Extending the Service Life of Oil Docks at

Port of Corpus Christi

Utilization of Two-Stage Concrete Cathodic Protection System

Figure 1: Port of Corpus Christi (POCC)

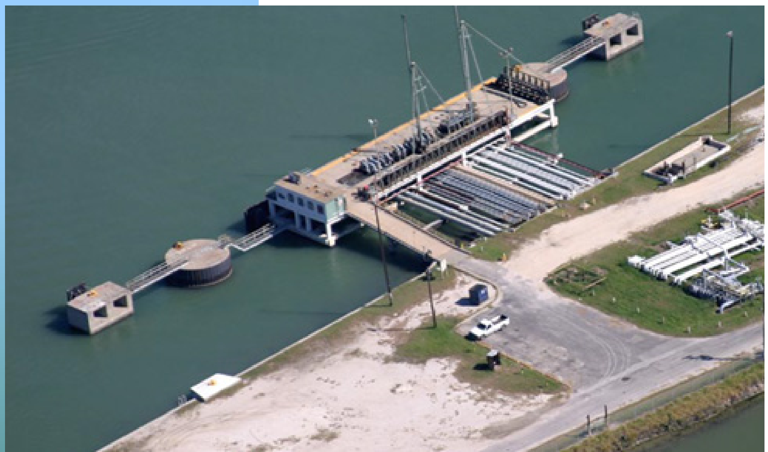

Figure 2: Aerial View of Oil Dock 7

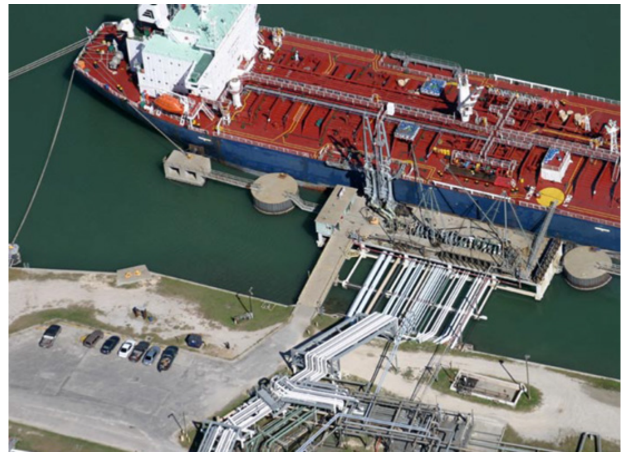

Figure 3: Aerial View of Oil Dock 4

History

In 1920, the United States Congress authorized the Army Corps of Engineers to conduct a feasibility study to recommend a location for a new deep-water port. Six years after the study was completed, in 1926, the Port of Corpus Christi located in Corpus Christi, Texas was conceived. Fast forward almost 100 years and the port once used for the exportation of cotton is now the nation's second largest port based on exportation of crude oil. Today, the Port of Corpus Christi has become a multifaceted port with cargo docks, liquid docks, bulk terminals, and storage and warehouses. The Port is also equipped with 15 docks developed for its various capabilities amongst which are for loading and unloading of liquid natural gas (LNG) and crude oil.

Rehabilitation Background

At the Port, there are two reinforced concrete oil dock structures that were the focus of this project, Oil Docks 4 and 7. Each dock is supported by reinforced concrete columns and beams comprised of two levels. The upper level serves as the primary loading/unloading area for any inbound or outbound oil tankers and the lower level provides a walkway and framing for the dock and access to the many incoming oil pipelines (Figure 4). Due to the geographical location of the port, being in an aggressive marine environment, the infrastructure along the port deteriorates at accelerated rates due to steel corrosion caused by seawater chloride penetration.

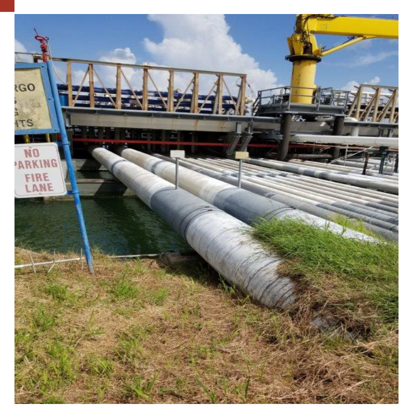

Figure 4: Incoming Oil Pipelines into Lower Level of Oil Dock

As a result of this severe corrosion deterioration, in 1993 the Port's asset management division installed an arc spray zinc (ASZ) galvanic cathodic protection (GCP) system to mitigate corrosion activity and protect the two dock's reinforced concrete elements from further deterioration. In 2019, 26 years after the installation of the original GCP system, Oil Docks 4 and 7 again began to show signs of concrete deterioration due to reinforcement corrosion (Figure 5). This was due to the original ASZ system no longer providing protection to the oil docks. An ASZ system typically has a service life between 10-20 years depending on the exposure environment, with a coastal environment being the most aggressive on the CP service life.

