Navigation Systems Research Program

A System for Collecting and Compiling Condition Data for Hydraulic Steel Structures for Use in the Assessment of Risk and Reliability and Prioritization of Maintenance and Repairs

Report 1
Miter Gates

Phillip W. Sauser and Guillermo A. Riveros

September 2009

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A System for Collecting and Compiling Condition Data for Hydraulic Steel Structures for Use in the Assessment of Risk and Reliability and Prioritization of Maintenance and Repairs

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Abstract: Civil works structures whose partial or complete failure could jeopardize the operational integrity of the project, endanger the lives and safety of the public, or cause substantial property damage shall be periodically inspected and evaluated to ensure their structural stability, safety, and operational adequacy. The risk of a navigation structural failure is usually evaluated by the economic consequences from loss of the navigation pool, instead of by the significantly more extreme criterion of risks to human life in downstream communities associated with the loss of a flood control reservoir.

This report presents a new Inspection, Reporting, and Evaluation System for Hydraulic Steel Structures that provides a systematic approach to identifying, documenting, and tracking deficiencies in a consistent, objective, and repeatable manner. This approach will serve as the basis to assess the current and future conditions of the structural system. The report also describes the deterioration states for navigation structures and defines the corresponding quantitative values for the different deterioration states. This approach will serve to identify when and how the structure will exhibit an unsatisfactory performance level that may become severe if the structure is not maintained properly. A new inspection form to record detailed inspection information for each member using condition state procedures is also presented and discussed. The approach presented in this report will assist those in charge of maintenance and repair to take a proactive rather than a reactive approach by which a significant amount of dollars can be saved. Therefore, it will serve in the decision-making process to make risk and reliability evaluations possible.
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Preface

This research was conducted under the Navigation Systems Research Program, Work Unit 291GD8, “Navigation Structures Inventory Management System (NAVSIMS).” Program Manager was James E. Clausner, Associate Technical Director, Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS.

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At the time of the publication of this report, COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.
1 Description and Background Information

1.1 Background

Each U.S. Army Engineer District is responsible for evaluating and maintaining their Hydraulic Steel Structures (HSS) inventory in accordance with Engineer Regulation 1110-2-8157 (Headquarters, U.S. Army Corps of Engineers (HQUSACE), 1997). The requirements include conducting inspections, recording the inspection information, and archiving this information for future reference. This information is to be used for evaluation of condition and determination of maintenance, repairs, and replacement needs. Guidance for conducting inspections can be found in Engineer Manual (EM) 1110-2-6054 (HQUSACE 2001), and includes procedures for visual inspections and nondestructive examination (NDE) and guidance on evaluations for repairs and future monitoring.

The guidance does not provide a means for collecting and assessing inspection data in a consistent manner that leads to uniform evaluations across Districts. Methods and tools for collecting data vary widely, and standard terminology for describing conditions is not used. Because the condition descriptions and impacts of condition on performance of HSS are not treated equally among the Districts, the results of evaluations are not consistent. Priorities are often determined within District boundaries without consideration for a national perspective on how resources are programmed. Thus HSS in one area of the country, where consequences from loss of performance are minor, may receive priority over HSS in another location, where inaction might result in loss of life and/or large economic impacts.

1.2 Purpose

This report proposes an HSS Inspection, Reporting, and Evaluation System that provides a systematic approach to identifying, documenting, and tracking deficiencies in HSS, a means to predict useful performance, and a tool to predict the future condition for prioritizing maintenance and replacement funding.

The information gathered is directly applicable to database application for storing information, tracking changes, measuring performance, making
uniform comparisons across different locations, aiding in the decision-making process, and making risk and reliability evaluations possible.

The collection of data must be as objective and repeatable as possible by using standard information-gathering procedures and describing conditions using standard technical language and terminology. These standards promote consistency in data gathered, which results in consistent and objective evaluations and comparisons across District boundaries.

The components that make up the system and their interaction are described in the following paragraphs.

1.3 Methodology

The system comprises several components, each related to or interacting with the others. Together they provide the information needed for populating the database and executing database functions. The system is built from the individual components as follows:

- Develop a list of members common to HSS or HSS type.
- Identify the significant types of deficiencies that impact member or HSS system function and performance.
- Develop specific descriptions of the types and causes of each deficiency.
- Develop up to five condition states to describe deterioration and defects using standardized description of conditions at a desired level of detail.
- Quantify each condition state present on each member using defined standard units, such as length or area.
- Develop influence factors and apply to each member.

To ensure success in implementation, the system should not be overly complicated; i.e., detailed measurements and data collection should not be necessary.

1.4 Member types and definitions

Each member of an HSS type is identified and the function of that member described. A formal definition of each member must be developed to clarify and distinguish each member. Each specific member should be significant from the standpoint of maintenance cost or functionality. Drawings are supplied to provide a graphical depiction of each member.
1.5 Deficiency identification and description

Specific types of deficiencies, e.g., coating system failures, corrosion, cracks, and member damage, that may be associated with a particular member are identified and recorded. A detailed description of each deficiency and causes of the deficiencies are provided to aid the inspectors and evaluators in understanding the impacts to the immediate and long-term performance of the member.

1.6 Condition states

Condition states use standard engineering terminology to describe deterioration of HSS members. Deterioration behavior and maintenance alternatives for the member must be sufficiently understood to provide useful descriptions. Various condition states follow a natural progression of deterioration that typical members experience. Subjected to similar conditions, all members of similar materials should deteriorate at similar rates. Therefore, to track conditions and predict deterioration rates, the exact number and extent of condition states are not important. What is important is understanding the mechanism for deterioration, recognizing the various stages of deterioration, and understanding the impact on performance and reliability. For example, behavior of steel members subjected to conditions that lead to corrosion and section loss can be explained in the following stages:

1. The member is protected by a protective coating or other means against or has not been subjected to corrosive action. The member is in like-new or as-built condition and has no deterioration.

2. The member has lost some of its protection or has been subjected to corrosive action and is beginning to deteriorate (corrode) but has no measurable section loss. Deterioration does not impact function. This state is bounded minimally by the onset of corrosion and maximally by section loss that is not measurable, e.g., pitting not measurable by simple hand tools.

3. The member continues to deteriorate and measurable section loss is present but not to the extent to which function is affected. The upper bound of this state is, for example, pitting to a depth less than 0.0625 in. or total loss of section thickness less than 0.125 in.¹

¹ To convert inches to meters, multiply by 0.0254.
4. The member continues to deteriorate, and section loss increases to the point where function may be affected. An evaluation may be necessary to determine if the structure can continue to function as intended, if repairs are needed, or if use should be restricted. The upper bound is a function of member strength, member load, and member use, but could be capped at 10 percent of total section loss for ease of and consistency in reporting.

