Shasta Dam Unit 5 Penstock – Historic Linings Field Test Site

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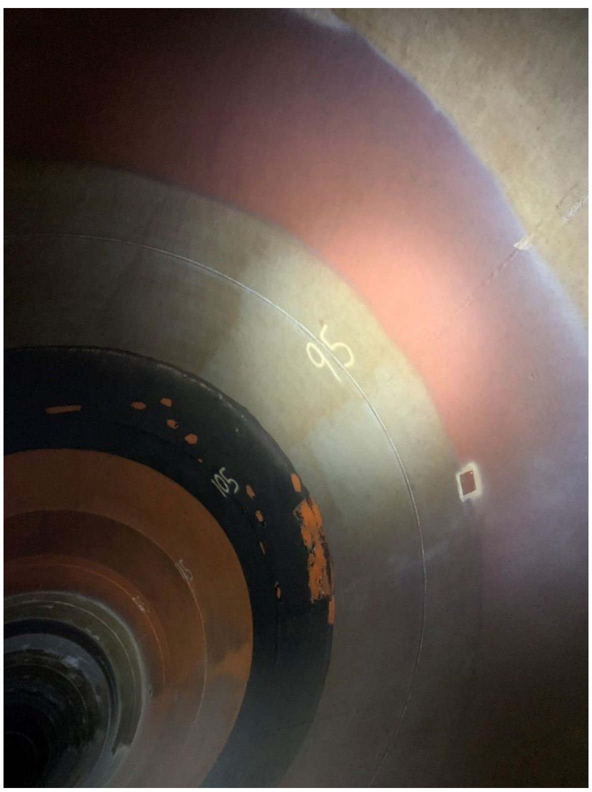

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14. ABSTRACT
Corrosion protection is fundamental to achieve infrastructure longevity. Coatings are the primary defense against corrosion. The Bureau of Reclamation began a field study in 1949 at Shasta Dam Unit 5 Penstock. Originally 26 different linings were installed in the field trial, seventy years later a detailed inspection was conducted in 2019, seven linings were still providing corrosion protection. Additionally in 2009, spot repairs were conducted due to failed coal tar enamel using a 100% solids epoxy and was in excellent condition after 10 years of service. Each lining was evaluated using Electrochemical Impedance Spectroscopy (EIS) to determine the barrier properties.

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Cover Photo: Historic linings in Shasta Unit 5 penstock.

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Shasta Dam Unit 5 Penstock - Historic Field Test Site

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Contents

Executive Summary

Corrosion protection is fundamental to achieve infrastructure longevity. Coatings are the primary defense against corrosion. The Bureau of Reclamation began a field study in 1949 at Shasta Dam Unit 5 Penstock [1] [2]. A total of 26 different lining systems were applied for the field trial. In 2019, seventy years later, a detailed inspection was conducted finding nine of the system were still providing corrosion protection. Additionally in 2009, spot repairs were completed using 100% solids epoxy due to failed coal tar enamel. The repair was in excellent condition after 10 years of service.

Each lining was evaluated using Electrochemical Impedance Spectroscopy (EIS) to determine the barrier properties. EIS can be a valuable tool when performed as part of a coating condition assessment, but EIS only provides localized information and this study showed there can be disagreement between a local impedance magnitude and the general condition determined by visual inspection. For example, the highest impedance magnitude from the 1949 field trial was CA-50, which had the worst visual appearance and should be considered for complete replacement. The increase in capacitive behavior at lower frequencies observed by EIS shows the formation of a stable oxide layer only observed when lead-based primers were applied directly to metal. The increased capacitive behavior was not observed when an oil-based primer or vinyl wash primer was used; only resistive behavior was observed in these systems. Some samples also showed two-time constants. Two-time constants typically indicate corrosion is occurring under the lining but could also mean that there are multiple layers of linings with different rates of diffusion.

The detailed inspection shows some of the lining systems have remaining service life after 70-years of service. However, EIS data show they are nearing the end of their useful service life due to the decrease in magnitude on impedance values and two-time constants. Some key takeaways from the research are as follows:

- EIS can be a useful tool to measure the electrical properties of linings.
- EIS magnitude can be as low as 10^4 without visible corrosion showing through the lining.
- Low impedance may indicate the presence of porosity that is not visible to the naked eye, however, porosity in one location does not mean that porosity persists throughout the entire lining. Some linings may have low impedance due to their inclusion of conductive materials but may still form a good barrier to ion transport.
- For lead-based paints, phase angles indicate increased capacitive behavior at low frequency which is most likely the result of a stable oxide layer forming as was observed with lead-based paints applied direct-to-metal.
- Caution should be used with EIS data, which can show adequate impedance magnitude despite the adjacent lining being damaged beyond repair, as seen in the CA-50 cold applied coal tar paint. Also, the small sample area of the cells may not represent the entire lining condition.

1. Introduction

Corrosion protection is fundamental to achieve infrastructure sustainability and optimized service life. Scientists at Reclamation conducted field trials at Shasta Dam Unit 5 Penstock in 1949 and at Collbran Project Salt Creek Siphon in 1959 to evaluate multiple linings for corrosion protection and erosion due to sediment loading [1] [2].

The Shasta Dam Unit 5 Penstock field trial evaluated 26 different experimental linings applied in a 160-foot (ft) section, shown in Figure 1. Vinyl and many of the other test linings were developed during or directly after World War II and had minimal service history in 1949. Figure 1 shows the test section layout as it was recorded in 1949. The test sections were inspected in 1957 and 1964. After eight years eight linings had an A rating, eight linings had a B rating, two linings had a C rating, and eight linings had a D rating [1]. The 15-year inspection found that seven linings remained an A rating, and four were a B rating. Class A or B rating: flame-sprayed polysulfide in section 3, two vinyl linings (VR3 and VR6) in sections 5 and 6; coal tar cutback (CA-50) in section 7; two phenolic red lead paints with and without two primer treatments (six total variations) in sections 8 and 8a, and a catalytic blown asphalt in section 20 [2]. Note that Section 8 contained zinc chromate and zinc oxide pigments in addition to red lead and Section 8A was lined with phenolic red lead, the report did not state that it was the Federal Standard TT-P-86a Type IV red lead. The lead-based paints were also sectioned off for a direct to metal application, oil-based primer section and a vinyl wash primer section.

Sometime after the 15-year inspection the linings in test sections 1-4 and 9-20 failed and were relined or were relined in 2009 during a maintenance contract. In 2009, repairs were made to the coal tar enamel lining throughout the penstocks using 100-percent solids epoxy. During this construction project, the contractor found the 1949 study was still on-going. In 2019, Reclamation coatings inspectors performed visual inspection of the remaining test linings and collected field electrochemical impedance spectroscopy (EIS) data on the remaining experimental linings and the 10-year-old 100-percent solids epoxy repair lining. Nine experimental linings remained in the study, [2] the visual inspection report stated they were in poor condition by visual inspection and as no longer providing adequate corrosion protection by EIS in 2019 [3]. However, the photos showed the linings to be in good condition, with minimal corrosion, no blisters, or flaking paint. Following the 1949 rating, the author would have given several of them a B rating, "Essentially performing the intended function, but showing slight deterioration and/ or minor defects." The remaining test linings in Figure 2 account for 55 ft of length within the original 160-ft test section.