Figure 5: Visible Concrete Deterioration

As part of the new rehabilitation efforts for Oil Docks 4 and 7, the Port decided to extend the service life of the docks by installing a new ASZ cathodic protection system along with other dock upgrades such as a new pipe lift. The proposed installation of ASZ system required extended hours of continuous hot work during operational hours of the two oil docks. Since the two structures were mainly utilized for loading/offloading of crude oil, the Port had required that any hot work be kept to a minimum so that port operations would not be impacted during construction.

It was stated by the Port during the initial bidding phase of the rehabilitation project, that each dock, in no order or consistency, will be available for hot work a total of 14 days per month, distributed over several single – or multiple – day work segments and that there are no guaranteed patterns. Due to the limited work windows and the installation nature of ASZ, most of the bids came in much higher than anticipated by the Port. Typically, ASZ is an economical form of CP, however given the circumstances with limited hot work windows it was not a feasible option for the Port to pursue.

Prior the installation of any ASZ CP system, it is critical to prepare the surface of the structure and then immediately apply the zinc layer. This form of CP system requires continuous operation and with potential risks of construction activities being shut down after the surface preparation was done but prior to ASZ application, the surface would potentially need to be prepared again which would incur additional unexpected costs and construction delays. As a result, this scheduling risk was priced into the incoming bids, making the project significantly overbudget.

The Port reached out to the initial low bid general contractor (GC) and stated that if the GC can provide a value engineered alternative that will bring the proposed bid price within the Port's budget, then the Port would proceed with the project. The GC teamed with a specialized engineering firm with expertise in cathodic protection for concrete structures and a specialized cathodic protection subcontractor. The team proposed the use of drilled-in two-stage anodes that provide both impressed current cathodic protection (ICCP) and GCP. The anode is comprised of an internal power supply which is utilized in the first stage to polarize the structure using ICCP. The initial charge output is designed to passivate the active corrosion and build up a protective alkaline environment around the reinforcement. The anodes then autonomously switch to a second stage which utilizes an alkali-activated zinc component to provide protective current and maintain the steel passivation for the remainder of the anode service life.

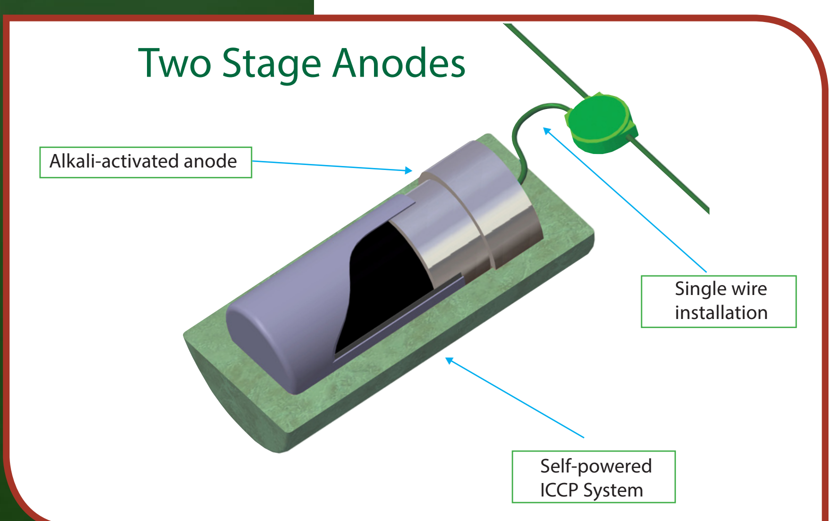

Figure 6: Proposed Drilled in Two-stage Anodes

The two-stage CP system was suitable for this project primarily because a substantial amount of the installation was not considered hot work activity. This allowed for continuous construction operations at Oil Docks 4 and 7 thereby reducing the project costs. The existing ASZ CP system was also left in place which added to the cost-saving benefits on this CP system given that no surface preparation was required.

Activities that could be completed when hot work was permitted consisted of drilling holes for the anodes, cutting wiring chases, and exposing reinforcement for structure connections. However, when hot work was not allowed the CP Contractor installed the anodes into previously drilled holes, ran wiring, and connect the anodes to the structure connections. Although some aspects of the installation process were still affected by the hot work down times, the construction team was able to continuously work by completing any non-hot work associated activities.