5. The member continues to deteriorate, and section loss increases to the point where the member no longer serves its intended function and safety is affected. An evaluation may be necessary to determine if the structure can continue to function safely.

Five general condition states are listed and described in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Protected</td>
<td>Member is sound, functioning properly, and absent of the deficiency.</td>
</tr>
<tr>
<td>2</td>
<td>Exposed</td>
<td>Member shows beginning signs of the deficiency but is still sound and functions as intended. There is no impact to performance or reliability.</td>
</tr>
<tr>
<td>3</td>
<td>Attacked</td>
<td>Deficiency has advanced and the member still functions as intended but continued, unabated deterioration will lead to the next state of condition.</td>
</tr>
<tr>
<td>4</td>
<td>Damaged</td>
<td>Deficiency has advanced to the point that function may be impaired.</td>
</tr>
<tr>
<td>5</td>
<td>Failed</td>
<td>Deficiency has advanced to the point that the member no longer serves intended function and safety is impacted.</td>
</tr>
</tbody>
</table>

### 1.7 Deficiency quantities

To get an accurate, overall assessment of condition and impact of a member on performance, each relevant condition state and the amount of each must be recorded. For example, a horizontal girder on a miter gate may have overall general corrosion with no section loss but have a small area of section loss. The general condition state of the majority of the girder will be recorded and the condition state that best matches the section loss present will be recorded for the isolated area. The quantities will be recorded in terms of length of girder affected by each condition state, or alternatively in terms of percent of girder affected. Alternatively, the condition states can be defined in terms of overall member condition based on amounts and severity of deterioration.
1.8 Influence factors

Influence factors describe conditions that affect member behavior and response to external actions, and aid in predicting future deterioration. Influence factors include environmental exposure, material properties, type of use, level of maintenance, system reliability and redundancy, and member criticality. Four levels of influence factors are defined in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>No conditions exist that are affecting deterioration or performance.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Factors create no adverse impacts, or are mitigated by past actions or highly effective protective or backup systems.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Factors have no immediate or short-term impact on deterioration or performance but may affect long-term conditions.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Factors contribute to rapid deterioration or have an immediate to short-term impact on performance.</td>
</tr>
</tbody>
</table>
2 Deficiencies and Condition States

2.1 Metal protection systems

2.1.1 Description

Metal protection systems include coatings, such as paints, galvanizing, and metalizing; cathodic protective systems; and weathering steel. The primary function of these systems is to protect members against corrosion and eventually section loss that affect member capacity and ultimately impair function and reduce member reliability. Multiple systems may be in use at one time. The condition of metal protection systems does not typically affect the function of an HSS member but does influence the rate of deterioration; therefore, the condition of the metal protection system may also be utilized as an influence factor. Metal protection condition states will be used here to report condition for the purposes of tracking protection system deficiencies and identifying optimal maintenance points. The influence of the condition of metal protection systems can be evaluated separately in any deterioration tracking scheme.

For example, a member for which the metal protection system is failing and corrosion and section loss have occurred will continue to deteriorate given the continued deterioration of the protective system. If at a point in time the protective system is restored, the deterioration rate will cease until the restored protective system begins to fail. In the absence of any repairs, the condition of the member and its level of performance and reliability remain unchanged; it still has the same amount of section loss. However, the rate of deterioration has changed, and the life of the member has increased.

2.1.2 Types of metal protection systems

Paint. Paint is one of the more common protective systems. Paint on steel is usually applied in up to three layers, or coats:

- Primer coat. The primer coat is in direct contact with the steel substrate. It is formulated to have good wetting and bonding properties and may or may not contain passivating (corrosion-inhibiting) pigments.
- **Intermediate coat.** The intermediate coat must strongly adhere to the primer. It provides increased thickness of the total coating system, abrasion and impact resistance, and a barrier to chemical attack.

- **Topcoat.** The topcoat (also called the finish coat) is typically a tough, resilient layer, providing a seal to environmental attack, water, impact, and abrasion. It is also formulated for an aesthetic appearance.

Two-coat systems are becoming more popular, and one-coat systems are under development.

**Galvanizing.** Galvanizing involves the application of a molten coating, typically zinc, onto the surface of steel typically through an immersion process or hot-dip bath. In this process, the steel reacts (alloys) with the molten metal to bond the coating onto the steel surface.

Galvanized coatings will not degrade (crack, blister, and peel) as with other barrier coatings such as paint. However, zinc is a reactive material and will corrode and erode slowly. For this reason, the protection offered by a galvanized coating is proportional to its thickness and to the corrosion rate. It is therefore important to understand zinc's corrosion mechanism and what factors affect the rate.

Freshly exposed galvanized steel reacts with the surrounding atmosphere to form a series of zinc corrosion products. In air, newly exposed zinc reacts with oxygen to form a very thin zinc oxide layer. When moisture is present, zinc reacts with water, resulting in the formation of zinc hydroxide. The final corrosion product is zinc carbonate, which forms from zinc hydroxide reacting with carbon dioxide in the air. Zinc carbonate is a thin, tenacious, and stable (insoluble in water) layer that provides protection to the underlying zinc, and is the primary reason for its low corrosion rate in most environments.

Galvanizing provides two mechanisms for protection:

- The main mechanism by which galvanized coatings protect steel is by providing an impervious barrier that does not allow moisture to contact the steel. The galvanizing process ensures that the metallic zinc coating has excellent adhesion, abrasion, and corrosion resistance.
The second shielding mechanism is zinc's ability to galvanically protect steel. When base steel is exposed, such as at a cut edge or scratch, the steel is cathodically protected by the sacrificial corrosion of the zinc coating. This occurs because zinc is more electronegative (more reactive) than steel in the galvanic series.

In practice, this means that a zinc coating will not be undercut by rusting steel because the steel adjacent to the zinc coating cannot corrode. Any exposure of the underlying steel from severe coating damage or a cut edge will not result in corrosion of the steel until the adjacent zinc has been consumed. Unless relatively large areas of steel are exposed, there is minimal effect on the overall service life of the coating. The distance over which the galvanic protection of zinc is effective depends on the environment. When completely and continuously wetted, especially by a strong electrolyte, e.g., seawater, relatively large areas of exposed steel will be protected as long as any zinc remains. In air, where the electrolyte is only superficial or discontinuously present (such as from dew or rain), smaller areas of bare steel are protected.

**Cathodic protection systems.** Cathodic protection is a technique to control the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Two basic methods of cathodic protection are the sacrificial anode method and the impressed current method, with the impressed current system being the preferred system.