The Shasta penstocks contain water most of the time, generating hydroelectric power with water velocities between 18-20 feet per second (ft/s). The exposure conditions are freshwater immersion with low percent dissolved solids ranging from 65-110 ppm. No sediment enters the penstock therefore, the linings are not subjected to erosive particulates.

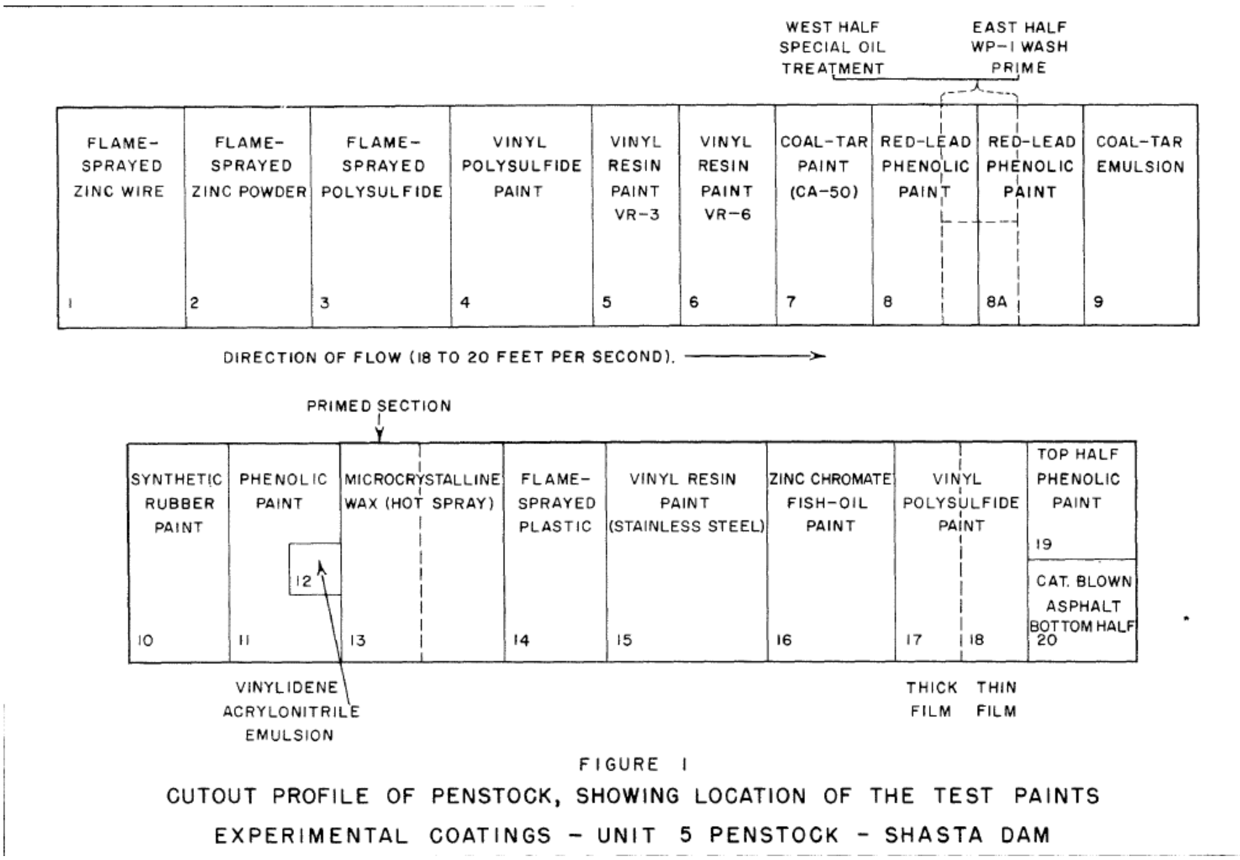

Figure 1. Test section layout in 1949, a total of 160 ft length

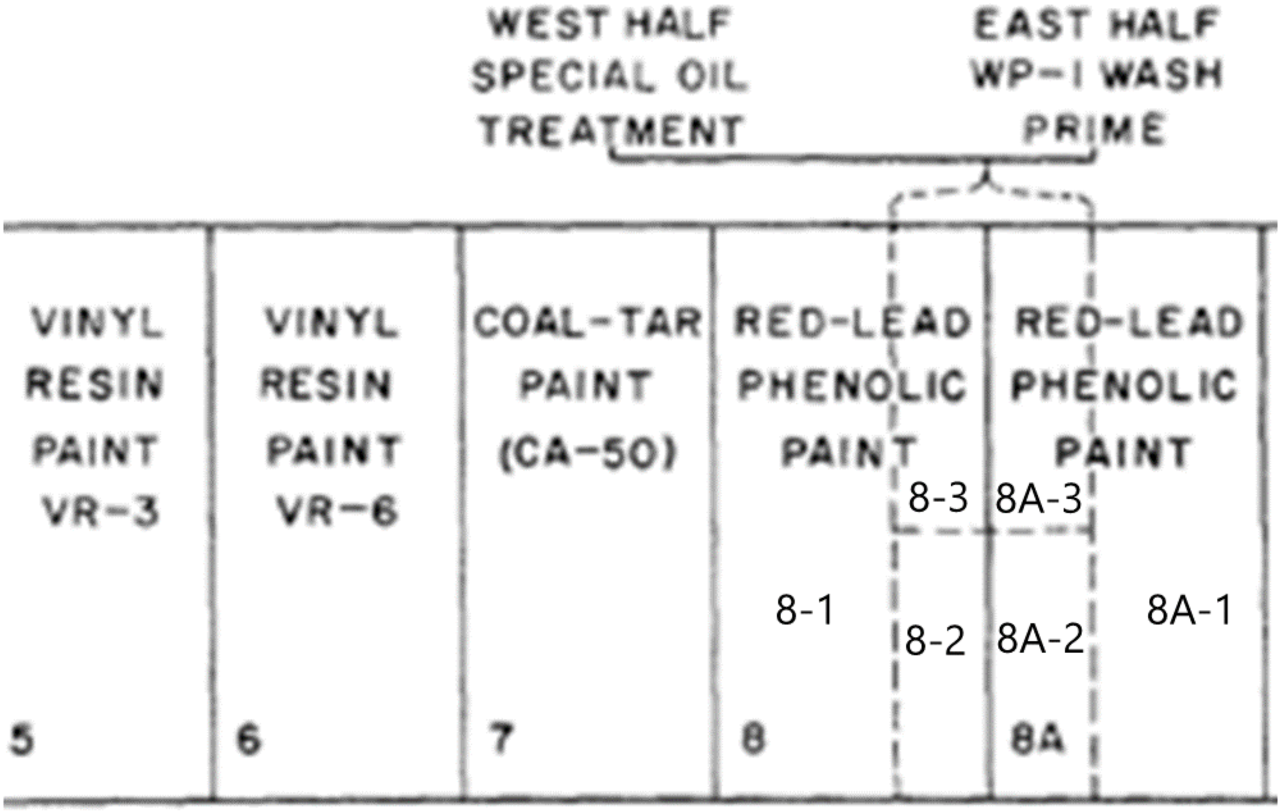

Figure 2. Remaining test sections: System 5 VR3, system 6 VR 6, system 7 CA-50 or CTE with red lead primer (uncertain if this was repaired after the other test materials 1-4, and 9-20 failed), red lead with chromate pigments system 8 was divided into 3 separate systems, and labeled ((8-1) direct to metal, (8-2) right side (west side) oil based primer), and (8-3) left side (East side) vinyl wash primer, and moving right phenolic red lead system 8A was divided into 3 separate systems, and labeled (additionally contains chromate inhibitor pigments) ((8A-3) left side (East side) vinyl wash primer, (8A-2) right side (west side) oil based primer, and, (8A-1) direct to metal).

