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MARINE PARK PARKING GARAGE CORROSION PROTECTION
REPORT ON EXISTING SYSTEMS
May 25, 1994

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I. AUTHORIZATION AND SCOPE OF SERVICES

On April 26, 1994, the City and Borough of Juneau issued a notice to proceed to KCM, Inc. to perform a review of the existing corrosion protection systems at the Marine Park Parking Garage. The services are to be performed under CBJ Contract No. E 94-263 and Purchase Order C.O. 00769.

The scope of services for this work is described under Task 1 to include:

1. Research, review and analysis of all existing as-built information and inspection reports.

2. Inspection of the existing galvanic- and impressed current-type foundation piling cathodic protection systems.

3. Submission of a report of findings and recommendations including options for restoring each system to full performance and life cycle cost estimates for each option.

Task 2, preparation of bid-ready drawings and specifications for upgrading the corrosion protection systems, may be authorized by amendment to the contract after CBJ review and acceptance of a design solution.

II. STUDY APPROACH

In order to complete Task 1, KCM performed the following work:

1. We assembled all information that the CBJ could provide relating to the original design and construction of the garage.

2. We reviewed the structural design calculations and construction documents used to construct the garage. Our review concentrated on identifying design elements that could be critically affected by corrosion. We did not perform a general review of the structural design for its adequacy.

3. We utilized the services John S. Tinnea & Associates (JSTA) to review and analyze the design and inspection reports on the existing cathodic protection systems.

4. Chris Birkeland, a structural engineer from KCM, and Jack Tinnea of JSTA inspected the structural elements that were protected by the corrosion protection systems previously installed. The inspections were both on foot in the intertidal area and by boat

in deeper areas. The inspections took place on April 29 and April 30 when low tides were -2.9 and -1.4, respectively.

5. During the inspections we utlized the services of Marion Hobbs Construction to perform underwater inspections on the systems. On April 29, he observed that the anode sleds installed in 1985 were buried approximately 1 to 2 feet in silty soil. He was unable to excavate the sleds manually, so after consultation with Ben Pollard of the CBJ, it was decided that Mr. Hobbs would return on April 30 with more equipment and labor to excavate one of the sleds.

6. On April 30, Anode Sled #1 (the southeastern sled) was excavated, raised, transported to the Intermediate Vessel Float, and removed from the water. On May 3, the individual anodes were weighed at the CBJ Building Maintenance shops.

7. During the inspections of April 29 and April 30, Mr. Tinnea energized the existing impressed current rectifier and took numerous electrical measurements at the structural elements protected by the original systems. He also inspected the two test stations for the underground galvanic systems.

8. On April 29, Mr. Birkeland and Mr. Tinnea also made a brief visual inspection of the upper decks of the parking garage for any evidence of cracking or corrosion.

III. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The results of our inspections and analysis of the existing systems are included in the appendices attached. A brief summary follows.

A. Conclusions

Structural Conditions:

1. There is no visible evidence of major structural damage to the facility due to corrosion. Among the visible steel foundation piles, there are numerous areas where loss of coating has occurred and a few areas where some loss of section has occurred.

2. The loss of section areas appear to be located at locations of welded connections used for construction (such as driving templates).

3. Inspection by boat was hampered by the presence of the old unused timber piles that were not removed during construction of the garage.

4. At least one of the "tie-back anchors" along the A and B grids appeared to be loose and was easily moved by hand. From the calculations provided we could not determine the function of these anchors or the degree of tension required.

5. The design calculations gave no indication of a corrosion allowance in the sizing of the piling.

Corrosion Protection:

1. The galvanic system may not have provided the protection anticipated because of the burial of the anodes that was observed during the underwater inspection of April 29.

2. The impressed current system failed because of corrosion of the anode cable to anode core connection. Substantial anode material still remained on Sled #1 removed on April 30.

3. Most of the coating system on the steel pilings is performing relatively well, except along the C.5 and D gridlines, where greater loss of coating was observed than in other areas.

4. The condition of the underground piling can only be estimated based on electrical measurements at the test station at pile group C-3. The magnesium anode shown on the design drawings at this location appears to be providing cathodic protection to the pile group.

B. Recommendations

Structural Conditions:

1. Remove existing unused timber piling.

2. Remove all existing construction items welded to steel piling, such as driving guides. Inspect piles for loss of section in weld areas.

3. Consult with original designer on the presence of any contingency or allowance for corrosion in the underground piling.

4. Consult with original designer on need for "tie-back anchors" and tighten loose rods to tension required by original design.

5. Visually inspect steel piles on annual basis. Remove marine growth from intertidal piles. Repair coating as recommended by the corrosion specialist or engineer.

Corrosion Protection:

1. Rehabilitate the cathodic protection system by installing a galvanic system employing six aluminum anodes designed for use in saline mud, equivalent to those specified in Appendix B.

2. Perform a thorough inspection soon after installation, using the services of a qualified corrosion specialist or engineer.

3. Monitor the system quarterly using CBJ personnel. Record the voltage across the shunts in the Level A junction boxes and the tide level at the time of the readings.

4. Perform a second thorough inspection approximately one year after installation of the anodes.

5. Preliminary estimates of costs are $11,880 for installation of the new galvanic system and $4,790 for the initial thorough inspection.

6. Obtain bids on coating rehabilitation of the C.5 and D piles in the splash zone (+15 to bottom of pile caps), and re-coat before corrosion begins to show loss of steel section.

7. Regarding the underground piling, continue to monitor the test station pile group C-3 on a quarterly basis. When the potential difference between the piling and the anode reaches 0.5V, the cathodic protection system for the underground piling should be rehabilitated. In addition, monitor other indicators of corrosion in the underground piles as described in Appendix B.

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MARINE PARK PARKING GARAGE CORROSION PROTECTION

APPENDIX A. STRUCTURAL CONDITIONS

I. DESIGN REVIEW

II. INSPECTION

III. CONCLUSIONS AND RECOMMENDATIONS

MARINE PARK PARKING GARAGE

CORROSION PROTECTION

APPENDIX A. STRUCTURAL CONDITONS

I. Design Review

The structural drawings and design calculations of piling foundations were reviewed to obtain information on the foundation features and which piling could least tolerate a corrosion loss. We did not review these documents for structural adequacy.

