

Corrosion Condition Assessment Program for Maritime Asset Management

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ABSTRACT

Corrosion management systems have been adopted widely by the oil, gas, and process industries. In contrast, adoption of these approaches in civil and maritime infrastructure is still in its early stages. A corrosion management plan begins with understanding a few key items. First, identify what infrastructure elements are present and should be inventoried. Second, identify what construction materials and corrosion protection measures are already in place. Third, understand the nature and severity of environmental and usage-related exposures and impact on corrosion. Lastly, implement a systematic approach to assessing the condition and performance of corrosion protection measures over time to improve design, maintenance, and repair.

This paper describes the development of a formal corrosion inspection and condition assessment program to support corrosion and asset management planning for maritime structures at Port Houston. A hierarchical, elemental-based inspection approach was developed using visual inspection criteria and prescribed measurements to characterize the condition of coatings and cathodic protection systems for above- and underwater elements in maritime structures.

Key words: Corrosion management, condition assessment, coatings, cathodic protection, asset management, maritime, structure, infrastructure.

INTRODUCTION

Maritime infrastructure is subjected to harsh exposures that can degrade corrosion protective measures for reinforced concrete and steel elements. For owners and operators of maritime facilities, the introduction of a corrosion management program represents a proactive approach to optimizing the use of resources for maintenance and repair as part of a strategic asset management program.

Over the past five years, Port Houston has developed and implemented a maritime structures Facility Inspection and Condition Assessment Program (FICAP) to support its strategic asset management

program. The maritime structures FICAP provides a systematic collection of structural condition information that is stored in a database for analysis and condition rating comparisons. The scope of the maritime structures FICAP did not originally include corrosion protection systems such as coatings or cathodic protection, nor did it include estimates of future corrosion damage or corrosion rates, information that is necessary for a comprehensive corrosion protection plan.

This paper presents a corrosion inspection and condition assessment program for above-water and underwater maritime assets. The element-based inspection approach is summarized, and key aspects of inspection planning, condition data collection and corrosion condition rating are described. The program combines concepts and approaches for maritime and bridge structure inspection into a comprehensive program specific to corrosion protection coatings and cathodic protection systems for maritime structures with the specific goal of supporting asset management prioritization and decision making. The program was developed such that inspections and condition assessments can be conducted by different parties to collect condition information in a consistent form and level of detail to provide the information needed for corrosion management programs and strategic asset management.

CONDITION ASSESSMENT: THE FOUNDATION OF INFRASTRUCTURE ASSET MANAGEMENT

The foundation for infrastructure asset management is complete and reliable asset condition data, including the current condition and performance of the structure and its estimated rate of corrosion damage. The condition must be known in sufficient detail to assess the type and urgency of remedial actions that may be needed and provide an estimation of the damage rate (which can be used to predict remaining service life). The current condition of an infrastructure asset is established through a condition assessment, typically performed by structural, material, or corrosion engineers. The information gathered and criteria used to characterize the asset condition must be defined in a standardized manner to provide meaningful comparisons of relative condition for assets in an infrastructure portfolio. Ideally, this involves definition of a rating system to allow the condition of different assets to be compared at a point in time, as well as to evaluate changes in condition over time. The inspection and condition assessment program should define the inspection scope, timing, and techniques, provide clearly defined inspection and condition rating criteria, and define documentation and reporting requirements. The goal of the program should be to balance inspection effort (time) with quality and quantity of data, and to ensure data reliability by using well-defined criteria.

Maritime Structure Condition Assessment at Port Houston

Port Houston is a 25-mile-long complex of 150-plus private and public industrial terminals along the 52-mile-long Houston Ship Channel. As of 2019, more than 200 million tons of cargo move through Port Houston each year, carried by more than 8,000 vessels and 200,000 barges. Eight of the public terminals within Port Houston are owned, managed, and/or leased by the Port of Houston Authority (PHA)⁽¹⁾ and include a wide variety of maritime structure assets, including cargo wharves, barge landing areas, small boat docks, bulkheads, and riprap shoreline. The assets range in age from a few years to more than 100 years old and are constructed with a wide range of structural systems and materials.