2. Experimental Method

In 1949, steel pipe fabricators manufactured the test pipe from four 40-ft lengths of 15-ft diameter pipe. The exterior and interior of the test pipe sections were abrasive blast cleaned to a white metal condition [1]. The test pipe exterior, which is exposed to atmospheric conditions, was coated with red lead primer (TT-P-86a Type IV) and a phenolic aluminum topcoat (TT-V-81). The test pipe interior was lined with 26 experimental linings, each applied in accordance with their respective manufacturer's data sheets.

The October 2019 inspection marked 70 years of service for the nine remaining test linings [3]. A visual inspection was conducted which considered cracking, blistering, and percent corrosion. A quantitative inspection was performed using field electrochemical impedance spectroscopy (EIS). EIS measurements followed procedures outlined in report 8540-2019-03 Electrochemical Impedance Methods to Assess Coatings for Corrosion Protection [4]. Photos were used to correlate the lining system to the 1958 report to verify the EIS test cell location [1] [3].

Four 2-inch diameter cells were glued to the original linings using a silicone adhesive. Two cells were evaluated at any given time, three random measurements were taken alternating cells to provide an average impedance value at the test location. The open circuit potential (OCP) was measured prior to recording data. The DC amplitude of the applied voltage was set to 50 millivolts (mV) root mean squared. The EIS frequency range was set to 10^5 to 10^{-1} Hz, which is sufficient to expose the resistive and capacitive properties of the linings. EIS data collection was set to five points per decade to shorten the test duration.

3. Results and Discussion

3.1 Visual Inspection

Visual inspections can be a useful method for quickly determine if a lining is providing corrosion protection. Note that silt accumulation tends to obstruct and obscure the lining appearance. Surface contaminates were cleaned and removed in EIS test locations and in spots in the lower 1/3 of the pipe for improved inspections. It was not possible to remove any surface contaminates above the spring line due to accessibility and inspectors had to make best judgement on lining condition in these areas. In addition, the inspectors noted that subsequent spot and zone repairs were made in the penstock, including repairs in the experimental test area. These factors and the overall condition of the experimental liners made it difficult to determine with certainty which product was which. Best efforts have been made to identify the linings remaining in the study by color, listed in Table 1. Figure 3 shows the field test area with multiple-colored linings which indicate a different coating system. Visual observations showed the VR-3 (red), and VR-6 (gray) vinyl linings were in good condition with no blisters or other defects within the test sections. The coal tar CA-50 (black) lining was in poor condition with significant delamination and the primer was exposed. The lead-based paint (red-orange color) linings were in good condition. The remaining Unit 5 penstock was coated with coal tar enamel (black) and spot repaired with 100% solids epoxy (light gray) and both linings were in good condition.

Based on visual observations and following industrial standard guidelines, the coal tar CA-50 lining was the only lining in the 1949 field trial that was in poor enough condition to justify removal and relining. However, the primer for CA-50 is still in acceptable visual condition and is likely providing some corrosion protection, thus maintenance could be deferred. The remaining linings were in good condition and deferred maintenance is recommended.

Table 1 Shasta Unit 5 Penstock field trial coating systems remaining in study.

EIS Cell Labels	Coating System	Color	Visual Observations
S3 & S4	System 5 VR-3	Red	No blistering or corrosion present
S5 & S6	System 6 VR-6	Gray or White	No blistering or corrosion present
S7 & S8	System 7 CA-50 or CTE	Black with orange primer	Black lining has delaminated in several locations exposing the orange primer
S9	System 8-1 Phenolic red lead direct to metal	Red	No visible defects
S10	System 8-2 or 8A-2 Phenolic red lead with oil-based primer	Red	No visible defects
S11	System 8A-1 Phenolic red lead DTM	Red	No visible defects
S12	100-percent solids epoxy	Light Gray	No visible defects
S13-S15	Coal tar enamel	Black	No visible defects, black lining with drip and sags due to mopped application

Figure 3. Visual condition of all test systems 5-8. Red lining system 5 VR3, (section 95 in photo) gray lining system 6 VR 6, (section 105 in photo) black lining system 7 CA-50 or CTE with red lead primer, (between sections 115 and 125) red lead systems 8 and 8A looking down the pipe ((8-1) direct to metal, (8-2) right side (West side) oil based primer), and (8-3) left side (East side) vinyl wash primer, and moving down the pipe red lead system 8A (additionally contains chromate inhibitor pigments) (8A-3) left side (East side) vinyl wash primer, (8A-2) right side (West side) oil based primer, and, (8A-1) direct to metal)

3.2 Electrochemical Impedance Spectroscopy Results and Discussion

Vinyl lining VR3 (System 5) was evaluated using EIS with four different test cells as shown in Figure 4. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 5 shows VR3 was only 10^5 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior with two-time constants. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 4. Visual assessment of VR3 (System 5) and EIS test setup. Notice no corrosion or blisters after 70 years of service in 18-20 ft/s flowing water conditions.