Piling driven eastward of Grid 7 are generally 12HP53 up to 50 feet in length. Maximum gravity load per H-pile is 148 kips. This load is acceptable as long as the soil layer above bedrock braces the pile against buckling, as assumed in design.

From Grid 7 westward, toward the channel, are 14HP73 up to 60 feet in length to bedrock. The soil/mud layer above rock varies from 30 feet at line 7 to 15 feet at Grid 9. Maximum gravity load per pile is 164 kips. The design assumes that the pile tip would be fixed against rotation when seated in bedrock. However, the pile driving records indicate penetration into rock of 3 to 6 inches at pile group B-9 where the load per pile is 137 kips.

In order to increase the allowable load capacity for the longer piles (which occur on Grids 8, 9, 9.7 and 10) a concrete wall was constructed to tie piles together from the pilecap down to elevation +5. These walls serve to reduce the buckling length in the weak axis direction.

Along Grids A and B, two prestressing rods run from the concrete deck at Grid 7 down to the mudline at Grid 9, and appear to have been intended to function as braces for the piles on Grid 9. These rods must be locked off under tension in order to function as a brace in each direction. We are uncertain about their intended function since no lock off load was specified on the drawings.

The design of the pile foundation is finely tuned and does not have any built-in conservatism. No allowance for corrosion losses were considered. Therefore, the cathodic protection system is a vital part of the parking facility and must be assured to function as intended.

II. Inspection

Several of the piles were inspected on April 29 with Chris Birkeland present. The next day, Don Beard and Jack Tinnea continued to completion.

Initial inspection was at low tide at pile group B-9 where also the anode sleds were to be found. Although the piles at this location looked bad with considerable rust and marine growth, it was found upon cleaning that occasional holidays in the pile coating had initiated corrosion which had "blossomed" out. Despite the disturbing appearance, no significant loss in section was found.

It was noted that corrosion was intensified where welds had been installed during construction. This may be due to loss of coating and stress concentrations due to welding heat.

The observation at B-9 appeared to be typical for other piling over water which support the garage (Grids A, B and C). The prestressing rods on Grids A and B which we believe should be taut, appeared to be loose and sagging.

Subsequent inspection at pile group A-6 revealed more intensive corrosion with flaking rust. Following removal of corrosion products, it was estimated that the surface loss was less than 1/16 inch. In addition, a pit of width 3/8 inch and depth 1/8 inch was formed in an area which had been welded.

Access for inspection was difficult because of a multitude of old unused timber piles and floating logs. Some wood formwork had been left in place and pile driving templates were still attached to piling.

III. Conclusions and Recommendations

1. Piling along the shore such as at A-6, appear to be more vulnerable to corrosive attack than piling in the water.

2. None of the garage piling (on Grids A, B and C) which we inspected, have experienced significant loss of section, even at pile group A-6.

3. The structural effects of corrosion to date is not of major concern.

4. The advance of corrosion over time can be watched at pile group A-6.

5. We recommend that unused piling, formwork and driving templates be removed to facilitate future inspections.

6. The piling should be inspected annually and a photographic record maintained to judge the advance of corrosion.

7. Piling with marine growth in the inter-tidal zone should be cleaned at the time of inspection. A high pressure water jet may be all that is needed.

8. At some future time, the piling should be recoated. A feasible paint system or water insensitive epoxy overlay may be identified now. Planning for this future work might include setting aside the funds required in the CBJ's maintenance budget.

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MARINE PARK PARKING GARAGE CORROSION PROTECTION

APPENDIX B. CORROSION PROTECTION

Prepared by John S. Tinnea and Associates

OVERVIEW

Constructed in 1984-1985, the subject facility's piling was electrically interconnected as a requirement of the design of two separate galvanic cathodic protection systems. One system provides protection to piles directly submerged in sea water and is provided by two galvanic anode sleds. These sleds employed aluminum anodes in a sea water operation design. A second galvanic system protects piles whose exposure is to the soil. The soil galvanic system uses magnesium anodes dispersed signally or in pairs at each of the pile clusters on grids 1 through 6.

Two distinct systems were required because the effective electrical resistivity of the soil differs markedly from that of Gastineau Channel. This inherent difference would make it very difficult to direct cathodic protection current if all of the piles were included in a common system. Electricity, like water, follows the path of least resistance. In a common system almost all of the cathodic protection current would go to the predominately marine piling and very little would go the predominately soil piling.

An armored cable ran from each sled to a junction box on the west side of the garage "A" level. A cable from the piling was run to a copper bus bar in each junction box. The copper wire from each sled was connected to its respective bus through a calibrated shunt to allow monitoring of the current each sled provided. The armor from each cable was directly connected to the bus to provide the steel cathodic protection in case the outer insulation was cut.

In sea water galvanic cathodic protection systems dissimilar metals are deliberately electrically connected. In essence a short circuited battery is formed. The armored cable is the short between the positive and negative terminals, and sea water is the electrolyte (battery acid).

The most electronegative metal, known as the anode, corrodes. and provides cathodic protection to the structure to be protected. The protected structure is polarized in a negative direction and becomes the cathode. Exceptional methods are not employed to avoid incidental exposure of other metals. If the steel core of the anodes or the copper wire of the connection cables is not coated and comes into contact with the sea water the galvanic difference between these metals and the aluminum will allow the aluminum to cathodically protect them as well as the piling.

Over the next few years the level of cathodic protection afforded by the galvanic system diminished. In 1990 Norton Corrosion Limited, Inc. (NCL) recommended "the galvanic anode system be converted to an impressed current system to fully protect the pilings." NCL is the firm that initially designed the cathodic protection system and had been inspecting the facility on an annual basis.

In 1991, NCL installed a constant current output rectifier to provide additional protective current. The piling network was connected to the rectifier's negative output terminal. The two cables from the galvanic anode sleds were connected to the positive terminal through the existing copper bus.