Sacrificial anodes are designed and selected to have a more negative electrochemical potential than the metal of the structure. The potential of the metal surface is polarized (pushed) more negatively until the surface has a uniform potential. At that stage, the driving force for the corrosion reaction is halted. The galvanic anode corrodes, consuming the anode material until eventually it must be replaced. The polarization is caused by the current flow from the anode to the cathode. The driving force for the current flow is the difference in electrochemical potential between the anode and the cathode.

Impressed current is required to protect large areas and uses anodes connected to a direct current power source. In this system, the power source provides the current to form a uniform potential in the metal rather than other materials and prevents the corrosion cell from developing.
**Weathering steel.** In the proper environments, weathering steel does not require painting but produces its own protective coating. When exposed to the atmosphere, weathering steel develops a protective oxide film, which seals and protects the steel from further corrosion. This oxide film is actually an intended layer of surface rust, which protects the member from further corrosion and loss of material thickness.

Weathering steel has been used where the steel cannot attain a protective oxide layer and where corrosion progresses beyond the intended layer of surface rust. Therefore, it is important for the inspector to distinguish between the protective layer of rust and advanced corrosion that can lead to section loss. It is also important to note that fatigue cracks can initiate in rust-pitted areas of weathering steel.

The frequency of surface wetting and drying cycles determines the oxide film’s texture and protective nature. The wetting cycle includes the accumulation of moisture from rainfall, dew, humidity, and fog, in addition to the spray of water from traffic. The drying cycle involves drying by sun and wind. Alternate cycles of wetting and drying are essential to the formation of the protective oxide coating. The protective film will not form if weathering steels remain wet for long periods of time.

**2.1.3 Metal protection system deficiencies**

**Paint system deficiencies.** The following deficiencies can occur in paint-protected surfaces (examples shown in Figure 1):

- Alligatoring, considered a widely spaced checking failure, caused by internal stresses set up within the surface of a coating during drying. The stresses cause the surface of the coating to shrink more rapidly to a much greater extent than the body of the coating. This causes large surface checks that do not reach the steel substrate.
- Bleeding, when soluble colored pigment from an undercoat penetrates the topcoat, causing discoloration.
- Blisters, caused by painting over oil, grease, water, or salt or by solvent retention. Corrosion can occur under blisters.
- Chalking, formation of a friable powder on the paint surface caused by the disintegration of the binding medium from degradative weather factors.
- Checking, slight breaks in the film that do not penetrate through the last applied coating.
- Cracking, a break in the paint coating extending through to the surface.
• Erosion, wearing away of the paint finish to expose the substrate or undercoat.
• Microorganism failure, caused by bacteria or fungi attacking biodegradable coatings. Oil/alkyds are the most often affected.
• Mud cracking, considered a widely spaced cracking failure, where the breaks in the coating extend to the steel substrate, allowing rapid corrosion. Mud cracking is often a phenomenon of inorganic zinc-rich primers, which are applied as a very thick layer or are applied on a hot surface. Rapid curing causes the shrinkage, which yields the alligating, and ultimately, mud cracks.
• Peeling, loss of paint caused by poor adhesion. Where there is a primer and top coat or multiple coats of paint, peeling may involve some or all coats.
• Pinpoint rusting, occurs at pinholes in the paint, which are tiny, deep holes in the paint, exposing the steel. It can also be caused by thin paint coverage. In this case, the "peaks" of the roughened steel surface protrude through the paint and corrode.
• Undercutting, occurs when surface rust advances under paint. It commonly occurs along scratches that expose the steel or along sharp edges. The corrosion undermines intact paint, causing it to blister and peel.
• Wrinkling, ridges and furrows that develop in a paint film when the paint dries.

Galvanizing system deficiencies. Deficiencies include damage to the galvanizing surface, loss of galvanizing coating from corrosion, and absence of coating caused by a deficiency in application.

Cathodic protection system deficiencies. Deficiencies include damage to or deterioration of system components, loss of anode (sacrificial anode systems), and loss of power (impressed current systems).
<table>
<thead>
<tr>
<th>Alligatoring</th>
<th>Bleeding</th>
<th>Blisters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalking</td>
<td>Checking</td>
<td>Cracking</td>
</tr>
<tr>
<td>Erosion</td>
<td>Microorganism Failure</td>
<td>Mud cracking</td>
</tr>
<tr>
<td>Peeling</td>
<td>Pinpoint Rusting</td>
<td>Undercutting</td>
</tr>
</tbody>
</table>

Wrinkling

Figure 1. Paint system deficiency examples.
**Weathering steel deficiencies.** The color of the surface of weathering steel is an indicator of the protective oxide film. The color changes as the oxide film matures to a fully protective coating.

A yellow-orange for new steel with initial exposure is acceptable. For HSS that have been in service for several years, purple brown is acceptable, while black indicates failed condition.

An area of steel that is a different color from the surrounding steel indicates a potential problem. The discolored area should be investigated to determine the cause of the discoloration. Color photographs are an ideal way to record the color of the weathering steel over time. A color coupon should be included in each photograph to enable comparison.

The texture of the oxide film also indicates the degree of protection of the film. An inspection of the surface by tapping with a hammer and vigorously brushing the surface with a wire brush determines the adhesion of the oxide film to the steel substrate. Surfaces with granules, flakes, or laminar sheets are examples of nonadhesion. Table 3 presents a correlation between the texture of the weathering steel and the degree of protection.

**2.1.4 Inspection procedures for metal protection systems**

Coating system failures typically start in a few characteristic places, then spread to larger areas. Examine the following areas:

- Sharp edges and square corners of structural members.
- All areas that retain moisture and salt and areas exposed to flows, spray, and drainage.
- Inaccessible or hard-to-reach areas that may have been missed during painting. Examine the inside surfaces of lattice girders and beams.
- Areas around bolts, rivets, and pins.
- Areas exposed to wind and rain, seawater spray, and other adverse weather conditions.
Table 3. Weathering steel deficiencies – texture and condition.

<table>
<thead>
<tr>
<th>Appearance</th>
<th>Degree of Protection</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tightly adhered, capable of withstanding hammering or vigorous wire brushing</td>
<td>Protective oxide</td>
<td></td>
</tr>
<tr>
<td>Dusty</td>
<td>Early stages of exposure; should change after few years</td>
<td></td>
</tr>
<tr>
<td>Granular</td>
<td>Possible indication of problem, depending on length of exposure and location of member</td>
<td></td>
</tr>
<tr>
<td>Small flakes, 6 mm (1/4 in.) in diameter</td>
<td>Initial indication of non-protective oxide</td>
<td></td>
</tr>
<tr>
<td>Large flakes, 13 mm (1/2 in.) in diameter or greater</td>
<td>Nonprotective oxide</td>
<td></td>
</tr>
<tr>
<td>Laminar sheets or nodules</td>
<td>Nonprotective oxide, severe conditions</td>
<td></td>
</tr>
</tbody>
</table>
Coatings are generally thinner at sharp edges and corners than at rounded edges and corners or flat surfaces. Rusting starts at sharp edges, then undercuts intact paint as it spreads away from the edge. Inside square corners often receive an extra thick layer of paint because of double or triple passes made over them. Extra thick layers are prone to cracking, exposing the steel. It is difficult to completely remove dirt and spent blast cleaning abrasive from inside corners. Painting over this foreign material results in early peeling and corrosion.