The valued engineering services and the newly proposed CP system was able to save the Port approximately $1.6 million in overall project cost, maintained the proposed completion schedule, and further extend the service life of the Oil Docks than what could have been achieved with ASZ.

Project Scope

The work began by redesigning the cathodic protection system to last 25 years using two-stage anodes along each beam and column supporting the oil dock structure. Due to the structural design of the docks, each group of beams and columns had varying rebar quantities at various spacing, hence each group of beams and columns had to be thoroughly analyzed using the original as-built drawings so that an appropriate anode spacing for each element could be calculated to provide adequate protection against corrosion (Figure 7). All anodes were designed to be installed in the vertical faces of each element and based on the original ASZ CP design criteria, several beams/columns on each oil dock were selected for monitoring the performance of the CP system.

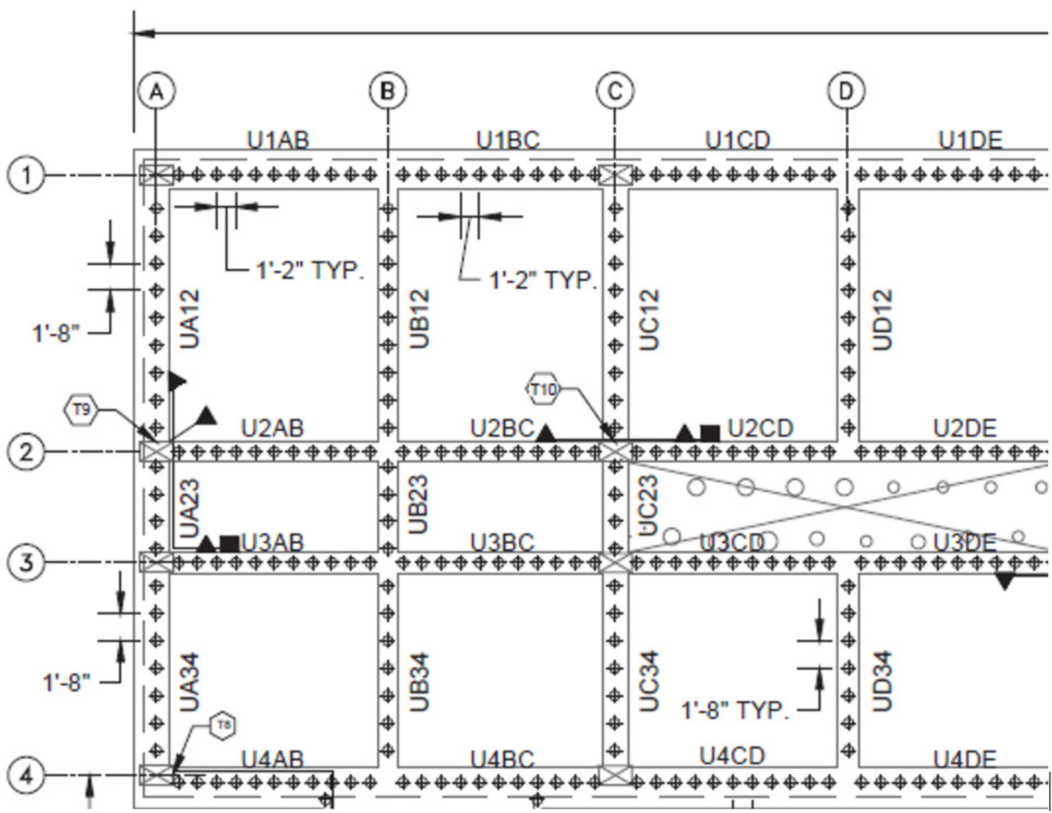

Figure 7: Typical Anode Placement Locations and Spacings

Figure 8: Drilling Anode Holes

The installation of the two-stage CP systems consisted of the following:

1. Drilling a 2-inch diameter by 5-inch-deep hole at specified locations based on the Project Drawings (Figure 8).
2. Identify reinforcing steel at the anode zone and chip out a 3-inch by 3-inch area of concrete to expose rebar (Figure 9).
3. Create a rivet connection to the reinforcing bar and establish structure connection. Each structure connection wire was redirected to the test station via the common chase (Figure 9).