With impressed current cathodic protection a DC voltage is applied between an anode and the structure to be protected. Rectifiers are usually employed to do this. Those elements connected to the positive terminal and exposed to sea water are polarized in a positive direction by the impressed current flow and become anodes Elements connected to the negative terminal of the rectifier are polarized in a negative direction and become cathodes. Instead of using the battery metaphor, think of impressed current systems as battery chargers.

The applied voltage of impressed current systems is much larger than those resulting from galvanic differences. This being the case special care is usually taken to avoid incidental exposure of non-anode metals to the sea water. With the application of impressed current any exposed aluminum anode steel cores or copper wire will be polarized in a positive direction and become anodes and the natural galvanic protection afforded by the aluminum would be lost. As the cross-sectional area of the copper wire in the armored cables is small, it would not take much metal loss to break the wire and interrupt current flow to the much larger aluminum blocks on the sled.

When the rectifier was installed the armor was disconnected from the structure bus as it was found to be electrically connected to the aluminum anodes. Disconnection was necessary to avoid a direct short. As the armoring was connected to the anodes on the sled, that steel would become an anode at any location that insulation was lost.

The impressed current rectifier was turned on in October of 1991. Initial output was about 19 amps. The rectifier output was monitored by CBJ personnel on a monthly basis. A log of those readings shows 18 amps output was maintained through January of 1993.

Initial output voltage was 2 volts. In January of 1992 the voltage readings increased to 4 volts. For the remainder of the system's operation measured voltage outputs were as follows: 2 volts twice; 3 volts four times; 4 volts five times; 5 volts twice.

Sometime in February of 1993 the rectifier current output went to 0 amps.

In April of 1994 the subject facility was inspected by the team of KCM, Inc. and John S. Tinnea & Associates. The team was assisted in their inspection by a professional diver, Mr. Marion Hobbs. The findings and conclusions related to the cathodic protection systems and corrosion of the pilings appears below.

CONCLUSIONS

Marine Piling Galvanic System Underprotection

The galvanic cathodic protection system was initially designed to provide cathodic protection for a minimum of twenty years. The design was later revised to include a rectifier to impress a direct current upon the sleds in an effort to increase the level of cathodic protection afforded the piling.

In the Findings Section, below, calculations show that it would have been reasonable to expect about 4 amps initial output from each sled. The observed output was half that value. Output calculations were based upon the anodes being directly exposed to sea water. Inspection of the sleds showed both buried under about 2-feet of silt. The fact that the actual galvanic sled output was lower than calculated estimates is consistent with sled burial.

A sled located at the nearby Marine Park rests on the bottom and is not buried under silt. Sled burial of the Library Parking Garage may have resulted from too rapid lowering of the sleds during construction and/or from silt dispersal from prop-wash/bow-thruster action of vessels berthed at the west of the structure.

Marine Piling Impressed Current System Failure

The impressed current system failed as a result of corrosion of the anode cable-to-anode core connection. The majority of the aluminum anode material was not consumed through the galvanic and impressed current usage. Both sleds were in working order when the impressed current system was energized in 1991.

From calculations and a review of the rectifier output log it appears that the #2 sled connection failed in January of 1992 and the #1 sled connection failed in February of 1993. An attached sheet "Anode Consumption Calculations," provides the mathematical basis for this conclusion.

Soil Piling Cathodic Protection

The anode located at pile cluster C-3 is still providing protective current to the cluster piling (test station located on the floor of the Utility Room). Current readings were not taken because no shunts were installed in the test stations.

The three lead wires running to the test station located along the Level "A" interior wall appear to all run to the piling. No lead wire running directly to an anode is present in the test station.

Three of the 30 magnesium anodes installed were to be connected to the piling through shunts in floor mounted test stations (see details on NCL drawing CP-2). One possibility for what happened at the Level "A" interior wall test station is that the two anode lead wires were first thermite welded to the piling. To meet the requirements for test station "anode" lead two additional wires were connected to the piles near where the lead wires that run directly to the anodes had been welded. The intent of the specifications and drawings would have been met for these wires from the anode and test station were now shorted together through their respective pile.

Unfortunately, such logic misses the fact that all of the piles in a cluster are shorted together. This would leave us with the situation where the test station has three lead wires short circuited through piling, and no means to interrupt the circuit between the anodes and the piling.

If the scenario, or one similar, is indeed the case the piling would have been cathodically protected. However, we would have lost our ability to monitor the anodes' consumption.

Piling to soil potentials were not obtained. Both test stations only provide access to concrete, not the soil. Placing the reference cell at those locations would provide the potential of steel embedded in the adjacent concrete and not the potential of the piling in the soil below the structure. The adjacent planter also is not a reasonable location. Although it contains soil, that soil abuts reinforced concrete. Measurements would be the voltage, or potential, between a reference cell sitting on the planter soil and steel embedded in concrete not the piling in the soil below the structure.

RECOMMENDATIONS

Marine Piling Cathodic Protection System Rehabilitation

We recommend that the cathodic protection system be rehabilitated using a galvanic system employing six aluminum anodes. These anodes should be non-mercury bearing aluminum anodes designed for use in saline mud (Galvanium III™ aluminum-indium-zinc anodes or non-proprietary equal). The anodes should have a reference potential of -1.15V, Copper Sulfate Electrode (CSE), a consumption rate of 7.62 lb/amp-yr and an alloy efficiency of 85%. The anodes shall be "pipe-through" design, with 325 net pounds of available aluminum alloy. The anode geometry should be such as to provide a resistance, based on Dwight's Equation, of 0.21 ohms in 87.5 ohm-cm saline mud (American Corrosion Services, Inc. alloy ACS-4, drawing 2031B, or equal).

The anodes should be located at grid 9 on lines A, B, B.7 and C and at grid 10 on lines C.5 and D. From approximately 3-ft below the bottom of the pile caps to the silt line, the cable should be run along the web of the piles as shown in Detail Q, NCL Drawing CP-2.

