessment of the coated surfaces of pipe type cable, and steel pipe casing were conducted to determine the extent, location, and any noticeable patterns of coating deterioration and/or corrosion. Findings of the visual examination are as follows: The coating on the steel pipe casings across all six vaults is in suboptimal condition. Notable defects observed, which are commonly attributed to the aging of the coating, include flaking, delamination, blisters, and cracking. These defects can be seen in the sample images provided in Figures 5 and 6.

Figure 5: Photograph showing coating deterioration and corrosion of the underlying steel pipe casing.

Figure 6: Photograph showing coating deterioration and corrosion of another steel pipe casing.

Furthermore, a significant majority of the Cad weld connections show signs of corrosion. The exposed steel surface surrounding these Cad weld connections presented signs of deterioration, captured in representative images of two separate pipe type cables are presented in Figures 7 and 8. The root cause for the corrosion of the cad weld connections is due to poor workmanship.

Figure 7: Photograph showing corrosion of the Cad weld connection.

Figure 8: Photograph showing corrosion of the Cad weld connection.

Examination of the coating on the carrier pipes revealed that the coating material is polypropylene. Further examination revealed that the condition of the coating on the 6-5/8 inches (16.8 cm) diameter carrier pipe is good. Sample images of two separate carrier pipes are provided in Figures 9 and 10. Polypropylene is one of the most suitable coatings when high mechanical properties (impact resistance, penetration resistance, etc.) and/or heat resistance are required. However, it should be noted that polypropylene coating when disbonded shields cathodic protection (CP), so condition of the coating must be checked every 3 years. CP shielding is defined as preventing or diverting the CP current from its intended path.[2] Electrochemical potential survey in the vault revealed that the carrier pipes and steel pipe casings are receiving adequate CP, more electronegative potential that -0.850 V_{CSE}, when they are submerged in water, when present in the vault.

Figure 9: Photograph showing the condition of the coating on the carrier pipe.

Figure 10: Photograph showing the condition of the coating on the carrier pipe.

<u>Coating Thickness Measurement using Hand-held, Electronic Instrument</u>

Coating thickness was measured using Positector[†]. Generally, underground coatings are applied much thicker than above ground coatings as they must be able to withstand an underground environment. The thickness of the polypropylene coating on the carrier pipe is 60 mils (1.52 mm) minimum. The coating type on the steel pipe casing seemed to be mastic coating and the thickness of the coating is much lower

[†] Trade Name

than the polypropylene coating present on the carrier pipe. Figure 11 is a sample picture showing the thickness of the coating (77.7 mils) present on the carrier pipe. Figure 12 is a sample picture showing the thickness of the coating (6.1 mils) present on the steel pipe casing.

Figure 11: Photograph showing the thickness of the coating present on the carrier pipe.

Figure 12: Photograph showing the thickness of the coating present on the steel pipe casing.

Wall Thickness Measurement

The wall thickness measurements are usually performed to prevent failures due to corrosion, and to guide decisions regarding component life span/replacement. The wall thickness of the carrier pipes and the steel pipe casings were measured using ultrasonic wall thickness gauge. However, wall thickness measurement was more focused on the steel pipe casing because the coating was deteriorated, and the corrosion of the underlying pipe steel casing was evident to the naked eye. The nominal wall thickness of the steel pipe casing is 0.375 inches (9.52 mm). Figure 13 shows the sample picture showing the wall thickness of the steel pipe casing. Considering the number of years, the steel pipe casing was in service and the measured wall thickness readings, there is no reduction in wall thickness and the observed corrosion on the exterior of the pipe has not decreased the overall wall thickness of the steel pipe casing, indicating that wall thinning is not a concern when addressing the integrity of the pipe. Figure 14 shows the wall thickness of the carrier pipe. The wall thickness readings indicate that there was no reduction in the wall thickness of the carrier pipe as well.

Figure 13: Photograph showing the wall thickness of the steel pipe casing.

Figure 14: Photograph showing the wall thickness of the carrier pipe

Concrete Condition Assessment

Condition assessment of the concrete in the inspected vaults also revealed discoloration of the lower portion of the concrete due to corrosion of the embedded rebar (Figures 15 and 16). For better understanding of the condition of the concrete in the vaults, pictures of two vaults are included. Moisture and de-icing salts can aggravate the corrosion reaction. Corrosion of the lower portion of the concrete suggests that the lower portion of the concrete vault was in contact with water at some point in service.

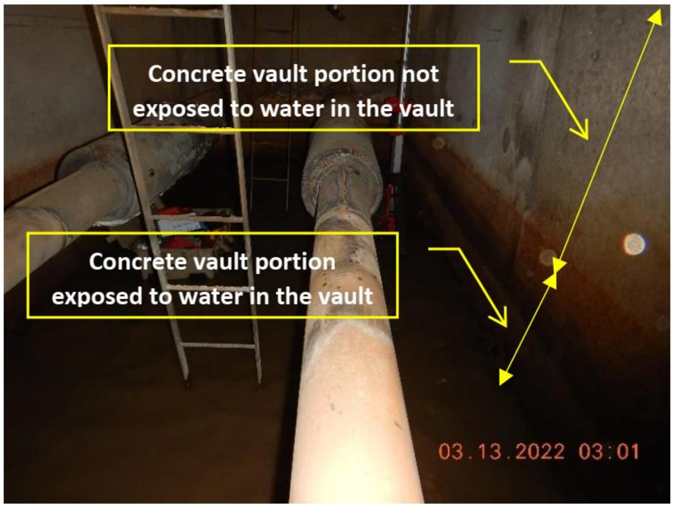


Figure 15: Photograph showing corrosion of the concrete vault.