Cathodic protection systems should be inspected for damage and deterioration and tested by conducting a structure to electrolyte potential survey using a reference cell.

It is particularly important for weathering steel to be inspected in the following locations:

- Where water ponds or the steel remains damp for long periods of time from rain, condensation, leaky joints, or traffic spray.
- Where debris is likely to accumulate.
- Where the steel is exposed to salts and atmospheric pollutants.
- Near defective joints or drainage devices.

2.1.5 Condition states

Descriptions of each of the condition states for metal protection systems and examples of each are shown in Table 4.

2.1.6 Deficiency quantities

Quantities for each condition state will be recorded in values of area (square feet) or percent of member affected. The quantities will be used to assess the overall condition of the metal protection system for the entire HSS. Small quantities will not have a significant impact on the overall evaluation of the HSS; therefore, quantities of each condition state reported within 5-10 percent increments of the total quantity provide a sufficient level of accuracy. Thus, detailed physical measurements for area of members affected are not required and are discouraged because of the amount of time needed to conduct these types of measurements.
Table 4. Condition states for metal protection systems.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The coating and protective systems are sound and functioning as intended to protect the metal surface.</td>
<td><img src="image1.png" alt="Example" /></td>
</tr>
<tr>
<td>2</td>
<td>The coating system may be chalking, peeling, curling, or showing other early evidence of coating system distress, but there is no exposure of metal. Protective systems have minor damage that does not affect performance.</td>
<td><img src="image2.png" alt="Example" /></td>
</tr>
<tr>
<td>3</td>
<td>Some of the coating and protective system has completely failed and there is some exposed or unprotected metal.</td>
<td><img src="image3.png" alt="Example" /></td>
</tr>
<tr>
<td>4</td>
<td>Most of the coating and protective system has completely failed.</td>
<td><img src="image4.png" alt="Example" /></td>
</tr>
<tr>
<td>5</td>
<td>The coating and protective system has completely failed.</td>
<td><img src="image5.png" alt="Example" /></td>
</tr>
</tbody>
</table>

Note: These condition states include cathodic and other types of protective systems.

2.2 Corrosion and section loss

2.2.1 Description

Corrosion is degradation of a material caused by reaction with its environment. All corrosion processes include electrochemical reactions. Galvanic corrosion, pitting corrosion, crevice corrosion, and general corrosion are purely electrochemical. Erosion corrosion and stress corrosion, however, result from the combined action of chemical plus mechanical factors.
Corrosion leads to section loss that affects the capacity, safety, and life of the HSS. Examples of corrosion and section loss are shown in Figure 2.

2.2.2 Corrosion and section loss deficiencies

In general, HSSs are susceptible to three types of corrosion: general atmospheric corrosion, localized corrosion, and mechanically assisted corrosion. For any case, the type of corrosion and cause should be identified to assure that a meaningful evaluation is performed.

General atmospheric corrosion is defined as corrosive attack that results in uniform thinning spread over a wide area.

Localized corrosion includes

- Crevice corrosion or pack rust, corrosion occurring in narrow openings between two contact surfaces.
- Pitting corrosion, small cavities penetrating into the surface over a very localized area (at a point).
- Galvanic corrosion, different electrochemical potentials (dissimilar metals) in contact.
- Stray current corrosion, resulting from sources of direct current.
- Filiform corrosion, fine filaments emanating from one or more sources in random directions and occurring under thin paint films.

Mechanically assisted corrosion includes

- Erosion corrosion, removal of surface material by action of numerous individual impacts of solid or liquid particles and usually has a direction associated with the metal removal.
- Cavitation corrosion caused by cavitation associated with turbulent flow.
- Fretting corrosion, a combination of wear and corrosion in which material is removed between contacting surfaces when very small amplitude motions occur between the surfaces.
2.2.3 Inspection procedures for corrosion

Corrosion is usually a result of failure of the metal coating system. Therefore, areas of coating system failures should be inspected for corrosion. Inspect all surfaces for presence of and amount of section loss. Measure and record the thickness of remaining section where section loss exists. See EM 1110-2-6054 (HQUSACE 2001) for detailed inspection procedures on HSS.

Additionally

- Examine all areas that retain moisture and salt or other corrosive agents and areas exposed to flows, spray, and drainage.
- Inspect inaccessible or hard-to-reach areas that may have been missed during painting. Examine the inside surfaces of lattice girders and beams.
- Inspect around bolts, rivets, and pins. Rust detected around the heads may indicate corrosion along the entire length of the bolt, rivet, or pin, causing reduced structural integrity.
- Examine areas exposed to wind and rain, seawater spray, and other adverse weather conditions.

2.2.4 Condition states

These condition states address section loss, as well as corrosion. Even if the member has been recoated, section loss will still be recorded. There is a direct correlation between coating system failures and corrosion. However, these conditions are treated separately because section loss may still be present after coatings are reapplied. They are also treated separately because corrosion leads to section loss and section loss affects structural capacity whereas coating conditions are a function of maintenance. Coatings are addressed in Section 2.1. Descriptions of each of the condition states for corrosion and section loss and examples of each are shown in Table 5.