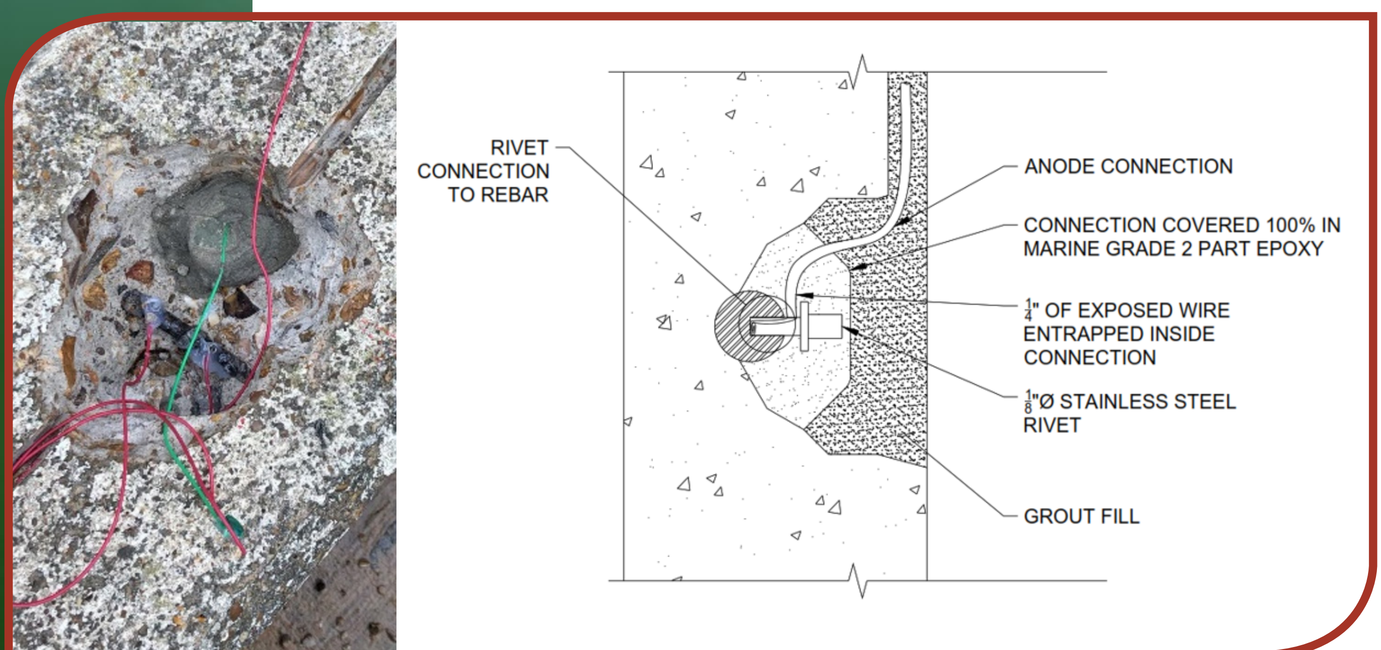

Figure 9: Establishing Structure Connections

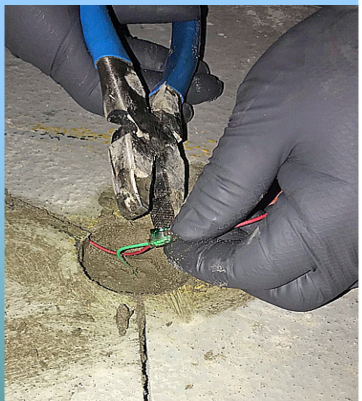

Figure 10: Step 4

Figure 11: Step 5

4. Each anode was connected to the common header wire via a sealed button connection and each end of the common header wire was redirected to the test station via the common chase. A minimum of two reinforcing connections was established per string of 10 anodes (Figure 10).
5. Grout in two-stage anodes (Figure 11).
6. Install a silver-silver chloride reference electrode in the monitored beam/column and redirect wire to the test station via the common chase (Figure 12).
7. Grout all wires inside the common chase (Figure 13).