In 2016, Port Houston initiated the development of an inspection and condition assessment program specific to their maritime structure assets. Working from a range of civil and structural inspection programs, including ASCE⁽²⁾ 130¹ and FHWA⁽³⁾ bridge inspection guidelines and programs,^{2,3} a maritime structures Facilities Inspection and Condition Assessment Program (FICAP) was developed using a hierarchical approach to describe asset inventory and document conditions. For maritime structures, a four-level hierarchy was defined, with the top level as the maritime terminal, which may consist of one or

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more maritime assets (e.g., wharf, dock, bulkhead, etc.) as a second level in the hierarchy. Each maritime asset is described in terms of structural and functional components (e.g., deck, superstructure, substructure, berthing and mooring hardware) as the third level in the hierarchy, wherein each component is comprised of uniquely defined elements (e.g., beam, wall, pile, bollard, etc.) at the fourth level. Condition inspections are performed at the element level using standardized condition descriptions and ratings. The element condition information collected is used to assess the condition of the components and component ratings are assigned, which in turn are used to determine the condition rating for the asset itself. This approach allows a systematic collection and reporting of condition information that is stored in a port-wide database for analysis and asset rating comparisons.

The maritime structures FICAP is presented in a formal manual and is supplemented with a 2- to 3-day training module. Trial implementations of the maritime structures FICAP were conducted in 2017, and the program was formally deployed in 2018. Initial baseline inspections have now been performed for all major maritime assets in the Port Houston inventory.

Enhanced Corrosion Assessment for Maritime Structure Asset Management

The maritime structures FICAP is focused on collecting current condition information for individual structural elements, including concrete beams, concrete deck slabs, steel piles, steel fender systems, and steel bulkhead walls. The scope of the maritime structures FICAP did not include corrosion protection measures or systems for the structural and functional elements of the assets. Of particular interest and importance to structural condition and service life are corrosion protection measures for structural metal elements in maritime structures, such as piles, fender systems and sheet pile bulkhead walls. The most common structural metals used in these applications are low-alloy carbon steel and stainless steel (austenitic grades). The typical corrosion protection measures used for structural metals in maritime structures are protective coatings and cathodic protection systems, as described below.

Surface Protection (Coatings, Wraps, Metalizing).

Surface protection elements provide corrosion protection by one or a combination of three primary mechanisms: as a physical barrier (barrier coatings or wraps), by passivating the metal surface (inhibitive coatings), or providing sacrificial galvanic protection (sacrificial coatings). Examples of barrier coatings include epoxies and polyurethanes, among several others. Inhibitive coatings react with moisture to passivate the steel surface by forming alkaline or ionic conditions on the surface. Sacrificial coatings can include zinc-rich coatings, thermal spray metalizing or hot-dip galvanizing.

Cathodic Protection of Steel Elements.

Cathodic protection involves techniques that reduce the corrosion rate of a metal surface by making the metal the cathode of an electrochemical corrosion cell. Cathodic protection systems take two general forms for maritime infrastructure: galvanic systems and impressed current systems. Generally, these systems are designed for an initial service lives of 15 to 20 years.

- **Galvanic systems** supply protective current by using galvanic anodes that have an electrochemical potential more electronegative than the structural metal to be protected. Galvanic systems, once installed, have limited ability for adjustment apart from moving or adding anodes. Consequently, inspections are focused on the initial installation (commissioning) to ensure that the system is working as designed, and then near the end of design life when anode consumption is likely to reduce output below desired levels. Interim inspections focus on whether or not wiring and connections remain undamaged and to confirm protection is being maintained.
- **Impressed current systems** use large anodes or dimensionally stable anodes to supply protective current. To produce charge flow to cathodically protect a structure, an external DC power supply is connected between the anode and steel structure. The level of effort needed for routine monitoring

and maintenance of impressed current systems is greater than galvanic systems because of the additional equipment and adjustable settings. Impressed current systems require routine maintenance and inspection to ensure current is being delivered as designed. Depending on the mode of operation, adjustments to rectifier voltage or set points may be needed at routine inspections.