2.2.5 Deficiency quantities

Quantities for each condition state will be recorded in values of area (square feet) or percent of member affected. The quantities will be used to assess the overall extent of corrosion and section loss over the entire HSS. Small quantities will not have a significant impact to the overall evaluation of the HSS; therefore, quantities of each condition state reported within 5-10 percent increments of the total quantity provide a sufficient level of accuracy. Thus, detailed physical measurements for area of members affected are not required and are discouraged because of the amount of time needed to conduct these types of measurements. Amount of section loss, or amount of material remaining, is a significant measurement and should be recorded with a degree of accuracy commensurate with the significance of the member being evaluated.
### Table 5. Condition states for corrosion and section loss.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Little or no corrosion is present. The weathering steel is coated uniformly and remains in excellent condition. Oxide film is tightly adhered. The connectors (welds, rivets, etc.) are sound.</td>
<td><img src="image1.png" alt="Example" /></td>
</tr>
<tr>
<td>2</td>
<td>Surface rust or surface pitting has formed or is forming. The weathering steel has not corroded beyond design limits. Oxide film has a dusty to granular texture.</td>
<td><img src="image2.png" alt="Example" /></td>
</tr>
<tr>
<td>3</td>
<td>Steel has measurable section loss from corrosion but does not warrant structural analysis. Oxide film is flaking (1/2 in. in diameter). Rusting between plates is beginning to distress the connection. Minor swelling exists.</td>
<td><img src="image3.png" alt="Example" /></td>
</tr>
<tr>
<td>4</td>
<td>Corrosion is advanced. Oxide film has a laminar texture with thin sheets of rust. Section loss is sufficient (≤ 10% of the total cross-sectional area) to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the HSS. Rusting between plates has caused serious distress to the connection. The plates may be badly distorted; however, all connectors (rivets/bolts) are still functioning.</td>
<td><img src="image4.png" alt="Example" /></td>
</tr>
<tr>
<td>5</td>
<td>Corrosion has resulted in section loss (&gt; 10% of the total cross-sectional area) and is sufficient to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the structure. Rusting between plates has caused serious distress to the connection, which warrants analysis of the HSS to ascertain the impact on the serviceability of the HSS. Some rivets or other connectors may have popped or are no longer effective.</td>
<td><img src="image5.png" alt="Example" /></td>
</tr>
</tbody>
</table>
2.3 Fatigue and fracture

2.3.1 Description

Fracture of structural members occurs when a relatively high stress level is applied to a material with relatively low fracture toughness. Fracture usually initiates at a discontinuity that serves as a local stress raiser. The potential for fracture is influenced by the material fracture toughness, member stress, discontinuities, and component geometry that causes stress concentrations.

Fatigue is the process of cumulative damage caused by repeated cyclic loading. Fatigue damage generally occurs at existing discontinuities or details that create regions of stress concentration. Total fatigue life is defined as the number of load cycles that cause a discontinuity to reach a critical size and is composed of the crack initiation and propagation phases. A crack initiates from a point of stress concentration and propagates or grows under subsequent cycles until it reaches critical size, the size at which fracture is imminent. Fracture is defined as the separation of a member into two parts. Fatigue damage is a function of number of stress ranges and corresponding stress cycles and type of detail or discontinuity causing a stress concentration.

Fracture can result in partial or total collapse of a structure if the structure lacks sufficient redundancy within the system. Fracture Critical Members (FCM) are nonredundant members or components identified through an analysis of the HSS. Typically, only steel members are considered under the FCM definition. Attachments to FCMs that are greater than 4 in. in length oriented in the direction of primary stress must be treated as FCM. Welds on FCM must also be treated as fracture critical. All FCM and fracture critical welds on HSS must be identified.

Fatigue-sensitive details, i.e., those that are susceptible to fatigue damage, should be evaluated for each HSS. The number of cycles and stresses associated with those cycles are determined for each detail and compared to the fatigue strength of the detail. Those details where the fatigue life is nearing (within an inspection cycle) or exceeded are fatigue sensitive.
2.3.2 Deficiencies and conditions that contribute to fatigue and fracture

Deficiencies and conditions that affect fatigue and fracture include any discontinuity or member geometry that causes undesirable levels of stress concentrations.

Discontinuities include

- Existing cracks.
- Notches, gouges, and other discontinuities resulting from flame cutting, drilling, grinding, or other fabrication or installation processes or from improper handling.
- Localized pitting corrosion that forms notches that may serve as fracture initiation sites.
- Poor weld quality such as unacceptable levels of porosity, undercut, overlap, slag inclusion, incomplete penetration, and incomplete fusion that create stress concentrations.

Other areas of concern are those where the member configuration creates stress concentrations or affects the behavior of the member:

- Connection details.
- Abrupt changes in geometry and load path.
- Low fatigue resistance (American Association of State Highway and Transportation Officials (AASHTO) 2007).
- Intersecting welds.
- Thick members, thick welds, and other areas of high constraint.
- Areas where out-of-plane bending occurs.

2.3.3 Inspection procedures for members susceptible to fatigue and fracture

All FCMs must be identified on all HSS. Fatigue-sensitive details should also be identified. These areas should receive in-depth inspections to inspect for and identify cracks. Only tension members are subject to fatigue and fracture problems; therefore, these regions should be inspected carefully.

Identify deficiencies, poor quality welds, undocumented welds or repairs, all areas of constraint, damaged members, and areas subjected to out-of-plane bending. Document size, length, location, and orientation of cracks and extent of all cracks. Follow up on suspected cracks with

Details should be identified as meeting one of the AASHTO category descriptions or other details not categorized that impact performance, e.g., intersecting welds, areas of high constraint, out-of-plane bending, non-compliant welds, pitting and other corrosion, kinks or bends, nicks, cuts, or gouges. See AASHTO (2007) for descriptions of fatigue detail categories.

2.3.4 Condition states

Descriptions of each of the condition states for fatigue and fracture and examples of each are shown in Table 6.

2.3.5 Deficiency quantities

Quantities of each condition state shall be recorded. Only one condition state will be recorded for each member with preference given to the higher condition state. Noncritical members are those members containing propagating cracks or fractures that will not adversely affect the strength or function of the HSS.

2.4 Impact damage and overload

2.4.1 Description

Impact damage, as defined here, is due typically to marine traffic, floating debris, and floating ice that lead to permanent deformations, distortions, dislocations, dents, or separation of material (e.g., tearing and fracture).

Overloads are the result of an unanticipated or accidental load that is greater than the strength of the member and result in permanent damage to a member in the form of buckling and other permanent deformations, distortions, plastic deformation, or fracture.
Table 6. Condition states for members susceptible to fatigue and fracture.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No discontinuities, such as pitting, gouges, or noncompliant welds, exist that can lead to cracking.</td>
<td><img src="image1.jpg" alt="Example" /></td>
</tr>
<tr>
<td>2</td>
<td>Some deficiencies, such as pitting, gouges, noncompliant welds, are present; but there is no visible cracking.</td>
<td><img src="image2.jpg" alt="Example" /></td>
</tr>
<tr>
<td>3</td>
<td>Cracks exist in noncritical locations and have been identified in the current inspection or are unchanged from the last inspection.</td>
<td><img src="image3.jpg" alt="Example" /></td>
</tr>
<tr>
<td>4</td>
<td>Cracks exist in primary members, and analyses have been completed to determine an acceptable remaining life or critical crack size; or cracks in noncritical locations have grown since the last inspection.</td>
<td><img src="image4.jpg" alt="Example" /></td>
</tr>
<tr>
<td>5</td>
<td>Cracks exist in primary members that warrant analysis of the element to ascertain the impact on the serviceability or strength of the element.</td>
<td><img src="image5.jpg" alt="Example" /></td>
</tr>
</tbody>
</table>
While the two may be related, impact damage is typically limited to the area of the structure that has been impacted.