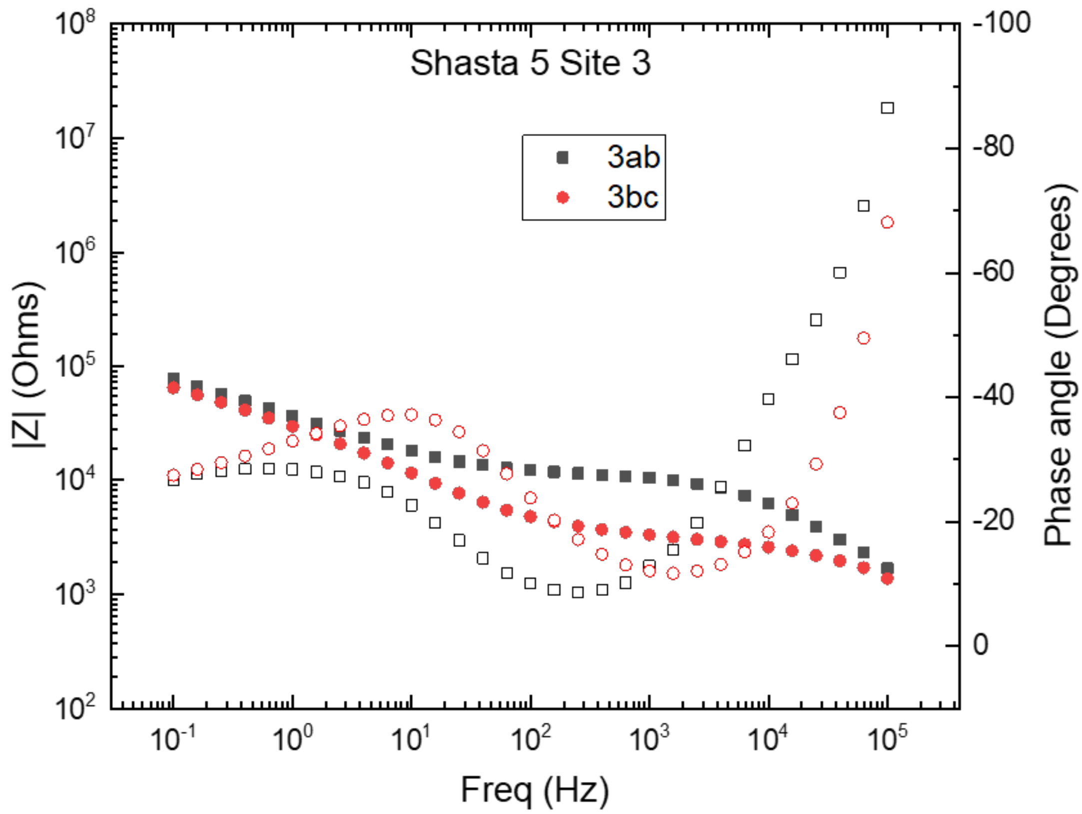

Figure 5. Typical EIS Bode plot of VR3 (System 5), the solid markers are the impedance magnitude.

Vinyl lining VR6 (System 6) was evaluated using EIS with four different test cells as shown in Figure 6. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 7 shows VR6 was only 10^5 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 6. EIS location S5, VR6 (System 6).

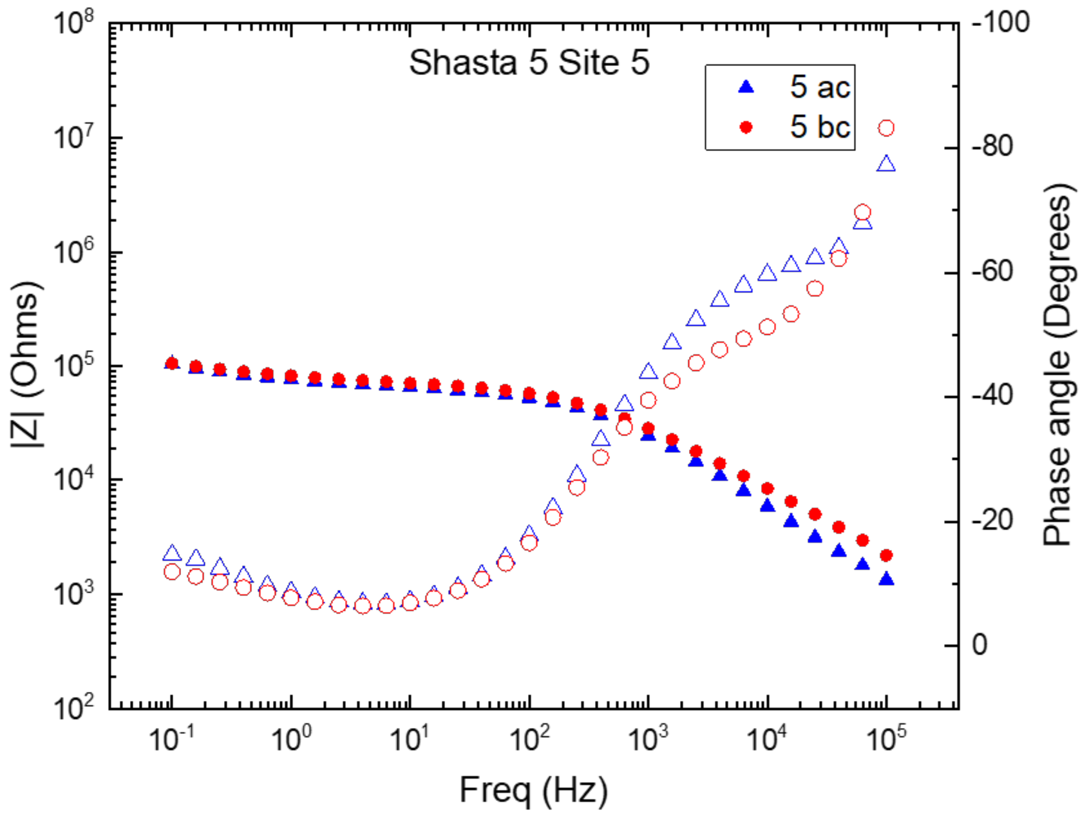

Figure 7. EIS Bode Plot VR6 (System 6)

Coal tar CA-50 (System 7) lining was evaluated using EIS with four different test cells as shown in Figure 8. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 9 shows CA-50 was only 10^6 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior with two-time constants. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 8. EIS location S7 coal tar CA-50 (System 7)

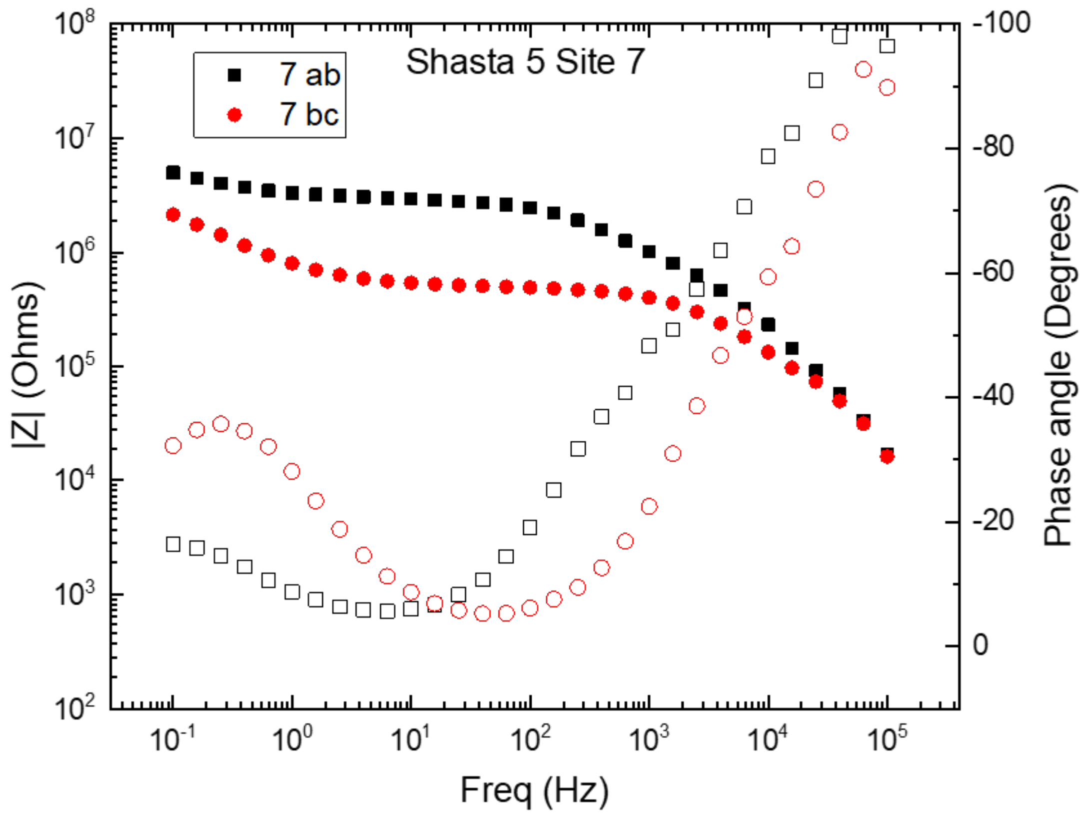

Figure 9. EIS Bode plot at S7 for coal tar CA-50 (System 7)

A second location of coal tar CA-50 lining was evaluated adjacent to the damaged area using EIS with four different test cells as shown in Figure 10. The photo shows exposed primer adjacent to the CA-50 lining. The Bode plot in Figure 11 shows CA-50 was 10^6 on one scan and two scans at 10^7 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior. CA-50 lining shows the highest impedance magnitude of all the linings from the 1949 field trial, while having the worst visual appearance. This may be since the EIS measurement was taken on an area where the coal tar lining was mostly intact. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 10. EIS location S8, Coal tar CA-50 (System 7) with adjacent exposed primer.