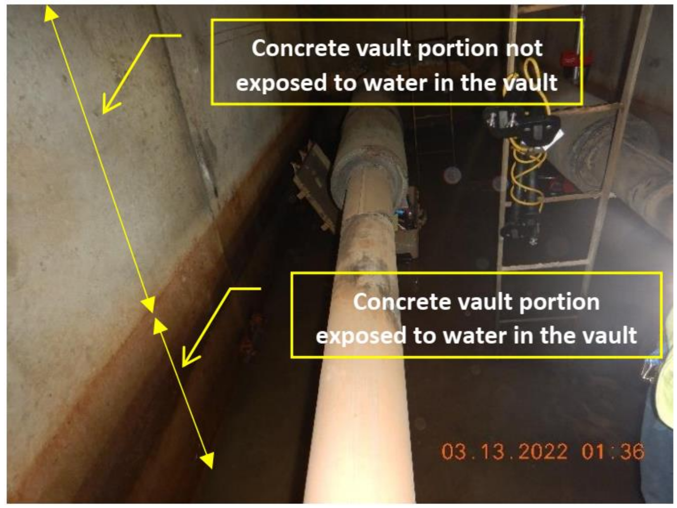


Figure 16: Photograph showing corrosion in another concrete vault.

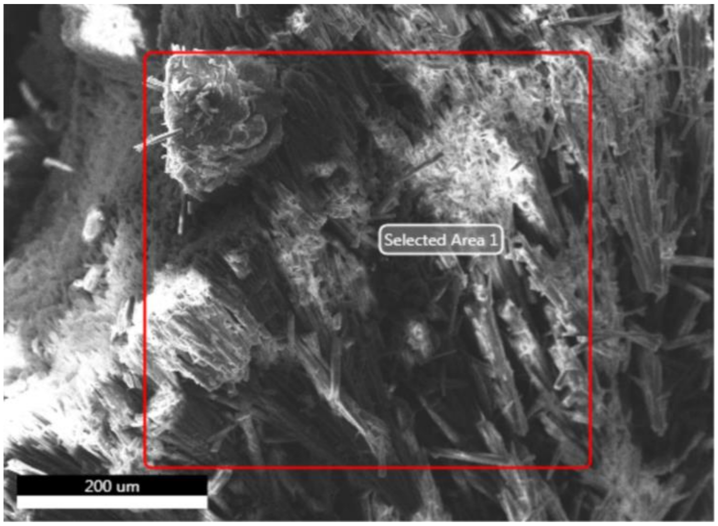
During condition assessment of the concrete, it was observed that white fuzzy build up was noticed predominantly on the bottom side of the pipes in the concrete vaults (Figure 17). The build-up could be efflorescence from the concrete. When the pipe comes in contact with water, the dissolved salts or minerals from the concrete might have settled on the pipe surface.

Figure 17: Photograph showing white deposit build-up on the pipe at the 6 O' clock position.

Scanning Electron Microcopy (SEM) – Energy Dispersive X-ray Spectroscopy (EDS) analysis

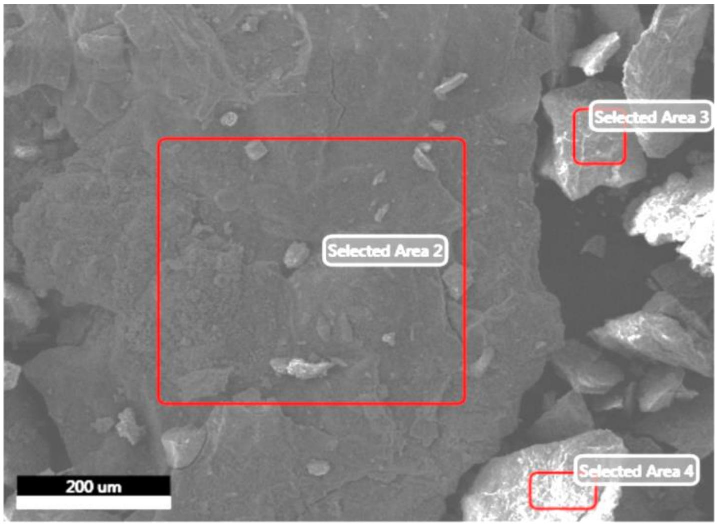
Corrosion product, and one of the white deposits collected from the carrier pipes in the vaults were analyzed in the lab using SEM/EDS analysis. The presence of elements such as calcium (Ca), oxygen (O), carbon (C), magnesium (Mg), and aluminum (Al) from the EDS analysis indicate that the white deposit is in fact the efflorescence product of the concrete (Figure 18). A typical efflorescence is formed by calcium carbonate ($CaCO_3$). Moreover, efflorescence could be sulfate and carbonate compounds of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and aluminum (Al).