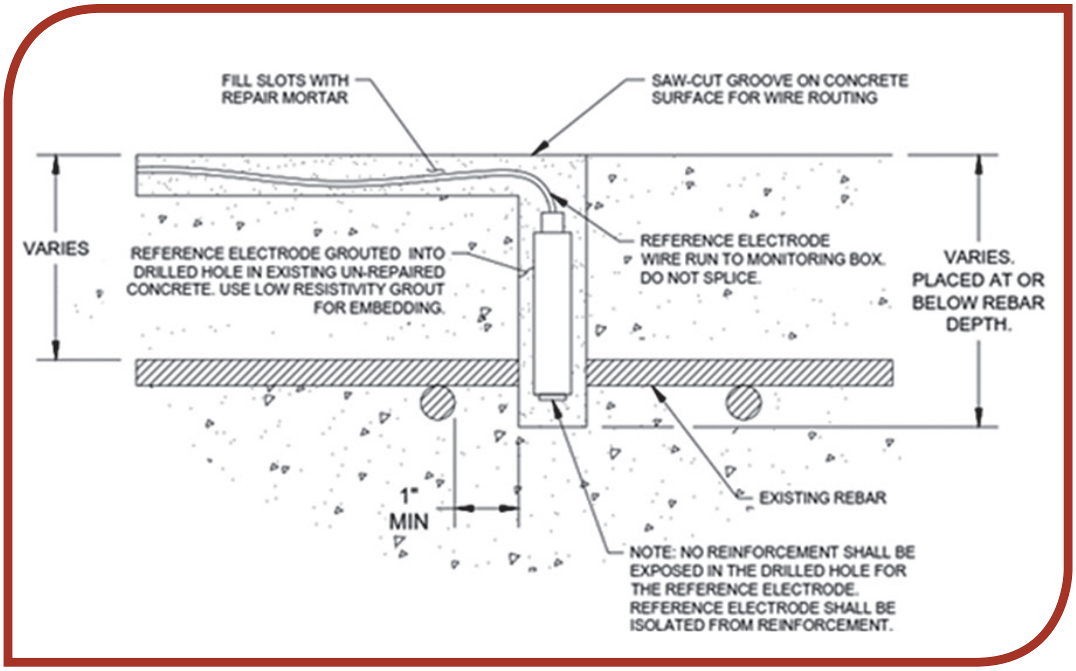

Figure 12: Step 6

Figure 13: Step 7

Figure 14: Installed Monitoring Station

Each dock was equipped with 14 test stations to monitor the performance of the CP system after completion of installation. Using the 14 test stations, a total of 36 zones (consisting of beams and columns) were monitored on each dock. A typical test station panel is shown in Figure 14. Each monitored zone was equipped with the following:

- Shunt: current output of anodes
- On-off Switch: interrupt the circuit to perform further testing.
- Reference electrode: polarization of each zone.

Project Challenges

Although prior to the start of the on-site construction activities many of the challenges were predetermined, additional unforeseen challenges occurred throughout the construction phase and were successfully handled by the engineer and contractor.

- One of the heaviest challenges of this project was the fact that ship docking schedules were only determined 2 to 3 days prior. This required constant re-mobilization of the installation team from one oil dock to the other. This meant that at any given notice, the construction crews needed to complete their immediate tasks and begin preparations for mobilizing to another dock or off the site completely. Each time the crew halted activity and switched docks, the vacated dock needed to be examined to determine the extent of remaining work to verify that the schedule was on track. This logistical challenge also posed a potential complication for any new incoming crew member, given that they had to familiarize themselves with the structure and scope of work. Hence a goal for the construction team was to keep the same crew members throughout the life of the project.
- Another logistical challenge was the fact that all lower-level beams and scaffolding on both oil docks would become submerged in water during work hours due to high tide. This in conjunction with the constant mobilizations further diminished the amount time which could be spent working on the lower-level beams.
- Several of the upper-level beams were obstructed on one side by large incoming pipelines carrying crude oil and reinforced with large C-Channels on the other side. This eliminated all options except for the anodes to be drilled from the bottom face of the beams which were heavily congested with reinforcing steel. Drilling anodes overhead into the upper-level beams congested with reinforcement slowed down the installation operations.
- Given that both oil docks had ASZ previously applied, it created difficulties in obtaining ground penetrating radar (GPR) scans to help identify the location of embedded reinforcement to establish structure connections for the two-stage CP system. The existing ASZ reflected the GPR signal, blocking penetration into the concrete to locate the reinforcement. The only viable option was to refer to the original hand drawn as-builts created in the 1960's to obtain the reinforcing spacing in each of desired columns and beams and locate the steel by trial and error.

Figure 15: Drilling Overhead on Upper-Level Beams

Project Summary

Over a period of 6 months, over 3,000 two-stage anodes were installed into the beams and columns to extend the service life of Oil Docks 4 and 7 at the Port of Corpus Christi, Texas. The project was completed successfully within the desired schedule and budget. Both oil docks are currently active and fully operational without any signs of active corrosion and anode monitoring shows the system is functioning as designed. There were many challenges to the project however through consistent communication and teamwork, the construction activities did not affect the berthing and loading/unloading of the inbound or outbound oil tankers and the Port was ultimately able to keep the oil docks operational throughout the construction phase and continue to be one of the nation's most important ports.