The anode wire clips should be made of 1-inch x 1/8-inch galvanized mild steel flat stock. The clips should be bent to a block "U" shape as shown with lips of sufficient depth so that the cable will be fully enclosed by the clip-stud-web combination. The studs should be 3/8-inch -16 x 2-inch zinc plated. The studs should be welded to the center of the web using a stud welding system. The web ends of the studs should be free of zinc prior to welding. Surface preparation and welding should be performed in accord with relevant AWS specifications. The clips should be held in place with appropriately sized galvanized steel flat washers and nuts. Care should be taken in tightening the stud nuts to avoid any damage to the cable insulation. The anodes should have sufficient cable to allow their placement 10-feet from the closest pile.

Cables from the anode to the piles should be AWG# 4, armored. The existing cables should be used for anodes placed near pile clusters B-9 and B.7-9. Cables at other locations should have their upper end thermite welded to the pile in which they run. Required thermite welds should be made within 3-feet of the bottom of the respective pile cap and as shown in Detail N, NCL Drawing CP-2.

A galvanic cathodic protection system of this type would provide an estimated service life of over 30 years. A preliminary estimate of the cost to install this system and perform a thorough initial inspection would be $16.670. A thorough inspection means close proximity readings (reference electrode within 3-inches of the pile) on 5-foot intervals from the surface to the bottom for all free standing piles and at least one pile from each pile cluster from offset 7 through offset 11. Calculations, based on assumptions made below, give a system estimated life in excess of 30 years.

Monitoring of the anode consumption could be performed using the existing shunts in the junction boxes on the west side of the "A" parking level. It would be reasonable to assume that the anode consumption at all locations should be more or less equal, if the anodes are placed sufficiently remote from the piling. Using the existing cable for anodes at clusters B-9 and B.7-9 allows anode current output monitoring and refining of actual anode consumption rate. This is valuable in monitoring long life galvanic systems where the assumptions used to estimate life can differ substantially from actual conditions.

Quarterly readings by CBJ personnel would be quite valuable. It would require a digital volt meter with an input impedance of at least 1meg-ohm. Readings would be taken across the shunts in the level "A" junction boxes. The shunts are sized so that a DC voltage reading of 1 millivolt equals 1 amp of anode current output. The tide level at the time of the reading should also be recorded. The tide rule on the breasting dolphins could be easily used to obtain tide height.

A second thorough inspection of the system should be made by a corrosion professional approximately one year after installation. The cost for that inspection is estimated at $5,030. After that point quarterly readings would be continued by local forces, and that data is forwarded for review to a firm that is experienced in marine cathodic protection. That firm could report back to the owner estimates on the system life and could provide abbreviated inspections to verify the level of protection. NACE recommends that cathodic protection systems be inspected annually by personnel competent in cathodic protection.

As alternatives to the galvanic system described above, we considered a rack-mount galvanic system and an impressed current system, either of which would each provide an estimated service life of 20 years. First costs for both these systems were substantially higher than the silt mud galvanic system. Ongoing costs for the rack-mounted impressed current system would be the same as for the silt mud system. The impressed current system would require monthly monitoring of the rectifier panel meters, while annual inspections would require additional time and costs of around 10%. Further, impressed current cathodic protection will have ongoing power costs.

Soil Piling Cathodic Protection

Rehabilitation of the soil piling cathodic protection system will be required when the magnesium anodes are consumed. The piles involved on lines A through C are those from girds 1 through 6. For lines C.5 and D the piles are those extending from gird 1 to 6.5 and 7, respectively.

The initial design included the capability to monitor the current output of three magnesium anodes, or about 10% of the total. Today we are only able to monitor the anode located at cluster C-3. Further, the installation of a shunt would be needed to monitor current. No record exists of earlier anode consumption. Therefore, tracking that information at this date would be of limited value. The absence of a reasonable sample of historical anode current outputs makes projections based upon the present driving voltage of just one anode an educated guess.

There is not an existing design contingency for rehabilitating the galvanic soil cathodic protection system. A galvanic or impressed current cathodic protection system could be employed when the existing anodes are consumed. Soil resistivity measurements and determination of soil area pile cap-to-pile cap electrical continuity would be required to provide cost and system approach recommendations and design calculations. For rehabilitation pile cluster-to-cluster electrical continuity would be necessary.

Soil resistivity measurements and limited continuity measurements would require about 1½ field engineering days, or about $1400. Preparing cost and system approach recommendations would require about the same amount of time and expense. That work could be added to the scope of the marine system inspection, and save transportation expenses.

Previous experience gives an installed cost estimate of about $1000/anode for either impressed or galvanic systems. Preservation of architecture, that is avoiding patching or saw-cut installation of cable could add considerably to the cost. Having to electrically bond pile caps would require exposing piling and would also add expense.

We recommend that CBJ personnel monitor the electrical potential between the structure and the anode at cluster C-3. The test station for this location is located on the floor of the utility room near the facility entrance. Measurements should be made on a quarterly basis. We further recommend that CBJ follow-up on the rehabilitation system approach recommendations and secure a design to meet the recommendations. That design could be held back until monitoring indicates the anode has failed. At that time the design could be put out for bid.

A stylized drawing of the test station is shown in Detail M, NCL drawing CP-2. Two wires come up into the test station. The red wire is connected to the magnesium anode and test station terminal "R". The green wire is connected to the structure and test station terminal "G". There is a short piece of wire that runs from terminal "R" to terminal "G". This wire forms a short circuit between the two terminals, which connects the anode to the structure.

To measure the electrical potential between the anode and structure the panel must first be pulled up from the test station. A counter-clockwise turn may be needed to free the cast iron cover from the embedded body. The wire between the "R" and "G" terminal should be disconnected at one terminal and pushed aside. Turn the voltmeter to DC volt scale. Connect the negative lead of a voltmeter to the "R" terminal and the positive lead to the "G" terminal. The measured voltage should be around +0.7 volts. After taking the reading, re-connect the wire previously disconnected.

When the anode starts to fail, the electrical potential between the anode and the structure should become smaller. This reduction in potential can be used as a flag to start the impressed current system design through the CBJ request-for-proposal procedures. There is not a standard to employ in determining when that flag point has been reached. It is our opinion that when the potential difference between the anode and the piling drops below 0.5 volts, the system should be rehabilitated.