Elemental composition of the corrosion product revealed presence of elements such as iron (Fe), oxygen (O), carbon (C), silicon (Si), chlorine (Cl), and manganese (Mn). EDS data indicates that the corrosion product is predominantly iron oxide, and iron carbonate (Figure 19).



Element	Weight %	Atomic %
C K	7.82	13.23
O K	51.93	65.95
MgK	0.68	0.57
AlK	0.78	0.59
CaK	38.79	19.66

Figure 18: EDS data showing the elemental composition of white deposit.



Element	Weight %	Atomic %
C K	4.57	10.10
O K	37.38	61.97
SiK	0.35	0.33
ClK	0.73	0.55
MnK	0.83	0.40
FeK	56.14	26.66

Figure 19: EDS data showing the elemental composition of the corrosion product collected from the surface of the steel pipe casing.

Review and Assessment of the Various Applicable Coating Types

Reviewed and assessed various potential coating types for the steel pipe casing and provided recommendations for the most suitable replacement coating(s). The following factors were considered in this review and assessment.

Service environment

The pipe sections in the vaults may experience prolonged flooding. Accordingly, the optimum coating should have excellent water immersion performance, resistance to corrosive species found in the environment of the vault and be capable of resisting steel casing continuous surface temperature variations (up to 105℃ or 221℉) without degradation.

Physical location

Space and access limitations due to the physical location of the steel pipe casing in the vault dictate that surface preparation be limited to mechanical cleaning with power and hand tools and the coating application be limited to the wrapping of tapes, heat shrink sleeves, or application of liquid coatings by brush or roller. Some advanced coating systems such as polyolefin and fusion-bonded epoxy systems can only be applied in coating facilities as they need special equipment.

The presence of CP

As the pipe casing has a CP system in place, the coating should be compatible with the CP system. In other words, it should not be CP shielding.

Based on these factors, the following candidate coating systems (Table 1) have been recommended for the various coating types.

Table 1:
Recommended candidate coating systems

Priority Ranking	Type	Primer/Mastic Needed? (Y/N)	Application Method (Spray/Roll/Hand)	Surface Prep (Minimal/Hand Tool/Blasting/ Extensive)	Application expertise needed? (Y/N)
1	Cold-Applied Tapes	Y	Brush/hand	Minimal/ hand tool	No
2	Hot-Applied Heat-Shrink Sleeves	Y	Heat Cured Epoxy	Not specified	Helpful

Table 1 (continuation):

Priority Ranking	Type	Max Coating Temperature (Cable MOT 221℉)	Belowground and Underwater Capable (Y/N)	Existing Cathodic Protection Friendly (Y/N)
1	Cold-Applied Tapes	230	Yes	Yes
2	Hot-Applied Heat-Shrink Sleeves	248	Yes	Yes

CONCLUSIONS AND RECOMMENDATIONS BASED ON CONDITION ASSESSMENT

The findings and the recommendations from the condition assessment of the underground piping in the vaults are as follows:

1. The condition of the polypropylene coating on the 6-5/8 inch (16.8 cm) diameter piping (carrier pipe) is good.
    - However, it should be borne in mind that polypropylene coating shields CP.
2. The nominal thickness of the polypropylene coating on the carrier pipe is ≈60 mils (1.52 mm).
3. The condition of the mastic coating on the 14 inch (35.56 cm) diameter steel pipe casing is poor and should be recoated immediately.
    - It is recommended that the existing coating on the steel pipe casing should be removed using chemical strippers or blasting systems.
    - Then, apply new coatings with a brush and roller, or a conventional spray system.
4. The wall thickness measurements on the 6-5/8 inch (16.8 cm) diameter piping, and 14 inch (35.56 cm) diameter steel pipe casing does not show any abnormality.
    - The average wall thickness of the 6-5/8 inch (16.8 cm) diameter piping is ≈0.250 inches (6.35 mm), and 14" diameter steel pipe casing is ≈0.375 inches (9.52 mm).
5. All Cad weld (thermit weld) connections showed green deposits which is a corrosion product of the copper lead wire connected to the casing.
    - The root cause for the corrosion of the cad weld connections is due to poor workmanship. After the cad welding, all cable attachments to structures should be coated. This coating should be compatible with the structure coating.
    - Before recoating on the steel pipe casing, client should ensure that all Cad weld connections of lead wires to the pipe casing are mechanically secure, then remove the green corrosion product on the cad weld connection, remove the existing coating on the steel pipe casing using chemical strippers or blasting systems, and then apply the recommended coating on the steel pipe casing and the cad weld connections.
6. Electrochemical potential survey performed in the vaults suggest that the pipes are receiving adequate CP i.e., more electronegative potential that -0.850 V_{CSE}.

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