The structural metal elements in maritime assets at Port Houston employ some form of corrosion protection. The nature of the protective systems described above is that their expected life or duration of effective corrosion protection is typically less than the expected service life of the structural metal element. As such, understanding the condition and performance of the protective system itself provides information on the expected remaining life of the protected metal element. Knowledge of the protective system condition is therefore essential to having a complete indication of the asset condition for asset management purposes. To this end, Port Houston commissioned the development of a corrosion assessment program (corrosion FICAP) to supplement the maritime structures FICAP.

CORROSION CONDITION ASSESSMENT FOR MARITIME STRUCTURES

The corrosion FICAP was developed to provide a more complete indication of the condition of maritime assets at Port Houston with specific focus on corrosion protection components and field measurements of the base metal elements those components protect. The corrosion FICAP defines the process, procedures, and requirements for completing inspections and condition assessments for corrosion protection components and base metal elements in a consistent manner and level of detail to meet the asset management needs of Port Houston. Whereas the maritime structure FICAP is based entirely on a visual inspection to evaluate the existing condition of a given asset, the corrosion FICAP includes visual inspection and collection of field measurements to evaluate the performance of corrosion protection measures and the condition of the associated base metal elements. The field measurements allow for a more in-depth assessment of existing conditions as well as estimations of future performance and associated corrosion rates of base metal elements. The field measurements also provide data to perform a remaining service life analysis of base metal elements if such analysis is required.

The corrosion FICAP uses the same element-based inspection approach as is used in the maritime structures FICAP. This approach is similar to that used for bridges as developed by AASHTO⁽¹⁾ and presented by Ryan et al.² and AASHTO,³ and as used for waterfront facilities inspection.

Hierarchy of Terminology in Element-Based Inspection

The element-based inspection approach defines a hierarchy from the property or terminal level down to the individual elements of an asset. The hierarchy used for corrosion FICAP is described in Table 1 and illustrated in Figure 1 for a hypothetical wharf asset with corrosion protection systems in place.

Element-Based Inspection Approach

The fundamental premise of the element-based inspection approach is that the field investigation is performed at the element level, documenting the condition of each inspected corrosion protection element of the asset (e.g., a single rectifier, wiring system, anode, or coating system with defined extents). Element condition states are used to provide a clearly defined indication of the type, severity, and extent of the observed conditions (damage, deterioration, or defects) for a given element. An individual element may exhibit more than one type of condition and may also exhibit different levels of observed conditions. Accordingly, the element-based inspection requires quantification of each condition type, severity, and extent for a given element. The definition and use of condition states at the element level improves the objectivity and repeatability of the inspection and condition assessment.