We emphasize that this procedure involves monitoring only 1 of 30 anodes. Further, the data obtained does not provide any information for future life prediction. It is simply tells us that there is some life left in the anode. If all soil piles were of equal length and had equal coating damage during driving, the anode being monitored would have a service life in the upper third of the anodes installed. Anodes at other locations would be expected to be consumed in much less time.

Consequently, other indicators, such as signs of structural distress or simply the passage of time, should be considered in determining the need for rehabilitation of the underground piling cathodic protection system. For example, if the test station at pile group C-3 indicates no sign of reduced effectiveness after 5 more years of use, the City should attempt to expose and inspect one of the underground groups to confirm the cathodic protection system's effectiveness. Pile group A-5 is somewhat accessible and would have a shorter service life than group C-3, if all pile length and coating damage were equal.

An even more conservative approach would be to expose pile group A-5 as part of the rehabilitation of the marine system. The piles could be inspected and a reference cell could be installed with separate lead wires from both that cell and the piling brought to a wall mounted test station. The installation and monitoring of such a test station would provide valuable information for the present and would become an integral part of future works. Permanent reference cells with manufacturer listed service lives of up to 30 years are available. Cost for such a reference, which can be installed in a 2" diameter hole is about $400. A water tight test station should be available for under $100. Add to these materials cost the cost to excavate the piling, thermite weld an AWG #10 wire to the piles and auger a hole for the reference. The hole should extend through the A-J fill five feet into the underlying glacial marine silt. A hollow stem auger, whose core provides the 2" diameter needed for the reference, could be used for installation.

Coating Rehabilitation

The cathodic protection system can only protect steel that is routinely submerged in sea water. The cathodic protection system will provide less corrosion protection to areas high in the tidal zone than the system provides to continually submerged areas. This is because the protective current must pass through the sea water while flowing from the anode to the piling.

Submerged anode cathodic protection systems cannot protect areas above high tide levels. This includes the splash zone that runs from highest high tide up 5 to 15 feet, depending on the area. First lines of defense in these areas include coatings or galvanizing. The library parking garage piling uses coal-tar epoxy coating for protection in the splash zone and to reduce cathodic protection current requirements in tidal and submerged areas.

The coating system for lines A through C is performing well. The coating on the newer C.5 and D lines is in poor condition. It is recommended that some remedial work be performed on the upper tidal and splash zone levels for these two lines (elevation +15 up to the bottom of the pile caps). By-the-numbers re-coating this area with coal-tar epoxy would be very expensive. Surface preparation, and keeping it dry, would be difficult. There are materials some manufactures claim can be successfully applied in this difficult environment. The CBJ should give consideration to obtaining bids for rehabilitating the coating on the C.5 and D line piles before significant loss of steel section occurs.

FINDINGS

Piling System

For line "A" through line "C" the coating condition was good, given its age. Observed corrosion, rust staining and metal loss was associated with localized coating defects. Only modest corrosion losses, < 1/16- inch, were observed for the steel piling from elevation -2 to the pile caps. Coating defects, and the related corrosion and staining, were observed in association with the flange tips (figure 1), pile driving template welding (figure 2) and with logs and timbers trapped in the piling network (figure 3). Rust staining was also observed associated with the concrete diaphragms located at elevation +5 and with web concreting extending from that elevation up to the pile caps (figure 4).

The coating system for lines C.5 and D was not performing as well as that employed in the other piles. Rust staining was much more prevalent, and not limited to local distressed areas. Corrosion metal losses, however, were modest.

The galvanized formwork under level "A" parking area is in excellent condition (figure 5).

Cathodic Protection System

Galvanic System Design

The galvanic cathodic protection system was designed for a service life of 20 years with each sled providing 5 amps output. Calculations for this would have followed something as:

Weight of aluminum per sled:	175#/anode x 4 anodes	=	700#
Combined anode efficiency & utilization:	95% x 85%		x 0.81
Net usable aluminum per sled:			565#

Aluminum anode consumption rate:	6.67#/amp-yr
Estimated sled current output:	x 4 amps
Estimated anode weight loss per year:	26.7#/yr
Estimated sled life:	20 years
Estimated anode weight loss per year:	x 26.7#/yr
Estimated total anode weight loss:	533#

Anode output calculations would have be estimated in a manner similar to the following:

Anode Resistance:

Water resistivity, ρ:	35 ohm-cm (a typical value for Alaskan coastal waters employed NCL at the time of design)
Initial radius[1] of anode, R1:	5.07 inches
Average radius[2], R2:	3.74 inches
Anode length, L:	24 inches
Initial weight of aluminum, W:	175 pounds

Resistance (from Dwight's Equation):

$$Resistance = \frac{\rho}{2\pi L}\left[\ln\left(\frac{4L}{R}\right)-1\right]\left(\frac{1\,\text{in}}{2.54\,\text{cm}}\right)$$

Initial anode resistance:	0.44 ohms
Average anode resistance:	0.51 ohms
De-rating for sled congestion:	20%
De-rated initial resistance:	0.53 ohms
De-rated average resistance:	0.62 ohms

Driving Voltage:

Pre-cathodic protection pile potential[3]:	-0.61V, CSE
Cathodically protected pile potential:	-0.90V, CSE
Anode potential[4]:	-1.15V, CSE

Driving voltage: *Driving Voltage = pile potential - anode potential*

Initial driving voltage:	0.54V
Protected driving voltage:	0.25V

Anode Output:

Anode output:

$$anode\ output = \frac{driving\ voltage}{anode\ resistance}$$

Initial single anode output:	1.02 amps
Protected single anode output:	0.40 amps
Initial per sled output:	4.04 amps
Protected per sled output:	1.60 amps

[1] Cylindrical equivalent of trapezoidal anode, $R = \sqrt{\frac{crossection\ area}{\pi}}$.

[2] Radius when anode one-half consumed

[3] Base on those values observed 4/29 and 4/30/94.

[4] Mfr. published value.

Anode Sleds

Both sleds were buried in about 2 feet of silt deposit. The cables to both anode sleds have failed at their connection to the anodes on the sleds (figure 6). Sled #1 of NCL Drawing CP-1 was removed from the water and inspected on land.