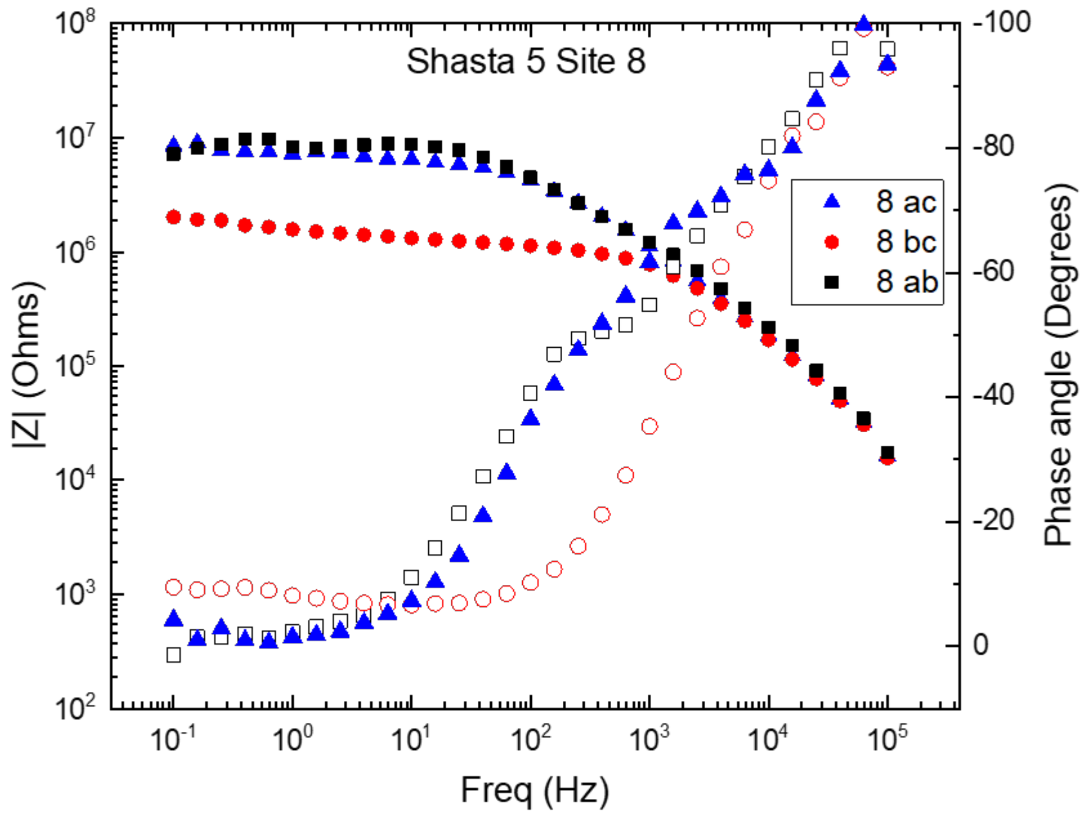

Figure 11. Bode plot of EIS location 8, coal tar CA-50 (System 7) adjacent to damaged coating with exposed primer.

Lead based paint lining with chromate inhibitive pigments (system 8-1) direct to metal was evaluated using EIS with four different test cells as shown in Figure 12. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 13 shows the system had one scan with 10^5 and two scans at 10^6 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior and the 10^5 scan also had two-time constants. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 12. EIS location S9, red lead with chromate inhibitive pigments direct to metal (System 8-1)

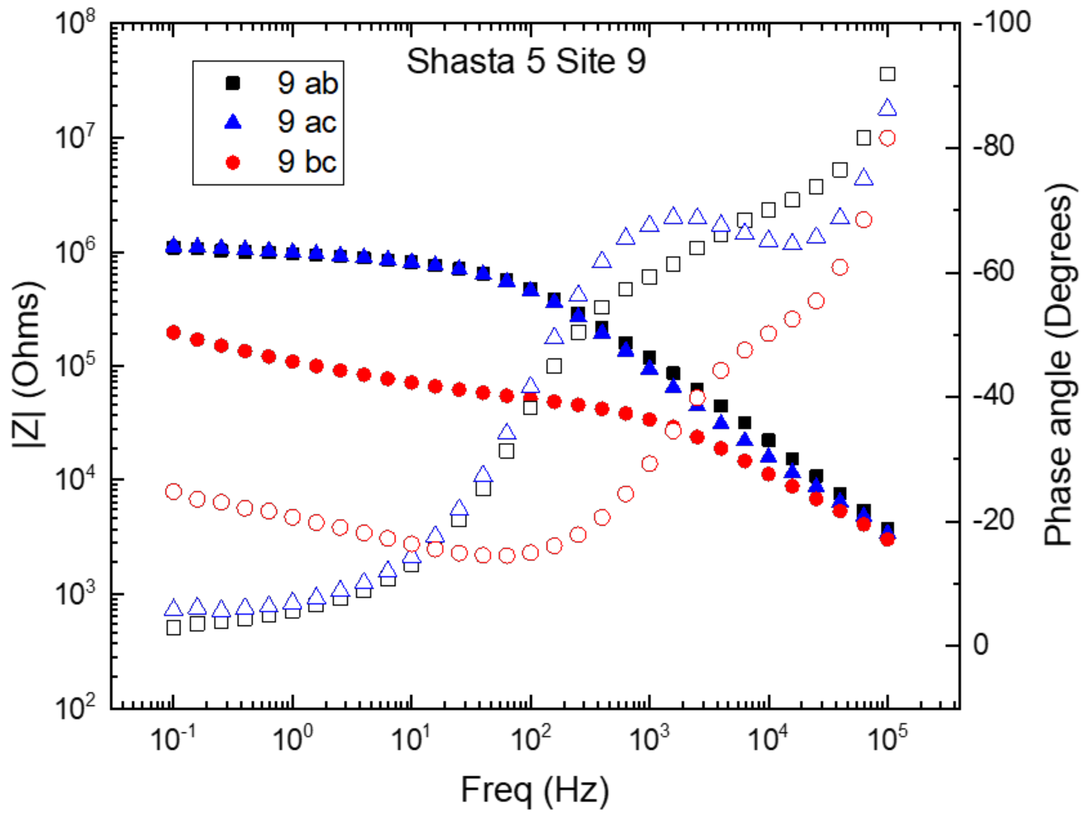

Figure 13. Bode Plot EIS location S9, red lead with chromate inhibitive pigments direct to metal (System 8-1)

Lead based paint lining with oil-based primer was evaluated using EIS with four different test cells as shown in Figure 14. It was too difficult to determine the exact location to determine if the topcoat was System 8 or 8A. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 15 shows the system was the lowest of all linings from the 1949 field trial at 10^4 at 0.1 Hz after 70 years of service. The phase angle shows resistive behavior with two-time constants. The two-time constants may indicate corrosion or a stable oxide layer under the coating.