Damage created by impact loads or overloads may reduce strength and/or performance. In redundant systems, loads will be transferred to other members. Their ability to sustain additional loading is a function of member strength, amount of overload, continuity of load path, and strength of connections through which the load may pass. While the system may sustain the overload, additional loads may lead to additional localized failures or result in shakedown or other failure modes. The extent of damage should be assessed, the impacts to strength and performance evaluated, and repairs identified prior to continued use of the structure.

2.4.2 Impact damage and overload deficiencies

Deficiencies associated with impact loads include damage and scraping (coating removal and/or gouging) of the impacted surface; permanent deformations such as bends, kinks, buckling, and twisting; and cracking, tearing, or complete fracture of the impacted area.

Deficiencies associated with overloads include permanent deformations such as bends, kinks, buckling, and twisting; cracking; and fracture.

2.4.3 Inspection procedures for impact damage and overload

Note all signs of impact damage and overload such as deformations, bends, kinks, tears, cracks, and fractures. Measure and record the extent of damage to include impacted area; depths or offsets of deformations; size, length, location, and orientation of cracks; and condition of the member connections. Provide sketches and photographs of the affected areas. The condition of adjacent members, effect on structure performance or operation, and possible causes of the damage should also be noted. Inspections should be completed immediately after the damage-causing incident occurs. See EM 1110-2-6054 (HQUSACE 2001) for detailed inspection procedures on HSS.

2.4.4 Condition states

Descriptions of each of the condition states for impact damage and overloads and examples of each are shown in Table 7.
Table 7. Condition states for impact damage and overload.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No damage exists, or it has been repaired to pre-existing conditions.</td>
</tr>
<tr>
<td>2</td>
<td>Small kinks, bends, or deformations have occurred but have no effect on strength or performance.</td>
</tr>
<tr>
<td>3</td>
<td>Secondary members have been damaged, but damage does not affect normal operations.</td>
</tr>
<tr>
<td>4</td>
<td>Significant damage has occurred but does not affect short-term operations. Repairs should be scheduled or analysis conducted to determine conditions for acceptable performance.</td>
</tr>
<tr>
<td>5</td>
<td>Damage has occurred, and the strength and/or performance of the member is impaired. Repair is needed immediately or analysis conducted to ascertain the suitability of continued use.</td>
</tr>
</tbody>
</table>

2.4.5 Deficiency quantities

Quantities of each condition state shall be recorded. Only one condition state will be recorded for each member with preference given to the higher condition state.
3 Influence Factors

3.1 Corrosive environment

A corrosive environment promotes coating system failures and corrosion and section loss. Many factors contribute to a corrosive environment:

- High acidity.
- High alkalinity.
- Deposits of film-forming materials such as oil and grease.
- Abrasive action from sand and silt, which can create crevices and ion concentration cells.
- High relative humidity.
- Alternating wet and dry cycles.
- Organisms in contact with steel.
- Sharp corners, edges, crevices, weld terminations, rivets, and bolts.

The proper application of this influence factor includes the evaluation of these factors. The existence of these factors will normally be based on observations or known conditions. Testing may be done for confirmation of observations or when highly corrosive environments exist. The condition of protective systems or presence of corrosion will not have a direct bearing on selection of the influence factors.

The value of this influence factor, described in Table 8, is used primarily to predict rate of corrosion and impacts to serviceability and function of each member.

<table>
<thead>
<tr>
<th>No.</th>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>Neutral conditions, no effect on corrosion or corrosion protection systems.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Factors create no adverse impacts, or are mitigated by past actions or highly effective protective or backup systems.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Acidic or alkaline or other corrosive conditions exist. Members may be affected in the long term.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Highly corrosive conditions exist and are contributing directly to corrosion or other damage.</td>
</tr>
</tbody>
</table>
3.2 Maintenance

Maintenance prolongs the service life of HSS, and lack of maintenance shortens it. Maintenance includes all activities that contribute to the HSS achieving its intended function and life. These activities include cleaning, painting, and performing minor repairs. Table 9 lists the descriptions of the influence factors for maintenance.

Table 9. Influence factors for maintenance.

<table>
<thead>
<tr>
<th>No.</th>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>Maintenance is not required or is conducted on a routine basis to maintain the member in a nearly new constructed state.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Minor maintenance is needed but is scheduled for the near term.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Maintenance is sporadic or past schedule, and deterioration and performance are impacted or will be impacted in the short term.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Maintenance is needed, overdue, and not scheduled.</td>
</tr>
</tbody>
</table>

3.3 Fracture and fatigue

Fracture and fatigue are directly related to member cracking in many cases. While not all cracks are due to fracture and fatigue, many are and cracks can lead to fracture and fatigue damage. The following factors influence fatigue, fracture, and cracking:

- Member and connection details that create stress concentrations, including typical fatigue category details (AASHTO 2007).
- Load history including number of stress cycles and stress ranges from applied loads, induced vibrations, and overload and impact loads that cause damage.
- Material toughness and factors that influence toughness including temperature and loading rate.
- Undocumented welds or weld repairs with unknown procedures and material properties or untested welds with unknown discontinuities.
- Areas of high restraint such as thick plates, thick welds, intersecting welds, or complex joints that can produce a high degree of constraint and limit the steel's ability to deform plastically.

Table 10 lists the influence factors for fracture and fatigue.
Table 10. Influence factors for fracture and fatigue.

<table>
<thead>
<tr>
<th>No.</th>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>Detail categories are B or above, all welds have been tested and are in compliance with accepted standards, a fatigue and/or fracture analysis has been conducted with acceptable results, material properties have been tested and are acceptable for the intended purpose, and there are no areas of high constraint.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Some C detail categories exist, only welds on critical members have been tested and are in compliance with accepted standards, a fatigue and/or fracture analysis has been conducted and shows minor problems, material properties have been tested and are acceptable for most purposes, and there are areas of high constraint in noncritical locations.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Some D detail categories exist, only butt welds on critical members have been tested and are in compliance with accepted standards, a fatigue and/or fracture analysis has been conducted and shows problems, material properties have been tested and are acceptable for most purposes, and there are areas of high constraint on some primary members.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Some E/E’ detail categories exist, weld testing has not been done on FCMs, a fatigue and/or fracture analysis has not been conducted or shows significant problems, and areas of high constraint exist in critical locations.</td>
</tr>
</tbody>
</table>

3.4 System reliability

System reliability is a measure of the structural performance of an HSS, including how well the system performs should one or more of its members become damaged, and consequences of system failure. The following factors influence reliability of HSS systems:

- System redundancy and the ability of the system to share loads or redistribute loads. Number of load paths, continuity of supports, degree of redundancy, and internal redundancy all contribute to determining system redundancy. A qualitative evaluation may be suitable for some structural systems; however, for complex systems, an in-depth structural analysis may be necessary.
- The presence of critical members whose failures may lead to partial or total collapse including members susceptible to instability and to fracture.
- Consequences of failure including impacts to or loss of operation of the HSS, economic impacts, and potential for loss of life.