The sleds were not fabricated as shown in Detail Q of NCL Drawing CP-2. No steel bus bar was used. Rather the AWG# 4 armored cable was connected to the steel pipe core of one of the four anodes by a thermite weld. Three additional short pieces of AWG# 4, HMW/PE wire replaced the steel bus. The cables run from anode-to-anode on each sled in a "daisy-chain" of steel anode cores, thermite welds and wire (figure 7).

The majority of aluminum anode material had not been consumed. Figure 8 shows the sled with an exterior anode set to the side of the sled itself. Figure 9 shows an end view of an interior anode. The four anodes were weighed and the results are reported on the attached data sheet. Note in the photos and from the measured weights that the exterior anodes were more heavily consumed than the interior anodes.

Rectifier

The rectifier is a Goodall Electric Company "Jemco" constant current type. It is air cooled, and uses a silicon single phase bridge to convert 240VAC input to a maximum dc output voltage of 36VDC and 60 amps. Its typical output was 18 amps at 3.4 volts, or a circuit resistance of 0.2 ohms. The rectifier was inspected, used in current demand testing and appears to be in good operating condition. Measurements taken during this inspection appear on the attached data sheet.

When testing was completed the anode lead wire was disconnected from the positive terminal, covered with several half-laps of electrical tape and tucked back into the rectifier chassis. The rectifier power switch was turned off, as was the circuit breaker leading to the rectifier.

Rehabilitation Cost Analysis

Assumptions:

Water resistivity:	35 ohm-cm
Silt mud resistivity:	88 ohm-cm
Current to polarize piles to -0.90V, CSE[5]	15 amps

Galvanic Anodes in Mud (aluminum-indium-zinc alloy)

Materials:

ITEM	UNIT COST	UNITS	COST
Anodes (6 ea. 325# aluminum)	$325/ea	6 ea	$1,950
Cable (AWG# 4, HMW/PE Type CP)	$1/ft	3 cft	$300
Anode/cable connector	$25/ea	6 ea	$150
Cadwelds (1box of 20, mold, igniter)	$100/set	1 set	$100
Mastic/low temp melt Zn/At sticks	$25/pile	6 piles	$150
Cable Clips & Studs	$100/ls	1 ls	$100
Work boat	$500/wk	1 wk	$500
Stud welder	$175/wk	2 wks	$350
Misc. materials	$100/ls	1 ls	$100
		MATERIALS TOTAL	$3,700

[5] Current requirement based of NCL data of galvanic and impressed current performance.

Labor:

ITEM	UNIT COST	UNITS	COST
Per anode set-up	$50/hr	4 hrs	$200
Per anode stud welding	$50/hr	2 hr	$100
Per anode cable prep	$50/hr	4 hr	$200
Per anode running cable/cadweld	$50/hr	2 hr	$100
		SUBTOTAL	$600
		x 6 anodes	x 6
		LABOR TOTAL	$3,600
		MATERIALS	$3,700
		LABOR	$3,600
		MOBILIZATION	$1,500
		SUBTOTAL	$8,800
		CONTINGENCY (20%)	$1,760
		PROFIT(15%)	$1,320
		TOTAL	$11,880

Galvanic Anodes Mount on Racks (aluminum-indium-zinc alloy)

Materials:

ITEM	UNIT COST	UNITS	COST
Anodes (4 ea. 325# aluminum)	$325/ea	4 ea	$1,300
Cable (AWG# 4, HMW/PE Type CP)	$1/ft	2cft	$200
Anode/cable connector	$25/ea	4 ea	$100
Cadwelds (1box of 20, mold, igniter)	$100/set	1 set	$100
Mastic/low temp melt Zn/At sticks	$25/pile	4 piles	$100
Cable Clips & Studs	$100/ls	1 ls	$100
Racks to mount anodes	$250/ea	4 ea	$1,000
Concrete to found racks	$100/ls	1 ls	$100
Work boat	$500/wk	1 wk	$500
Stud welder	$175/wk	2 wks	$350
Misc. materials	$100/ls	1 ls	$100
		MATERIALS TOTAL	$3,950

Labor:

ITEM	UNIT COST	UNITS	COST
Per anode set-up	$50/hr	4 hrs	$200
Per anode stud welding	$50/hr	2 hr	$100
Per anode cable prep	$50/hr	4 hr	$200
Per anode running cable/cadweld	$50/hr	2 hr	$100
		SUBTOTAL	$600
		x 4 anodes	x 4
		SUBTOTAL	$2,400
Dive time to dredge rack location	$175/hr	2 hrs	$350
Dive time to tremie concrete	$175/hr	1 hr	$175
Dive time to set rack	$175/hr	1 hr	$175
Dive time to set anode	$175/hr	1 hr	$175
		SUBTOTAL	$875
		x 4 anodes	x 4
		SUBTOTAL	$3,500
		LABOR TOTAL	$5,900

MATERIALS	$3,950
LABOR	$5,900
MOBILIZATION	$1,500
SUBTOTAL	$11,350
CONTINGENCY (20%)	$2,270
PROFIT(15%)	$1,700
TOTAL	$15,320

Impressed Current Anodes (Pile Mounted)

Materials:

ITEM	UNIT COST	UNITS	COST
Anodes (Morganodes & Hardware)	$3600/ea	4 ea	$14,400
Cable Clips & Studs	$100/ls	1 ls	$100
Mastic/low temp melt Zn/At sticks	$25/pile	4 piles	$100
Work boat	$500/wk	1 wk	$500
Stud welder	$175/wk	2 wks	$350
Misc. materials	$100/ls	1 ls	$100
		MATERIAL TOTAL	$15,550

Labor:

ITEM	UNIT COST	UNITS	COST
Per anode set-up	$50/hr	4 hrs	$200
Per anode stud welding	$50/hr	2 hr	$100
Per anode cable prep	$50/hr	4 hr	$200
Per anode running cable/cadweld	$50/hr	2 hr	$100
		SUBTOTAL	$600
		x 4 anodes	x 4
		SUBTOTAL	$2,400
Dive time to set Morganode	$175/hr	4 hrs	$700
		SUBTOTAL	$700
		x 4 anodes	x 4
		SUBTOTAL	$2,800
		LABOR TOTAL	$5,200

MATERIALS	$15,550
LABOR	$5,200
MOBILIZATION	$1,500
SUBTOTAL	$22,250
CONTINGENCY (20%)	$4,450
PROFIT(15%)	$3,340
TOTAL	$30,040

IN 1994!