Figure 14. EIS Location 10 red lead with oil-based primer, West side of pipe. It was too difficult from photos to determine if the topcoat was System 8 or 8A.

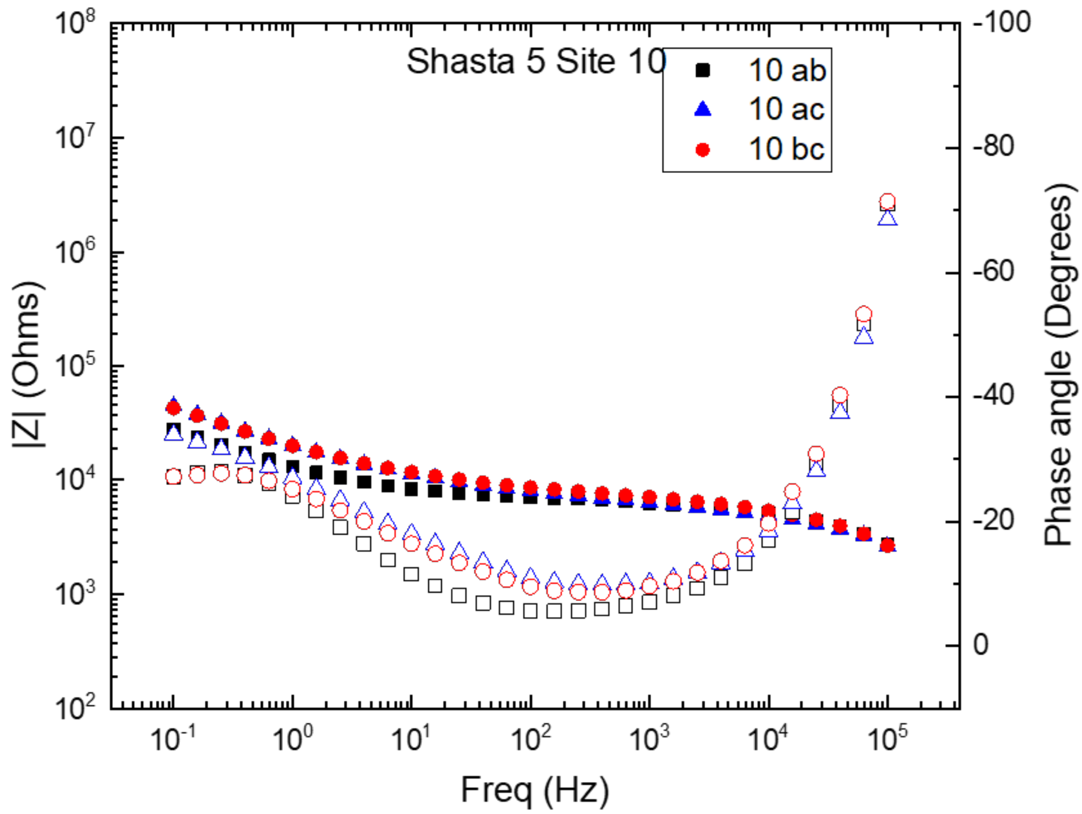

Figure 15. Bode Plot EIS location 10, Red Lead with oil-based primer.

Lead based paint lining applied direct to metal (System 8A-1) was evaluated using EIS with four different test cells at location S11 as shown in Figure 16. The photo shows no visible signs of coating damage or corrosion. However, the Bode plot in Figure 17 shows the system was the lowest of all linings from the 1949 field trial at 10^4 at 0.1 Hz after 70 years of service. However, the phase angle increases to more capacitive behavior to -45 or -50 degrees at low frequency with multiple-time constants. The increase in capacitive behavior may be the result of the formation of a stable oxide layer under the lead-based primers. The exact mechanism of how lead-based paints provided the stable oxide layer are debatable. Some of the most probable hypothesis is the formation of lead azelate salts which inhibits steel from corroding, or the deposition of metallic lead and will maintain the growth of the ferric oxide layer, the metallic lead acts as a catalyst [5][6].

Figure 16. EIS Location 11, System 8A-1 Direct to metal

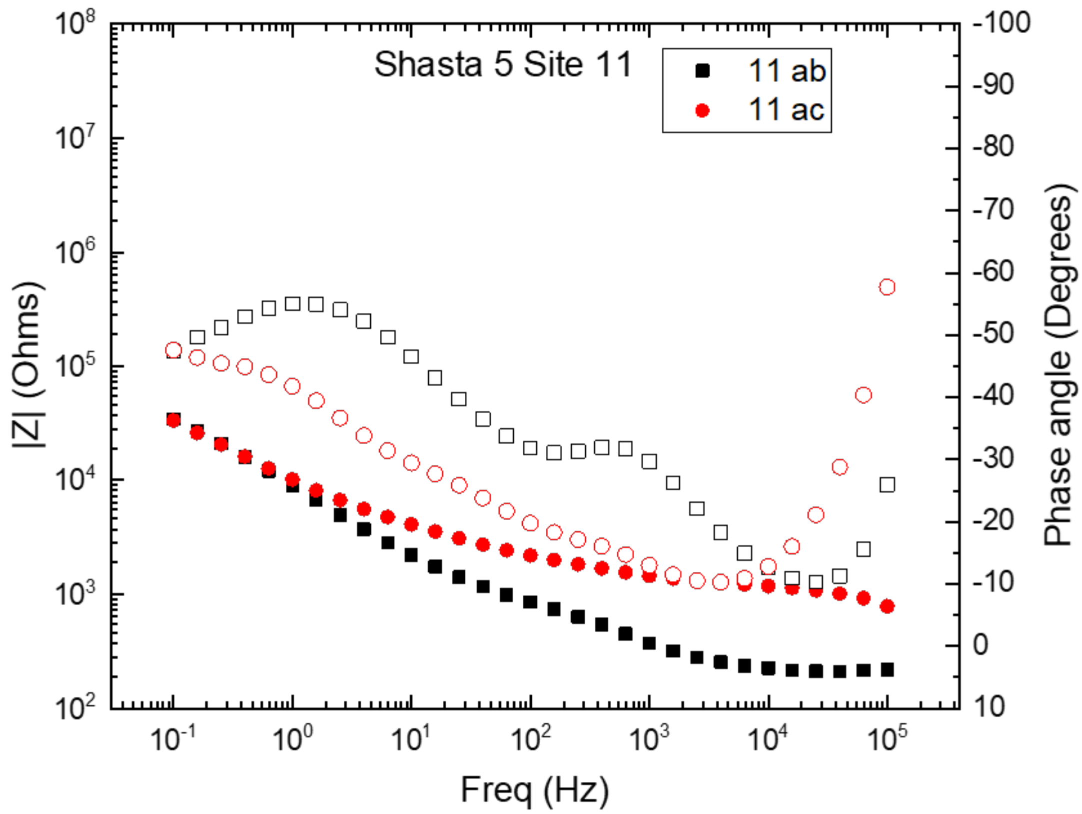

Figure 17. Bode Plot EIS location 11, Red Lead System 8A-1 direct to metal.