Table 11 lists the influence factors for system reliability.
Table 11. Influence factors for system reliability.

<table>
<thead>
<tr>
<th>No.</th>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>The system is fully redundant and has no critical members, or there are no significant impacts should the structure fail.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>The system is fully redundant, or impacts from failure are minor; i.e., no probable loss of life and minimal impacts to safety, operations, the environment, and the economy.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>The system has only partial redundancy. Failures could lead to localized or partial collapse or result in significant impacts to operations, the environment, and the economy.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>The member is nonredundant and failures could lead to total collapse. Failure results in probable loss of life or major impacts to operations, the environment, and the economy.</td>
</tr>
</tbody>
</table>

3.5 Inspection levels and intervals

Inspections must be conducted at regular intervals to identify problems early before they become significant and impact the performance and safety of HSS. Special inspections such as impact or overload damage inspections may be needed on an emergency basis to determine the immediate safety of a structure. Inspection intervals and types influence the safety and reliability of HSS. Inspections should be conducted by qualified individuals who understand the behavior, fabrication, and operation of HSS and are familiar with the types of deficiencies associated with them. Types of inspections include the following:

- Routine inspections, conducted at regular intervals to monitor conditions and identify problems and deficiencies in their early stages.
- In-depth inspections, conducted at close range on regular intervals to identify the presence or early signs of deficiencies that can lead to significant problems. Examples include inspection of FCM for cracks that could lead to fracture and collapse of the structure.
- Special inspections, conducted on an as-needed basis, to quantify and evaluate damage from impacts, overloads, or other unanticipated loads, or to evaluate failures to determine if the structure can be safely used.
- NDE, conducted as needed by qualified individuals using specialized tools to obtain more in-depth and detailed information about a deficiency that cannot be determined by a visual inspection.
- Material testing, conducted by removing specimens and testing for physical, mechanical, and chemical properties.
Factors that influence the quality of inspection (Table 12) include the following:

- Qualifications of the inspectors for the type of inspection being conducted.
- Access to members including equipment and cleaning of surfaces.
- Inspection intervals.

<table>
<thead>
<tr>
<th>No.</th>
<th>Influence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Benign</td>
<td>Inspections are conducted at required intervals with the required access and by qualified inspectors.</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Inspections are being done at the required intervals with qualified inspectors, but proper access is not provided or access to all members is not available.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Inspections are done but not at required intervals and/or not by qualified inspectors, and not with the required access.</td>
</tr>
<tr>
<td>4</td>
<td>Severe</td>
<td>Inspections are not being conducted.</td>
</tr>
</tbody>
</table>
4 Conclusions

It has been demonstrated that the proposed HSS Inspection, Reporting, and Evaluation System provides a systematic approach to identifying, documenting, and tracking deficiencies in HSS. This consistent approach will provide the basis to develop the assessment of the current conditions and prediction of the future conditions of our aging navigation infrastructure.

The proposed condition state and grading system has also been presented, and it will be the basis on which to develop deterioration curves for USACE navigation structures. Furthermore it will assist those in charge of maintenance and repair to take a proactive approach rather than a reactive by which a significant amount of dollars can be saved. It will also provide the tools to predict when and how the structure will exhibit an unsatisfactory performance level that may become severe if the structure is not maintained properly. Therefore, accurate, objective, and repeatable data collection can be achieved and will assist in data standardization by defining the deficiencies in the same manner.

The information gathered is directly applicable to database application for storing information, tracking changes, measuring performance, making uniform comparisons across different locations, aiding in the decision-making process, and making risk and reliability evaluations possible.
References


Appendix A: Database Program

DATA INPUT

BASE DATA
Design, construction, maintenance, and operation data

INVENTORY DATA
Location, age, materials

INSPECTION DATA
Condition

MODEL DATA
Drawings, FEM data

DATABASE STORAGE

DOCUMENT ACCESS
Access to designs, drawings, and other archived documents

QUERIES
Condition, use, operations

REPORTING
Automatic generation of inspection, maintenance, deterioration curves, and other reports

EVALUATION
Strength, fatigue, fracture, reliability, and other evaluations based on stored data

DATA OUTPUT
Appendix B: Inspection Forms

Note: Please reproduce these forms as needed.
Structure Inventory Data

These data are generally recorded at the initial inspection and normally do not change. These data should be monitored during routine inspections and any changes recorded at that time.

<table>
<thead>
<tr>
<th>Identification</th>
<th>Structure Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>HSS Number (8)</td>
</tr>
<tr>
<td>Location</td>
<td>Waterway (5)</td>
</tr>
<tr>
<td>State</td>
<td>County</td>
</tr>
<tr>
<td>Latitude</td>
<td>Longitude</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age and Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Built</td>
</tr>
<tr>
<td>Current Use</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Geometric Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure Type and Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Type</td>
</tr>
<tr>
<td>Toughness</td>
</tr>
</tbody>
</table>
HSS Inspection Data

This form will be used during each inspection. The front sheet provides general data pertinent to the HSS and the inspection and will be updated as needed during each inspection. The second sheet will be used to record detailed inspection information for each member using Condition State procedures.
## Inventory Data

<table>
<thead>
<tr>
<th>Project:</th>
<th>Waterway:</th>
<th>Structure Number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>District:</th>
<th>Location:</th>
<th>Use:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use:</th>
<th>Conditions:</th>
<th>Temp.:</th>
<th>HSS Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Inspection Type

<table>
<thead>
<tr>
<th>Inspection Type</th>
<th>Routine Visual</th>
<th>Fracture Critical</th>
<th>In-Depth</th>
<th>UW-Dive</th>
<th>UW-Surv.</th>
<th>UW-Probe/Visual</th>
<th>Mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last Insp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recom. Freq.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial</th>
<th>Damage</th>
<th>Interim</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Last Insp.</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>N/A</td>
</tr>
<tr>
<td>Recom. Freq.</td>
<td>N/A</td>
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General Inspection/Maintenance Notes

(Page 2 of 2)
Appendix C: Miter Gates

C.1 Member identification and terminology

**Anchor Arm:** Member with pinned ends connecting the **Embedded Anchorage** to the **Gudgeon Link**.

**Anchorage Links:** Members with pinned ends and a threaded section for adjustment connecting the **Embedded Anchorage** to the **Gudgeon Pin**.