KCM, Inc.
City/Borough of Juneau
Marine Park Parking Garage

System Initial Inspection SITE inspection

Labor:

ITEM	UNIT COST	UNITS	COST
Survey marine piles @ 5' intervals, surface to bottom			
Engineer	$95/hr	16 hrs	$1520
Assistant	$50/hr	16 hrs	$800
Adjust output (if required)	$95/hr	4 hr	$380
Check soil protected system	$95/hr	4hr	$380
Write Report	$95/hr	8 hr	$760
		LABOR TOTAL	$3840

Expenses:

Per diem	$150/dy	3 dys	$450
Travel costs	$500/ea	1 ea	$500
		EXPENSES TOTAL	$450
		+ TOTAL	$4790

THE CITY/BOROUGH OF JUNEAU
Data Sheet No. 1
April 29 - 30, 1994
By: J. Tinnea, D. Beard, C. Birkland

PILE-TO-WATER POTENTIALS

April 29, 1994
Zinc Reference Calibration to Silver-Silver Chloride Standard: -0.950V

NOTE: Potential obtained in as found condition, no cathodic protection from any source.

LOCATION	DISTANCE FROM SURF	POTENTIAL, V Zinc	CuSO4	LOCATION	DISTANCE FROM SURF	Potential, V Zinc	CuSO4
B-9 (SW)	surf	+0.385	-0.615	B-9 (SW)	surf	+0.390	-0.610
web	-5ft	+0.390	-0.610	W. flange	-5ft	+0.390	-0.610
S. face	-10(bot)	+0.395	-0.605	W. face	-10(bot)	+0.395	-0.605

April 30, 1994
Zinc Reference Calibration to Silver-Silver Chloride Standard: -1.037V

NOTE: Potentials obtained with rectifier on and applying 4 amps through dolphins.

LOCATION	DISTANCE FROM SURF	POTENTIAL, V Zinc	CuSO4	LOCATION	DISTANCE FROM SURF	POTENTIAL, V Zinc	CuSO4
A-9 (NW)	surf	+0.348	-0.739	B-8 (SE)	surf	+0.364	-0.723
web	-5ft	+0.342	-0.745	web	-5ft	+0.370	-0.717
N. face	-10	+0.336	-0.751	S. face	-8.5(bot)	+0.374	-0.713
	-15(bot)	+0.334	-0.753				
B.7-9(SE)	surf	+0.386	-0.701	C-10	surf	+0.444	-0.643
web	-5ft	+0.392	-0.695	web	-5ft	+0.447	-0.640
S. face	-9(bot)	+0.391	-0.696	W. face	-10	+0.441	-0.646
					-15(bot)	+0.455	-0.632

NOTE: Off potentials obtained with rectifier off about 1/2 hour. On potentials obtained with 6 amps applied.

LOCATION	DISTANCE FROM SURF	"OFF" POTENTIAL, V Zinc	CuSO4	"ON" POTENTIAL, V Zinc	CuSO4	POTENTIAL SHIFT
C.5-11	surf	+0.410	-0.677	+0.389	-0.698	-0.021
E. web	-5ft	+0.410	-0.677	+0.386	-0.701	-0.024
S. face	-10	+0.409	-0.678	+0.384	-0.703	-0.025
	-15	+0.409	-0.678	+0.384	-0.703	-0.025
	-20(bot)	+0.409	-0.678	+0.384	-0.703	-0.025

LOCATION	DISTANCE FROM SURF	"OFF" POTENTIAL, V Zinc	CuSO4	"ON" POTENTIAL, V Zinc	CuSO4	POTENTIAL SHIFT
D-11	surf	+0.460	-0.627	+0.438	-0.649	-0.022
E. web	-5ft	+0.461	-0.626	+0.439	-0.648	-0.022
S. face	-10	+0.462	-0.625	+0.438	-0.649	-0.024
	-15	+0.460	-0.627	+0.435	-0.652	-0.025
	-20(bot)	+0.458	-0.629	+0.422	-0.665	-0.036

RECTIFIER MEASUREMENTS

Rectifier found turned off:

AC input:	212VAC
DC back voltage:	-0.115VDC, "-" to piling
Pwr gnd to piling:	-0.117VDC, "-" to gnd

Rectifer turned on with as found settings:

Panel meter:	40VDC, 0A
Portable meter:	42.9VDC, 0.32A

TEST STATION MEASUREMENTS

Level "A" wall:

-	+	Reading
1	2	-0.3mV
1	3	0.0mV
2	3	+0.4mV

Utility Room:

-	+	Reading
red	grn	+0.694VDC
Pwr gnd	red	-0.814VDC (red anode)
Pwr gnd	grn	-0.116VDC (grn piles)

ANODE CONSUMPTION CALCULATIONS:

Assumptions:

Aluminum nominal consumption rate = 6.67lbs/amp-year

Galvanic Consumption (Mar 1985 through Oct 1991 – 6 years, 7.5 months)

1.93 amps	Average per sled output[1]
x 6.63 years	Time applied
12.81 amp-years	Total output
x 6.67 lbs/amp-yr	Consumption rate
85 lbs	Weight consumed by galvanic service

Impressed Current Consumption (Nov 1991 through Jan 1993 – 1 year, 3 months)

Estimate based upon both sleds failing in Feb '93:

9.05 amps	Average per sled output[2]
x 1.25 years	Time applied
11.31 amp-years	Total output
x 6.67 lbs/amp-yr	Consumption rate
75 lbs	Weight consumed by impressed current

Estimate based upon one sled failing in Jan '92 and the other in Feb '93:

9.05 amps	Average per sled output[2]
x 0.17 years	Time applied
1.51 amp-years	Paired sled output
18.04 amps	Average total output[3]
x 1.08 years	Time applied
19.54 amp-years	Single sled output
21.05 amp-years	Total impressed output
x 6.67 lbs/amp-yr	Consumption rate
140 lbs	Weight consumed by impressed current

Gavanic	+	Impressed	=	Total	
85 lbs	+	75 lbs	=	161 lbs	Estimated total weight loss (mutal failure in Feb '93)
85 lbs	+	140 lbs	=	226 lbs	Estimated weight loss (single sled since Jan '92)

Nominal	-	Measured	=	Total	
820 lbs	-	575 lbs	=	245 lbs	Weight loss measured May '94

1. Average of all sled galvanic outputs reported by Norton, 1985-1991
2. One-half of the average of the measured total impressed current output for period in question
3. Average of the measured total impressed current output for period in question

MARINE PARK PARKING GARAGE CORROSION PROTECTION

APPENDIX C. INSPECTION PHOTOGRAPHS

figure 1

figure 2

figure 3

figure 4

figure 5

figure 6

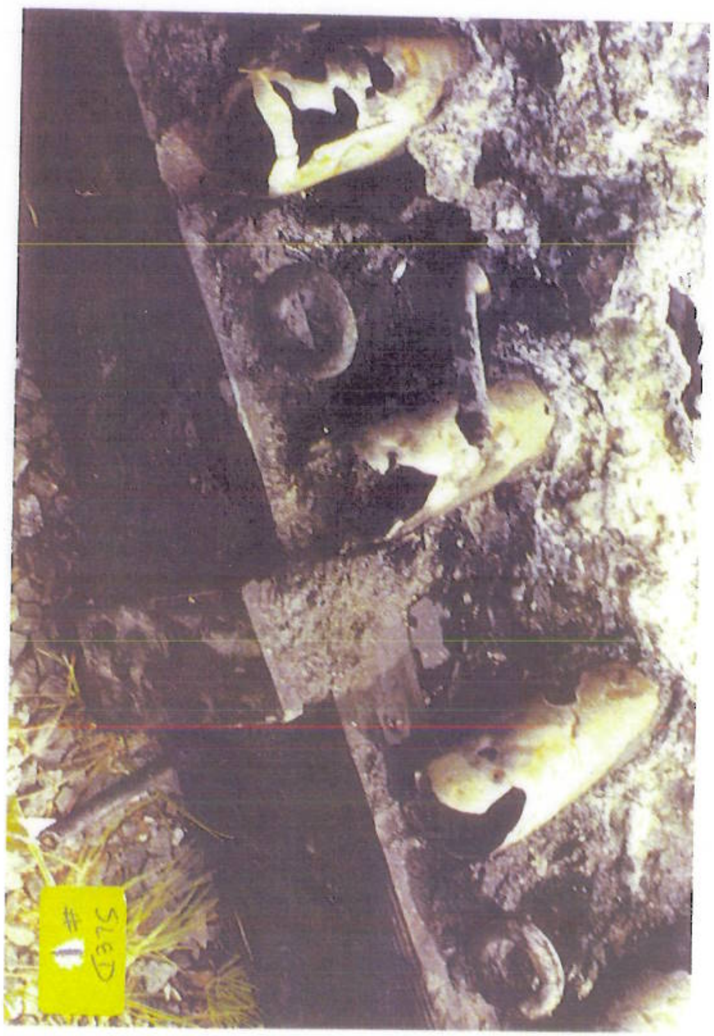

figure 7

figure 8

figure 9

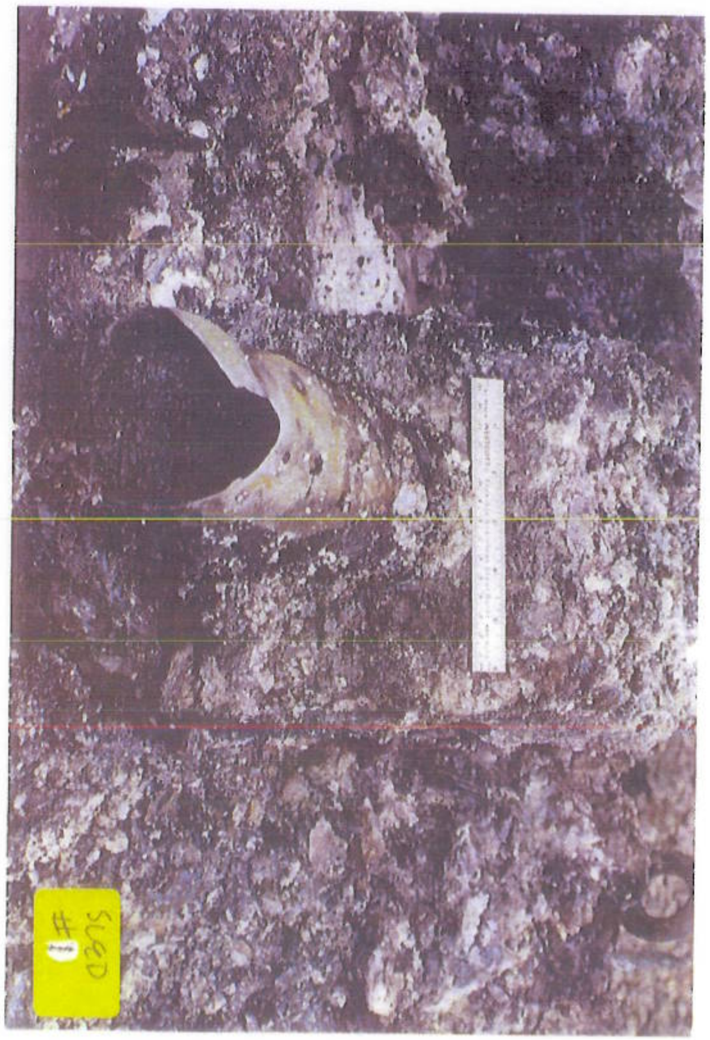

figure 10

figure 11

figure 12

figure 13

figure 14

figure 15