The 100-percent epoxy was a repair area during the 2009 contract. The 100-percent solids epoxy was evaluated using EIS with four different test cells as shown in Figure 18. The photo shows no visible signs of coating damage or corrosion. The Bode plot in Figure 19 shows the system has excellent barrier properties at 10^{10} at 0.1 Hz after 10 years of service. The phase angle shows capacitive behavior as its stays near -90 degrees. The noise in the plot is due to the lining barrier properties exceeding the limitations of the instrument.

Figure 18. EIS location S12, 100-percent solids epoxy.

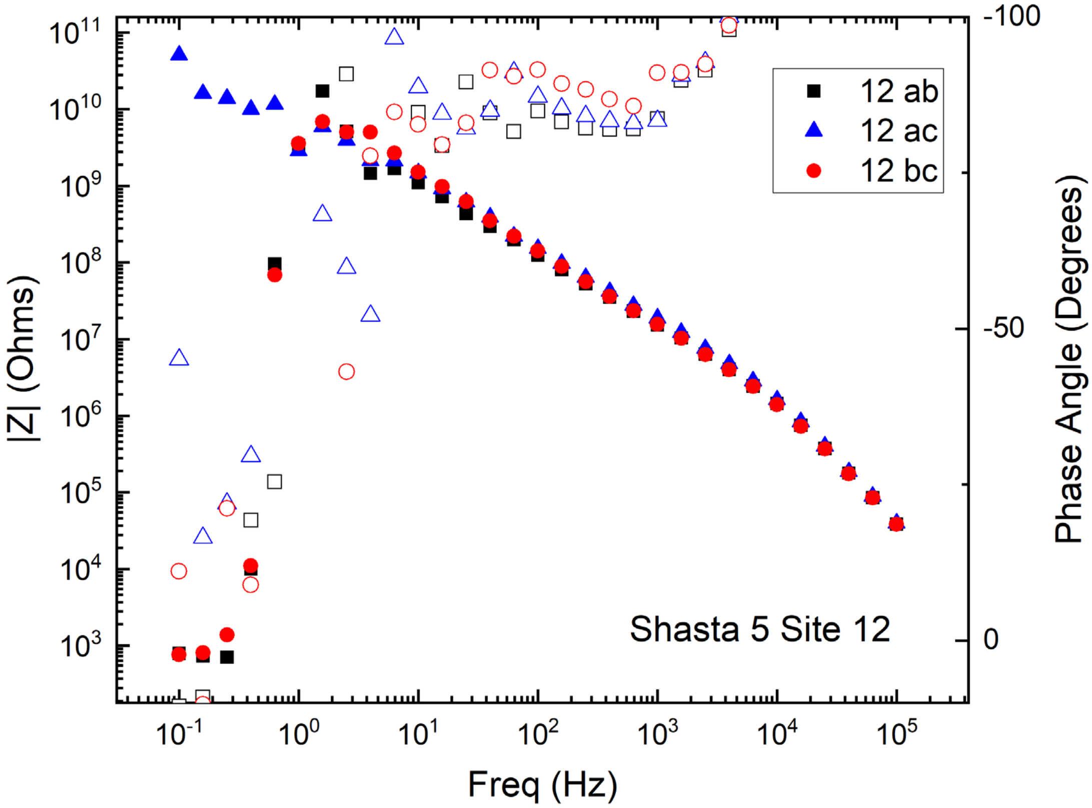

Figure 19. Bode Plot EIS location 12, 100-percent solids epoxy.

Coal tar enamel with a lead-based primer lining system was evaluated using EIS with four different test cells as shown in Figure 20. The photo shows some coal tar lining damage exposing the lead-based primer in some locations. The Bode plot in Figure 21 shows the system has low impedance magnitude at 10^4 at 0.1 Hz after 70 years of service. The phase angle increases to more capacitive behavior to -45 or -50 degrees at low frequency. The increase in capacitive behavior most likely is a result from the formation of a stable oxide layer under the lead-based primers. Even today, the exact mechanism of how lead-based paints provided the stable oxide layer is unknown. Some of the most probable hypothesis is the formation of lead azelate salts which inhibits steel from corroding, or the deposition of metallic lead and will maintain the growth of the ferric oxide layer, the metallic lead acts as a catalyst [5] [6].