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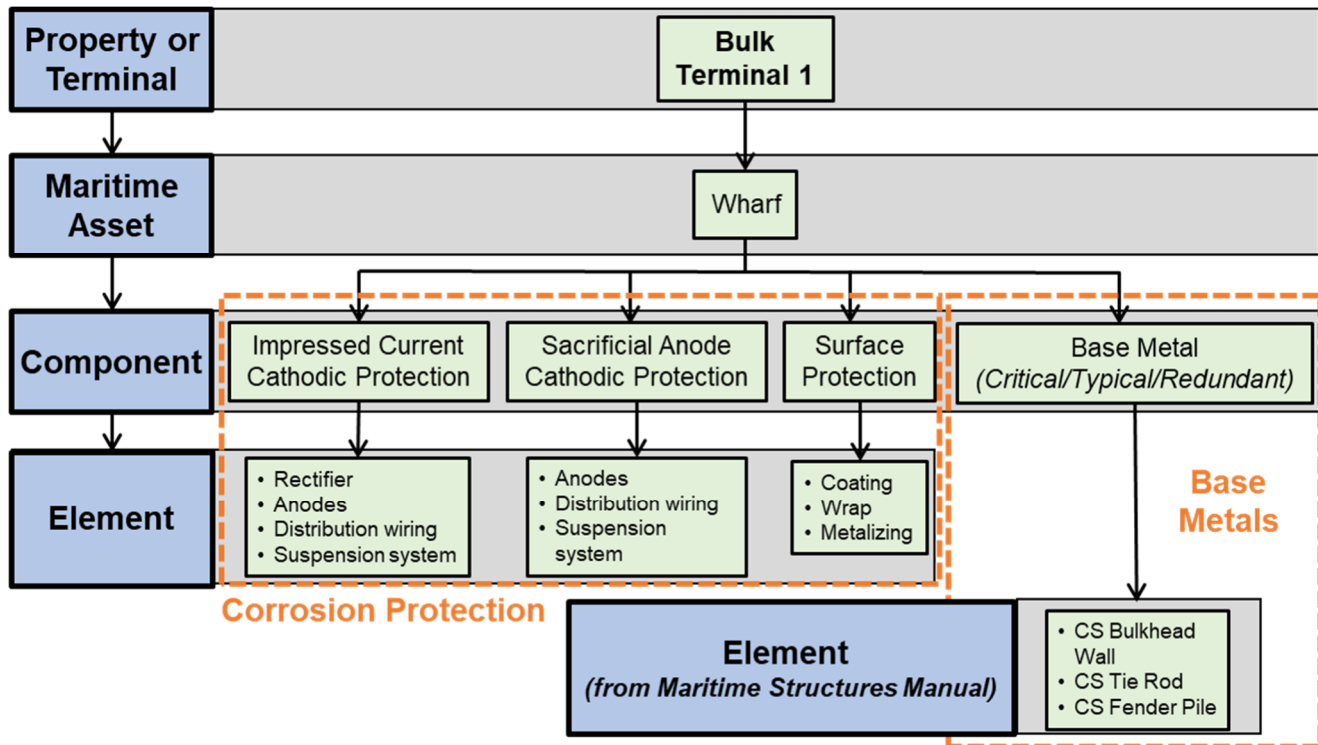


Figure 1: Corrosion Hierarchy Applied to Wharf Asset with Corrosion Protection

Table 1: Corrosion Hierarchy Level Descriptions

Hierarchy Level	Description
Property or Terminal	The property or terminal is typically comprised of a group of assets which taken together comprise a terminal or property.
Maritime Asset	Each property or terminal is normally divided into several maritime assets, each of which may serve a separate, similar, or common functional purpose. Asset types may include wharves, boat docks, bulkheads, or shoreline protection.
Corrosion Protection Component	Each maritime asset may be comprised of a single or several corrosion protection components. Typical corrosion protection component types include impressed current cathodic protection systems, sacrificial anode cathodic protection systems, and surface protection systems.
Corrosion Protection Elements	Each corrosion protection component is comprised of one or more elements. An element is an individual member of the corresponding system. Element types are defined by the component to which it belongs, its functional purpose, geometry, and material. Geometry includes the general shape and orientation of the element. Material for an element is defined generally and can include various metals, plastics, PVC, etc.
Base Metal Components	Individual structural base metal elements (e.g., fender pile, bulkhead wall) that are protected by the various corrosion protection components are assigned to Critical, Typical, or Redundant Base Metal component groups based on their importance to the overall function of a given component or asset. Unlike other components, the Base Metal component is not a system of elements that make up the same structural or functional system on the asset, but rather represents elements with similar importance to the asset.
Base Metal Element	Existing metal structural or functional elements in asset that are protected by corrosion protection components. These elements are inspected with thickness measurements in addition to the visual observations collected during an inspection under the maritime structures FICAP.