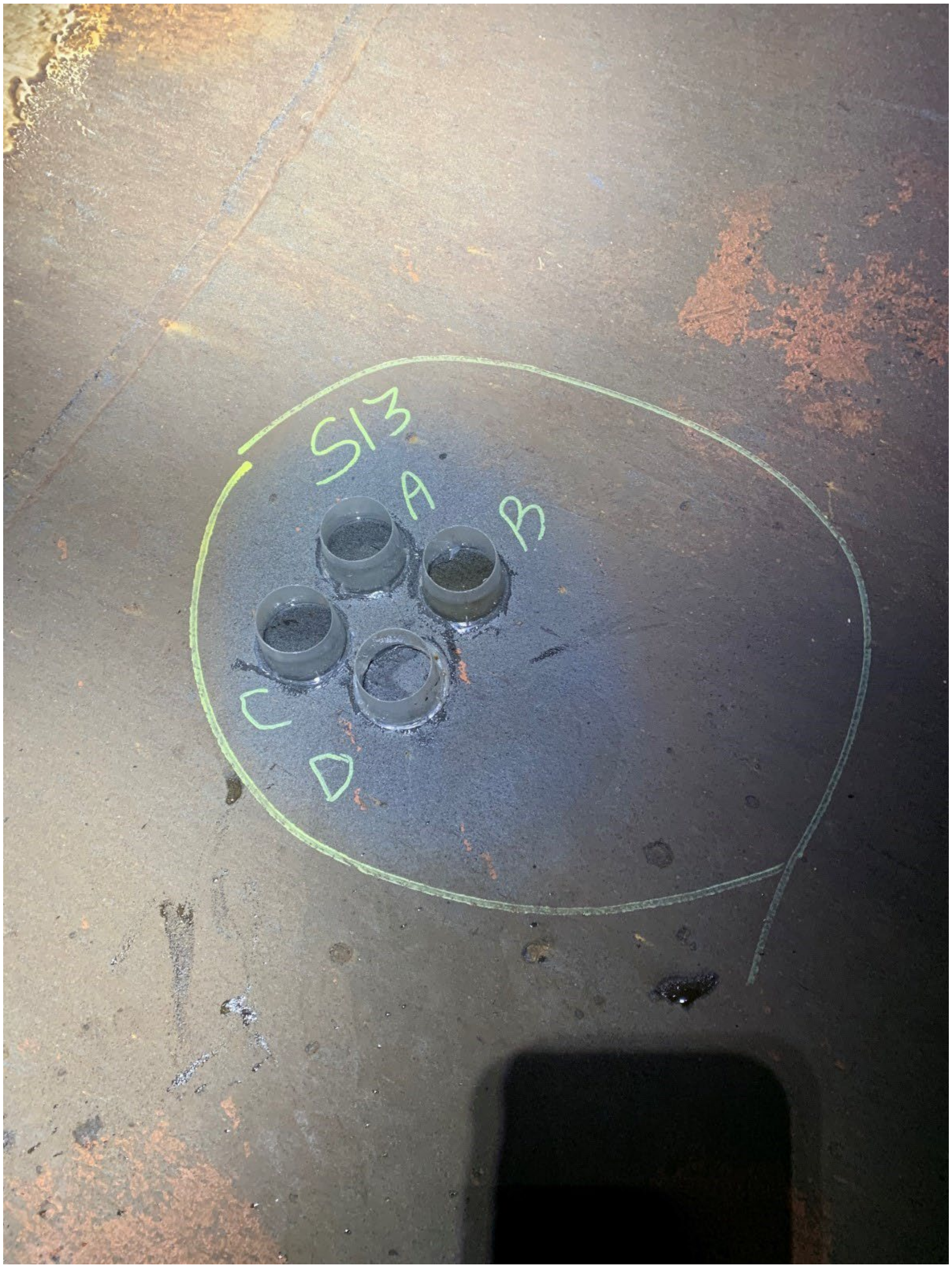

Figure 20. EIS location S13, coal tar enamel with lead-based primer

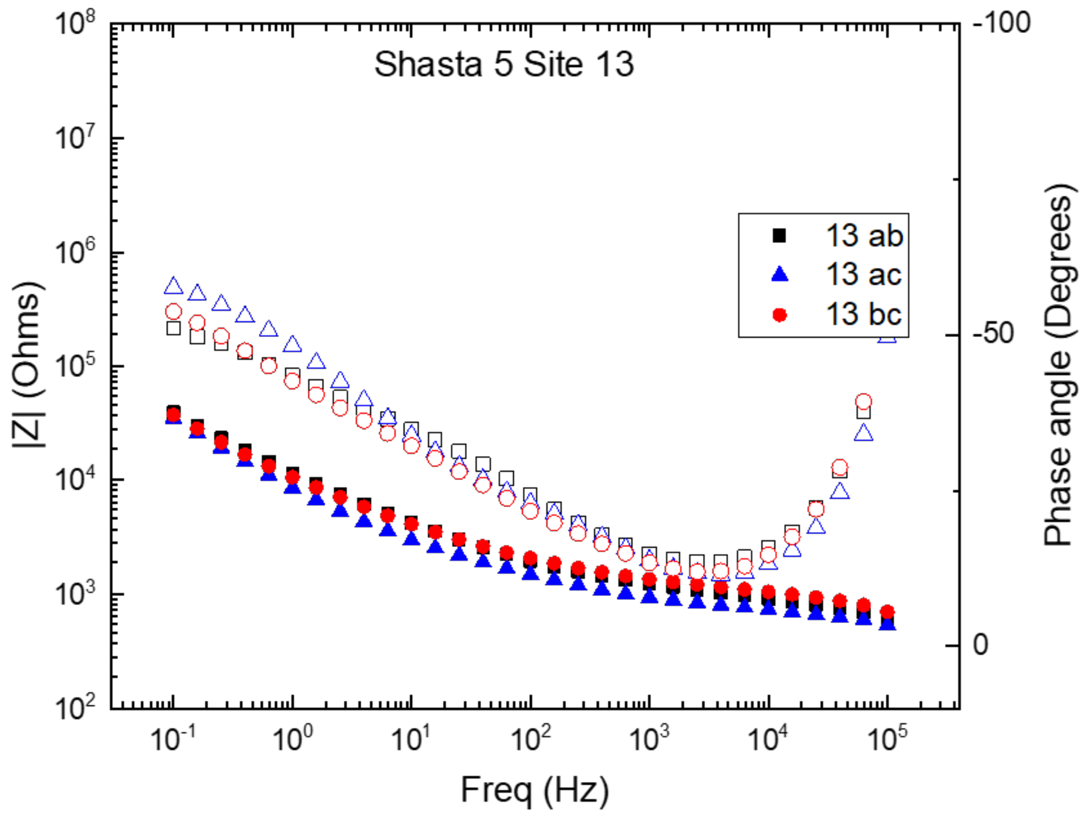

Figure 21. Bode Plot EIS location 13, coal tar enamel with lead primer.

The data shows that EIS is a valuable tool to do a quantitative inspection, but caution should be used since the highest impedance magnitude from the 1949 field trial was CA-50, which had the worst visual appearance and should be recommended for complete replacement. The increase in capacitive behavior at lower frequencies shows the formation of a stable oxide layer only observed when lead-based primers were applied directly to metal. The increased capacitive behavior was not observed when an oil-based primer was used, only barrier properties were observed with resistive behaviors and some samples also showed two-time constants. The data shows that a stable oxide layer did not form at the steel interface, due to the lead pigments not being in close enough to the steel. Two-time constants usually mean there is corrosion occurring under the lining but could also mean that there's multiple layers of lining with different rates of diffusion.

4. Conclusions

The detailed inspection shows some of the test materials provided 70 years of service, but the EIS data shows they are nearing the end of their useful service life. Some key take aways from the research are as follows:

- EIS can be a useful tool to measure the electrical properties of linings.

- EIS magnitude could be as low as 10^4 without visible corrosion showing through the lining.
- Low impedance may indicate porosity that you cannot see without a suitable microscope, however, porosity in one location does not mean that porosity persists throughout the entire lining. Some linings may exhibit low impedance if they are made of materials that are conductive (for example lead oxide converts to lead metal), but they may be continuous enough that form a good barrier.
- For lead-based paints, phase angles indicated capacitive behavior at low frequency most likely show a stable oxide layer forming as was observed with lead-based paints applied direct-to-metal.
- EIS data should not be relied on solely, because damaged lining can exist adjacent to a test cell with adequate impedance magnitude, as seen in the CA-50 cold applied coal tar paint. Also, the small sample area of the cells may not represent the entire lining condition.

References

[1] Paint Laboratory Report P-72, "Eighth Year Evaluation of Experimental Test Linings in Shasta Dam Penstock," Bureau of Reclamation , Denver, 1958.

[2] ChE 59 , "Fifteenth Year Evaluation of Experimental Test Linings in Shasta Dam Penstock Final Summary Report," Chemical Engineering Branch Bureau of Reclamation, Denver, 1966.

[3] 8540-2019-11, "Shasta Unit 5 Penstock Internal Inspection," Materials and Corrosion Laboratory, Denver, 2019.

[4] 8540-2019-03, "Electrochemical Impedance Methods to Assess Coatings for Corrosion Protection," Materials and Corrosion Laboratory Bureau of Reclamation, Denver, 2019.

[5] E. Kjoraas, The Protection Mechanism of Lead Based Paint, Trondheim: Norwegian University of Science and Technology, 2019.

[6] J. Mortensen, "Cavitation detection- Method development to detect damaging cavitation," Bureau of Reclamation. Hydraulics Investigations and Laboratory Services Group. Report HL-2017-10. , Denver, CO, 2017.