**Anchorage System:** Members that provide support for the miter gate leaves consisting of the **Gudgeon Pin Barrel**, **Anchorage Links**, **Embedded Anchorage**, and **Pintle** and **Pintle Base**.

**Cathodic protection:** Corrosion protection system consisting of a sacrificial anode or impressed current.

**Diagonals:** Tension members attached to the downstream faces of horizontally framed miter gates and on upstream and downstream faces of vertically framed miter gates to keep the **Gate Leaf** in vertical alignment while stationary, and to eliminate excessive deflection during operation.

**Embedded Anchorage:** A built-up member, generally of triangular shape, embedded in the concrete wall and connected to an anchor link.

**End Diaphragm:** Stiffener plate attached to the end of the **Horizontal Girder** adjacent to the tapered end that aids in the distribution of axial forces into the Quoin generated through the girder when the leaves are in the closed position.

**Fenders:** Deformable members attached to the gate that absorb impact loads and help to prevent damage to the gate members.

**Fixed Pintle:** Fits into the Pintle Shoe and is bolted to the embedded pintle base. The degree of fixity of the **Pintle** depends on the shear capacity of the **Pintle Shoe** bolts.
Floating Pintle: Fitted into a cast steel shoe, with a shear key provided to prevent the pintle from turning in the shoe. The shoe is not fastened to the base, thereby allowing the gate leaf to move outward in case of debris between the quoin and wall quoin preventing the leaf from seating properly.

Fracture Critical Members, Miter Gates, Horizontally Framed

- Downstream half of web and flange and of top Horizontal Girder
- Diagonals and associated gusset plates and connections
- Anchor Arm and Anchorage Links

Gate Latch: Assembly anchored to the recess and attached to the miter end of the gate to maintain the gate leaf in the recess.

Gate Leaf: One half of a Miter Gate consisting of Skin Plate, girders, Intercostals, stiffeners, and attachments

Gate Stop: Deformable members attached to the recess wall to absorb impact loads and help to prevent damage to the gate members when the gate is in the closed position.

Gudgeon Hood: An arrangement of plates forming the hinge connection at the top of the miter Gate Leaf.

Gudgeon Link: Members connecting the Anchor Arm to the Gudgeon Pin.

Gudgeon Pin Barrel: See EM 1110-2-2703 (HQUSACE 1994)

Gudgeon Pin: Pin connecting the anchor link with the Gudgeon Hood.

Horizontal Girders: Girders that lie along a chord of the thrust line curve, with the resulting eccentricity of thrust producing bending stress in addition to the axial stress.

Intercostals: Vertical stiffeners attached to the skin plate that provide stiffness to the skin plate.

Link Pin: Member connecting the Anchor Arm to the Gudgeon Pin.
**Miter Angle:** Angle measured between Gate Leaves on the downstream side in the closed position

**Miter Blocks:** A pair of opposing blocks, one with a concave surface and one with a convex surface, that provide mating surfaces for the miter ends in the closed position, and together with the thrust diaphragms and End Plates distribute the axial load from the horizontal girders in the vertical direction and form a contact bearing surface between the miter ends of the leaves.

**Miter Contact Point:** Point of contact between Gate Leaves when gates are in the closed position.

**Miter Gates, Horizontally Framed.** The primary structural elements of a single Gate Leaf consist of a series of Horizontal Girders, connected vertically by a Skin Plate, two End Diaphragms, and a number of intermediate diaphragms and Intercostals. Water loads are transferred from the Skin Plate to the Horizontal Girders to reaction points at the Miter Blocks (closed position only), and Quoin Blocks supported by a wall.

**Miter Gates, Vertically Framed.** The primary structural elements of a single Gate Leaf consist of a series of Vertical Girders, connected vertically by a Skin Plate, two End Diaphragms, and a number of intermediate diaphragms and Intercostals. Water loads are transferred from skin plate to vertical beams into a top and bottom horizontal beam to reaction points at the miter (closed position) and Quoin at the top and sill at the bottom. The system of vertical diaphragms forms a series of vertical continuous beams supported by the elastic horizontal girders.

**Miter Guide:** A pair of opposing members on the miter ends used to bring both leaves of the gate into the mitered position simultaneously facilitating seating of the miter blocks. The guide consists of two major components, a roller mounted on an adjustable bracket, and a two-piece adjustable v-shaped contact block and support.

**Operating Strut:** Member connecting the Gate Leaf to the operating machinery that opens and closes the gate.
**Pintle Assembly**: Bearing members that support the dead weight, allow rotation of each **Gate Leaf**, and with the **Gudgeon Pin** hold the quoin end vertical. The assembly consists of a **Pintle Socket**, **Pintle**, **Pintle Shoe**, and **Pintle Base**.

**Pintle Base**: Portion of the **Pintle Assembly** embedded in the concrete floor that supports the **Pintle Shoe**.

**Pintle Bushing**: Material inside the pintle socket that provides the wearing surface between the pintle socket and pintle.

**Pintle Socket**: Hemispherical shaped member generally made of cast steel connected to the bottom of the lower girder web. Fits over the pintle and provides the surface for pintle socket bearing and rotation.

**Quoin Block**: A bearing block with a concave surface that matches with the **Wall Quoin** to provide bearing between the **Quoin Contact** and wall.

**Quoin Contact**: Point of contact between the **Quoin Block** and the **Wall Quoin**.

**Quoin Post**: A column, vertically from the top to the bottom **Horizontal Girders**, consisting of a section of the thrust diaphragms, end plate, **Thrust Diaphragm Stiffeners** and flanges that supports the dead weight of the **Gate Leaf**.

**Recess**: A wall cavity that provides storage for the gate leaf within the wall when the gate is in the open position.

**Seal Plate**: Member that extends down from the bottom of the gate and supports the bottom seal.

**Seals**: Members, generally constructed of a deformable material, such as synthetic rubber or Neoprene, that provide uniform contact across the sill, miter, and quoin and minimize leakage at these locations.

**Sill**: Member protruding from the lock floor, generally consisting of a steel beam embedded in reinforced concrete, that provides the sealing surface for the bottom of the gate leaves.
Skin Plate: Constitutes the damming surface of the Gate Leaves.

Tapered End: End of horizontal girder tapered for fit and to avoid interference with the recess wall during operation.

Thrust Diaphragm: Plate that distributes the reaction of the girders from the Quoin Block into the girder webs, acts as the damming surface between the End Plate and the End Diaphragm, and makes up part of the Quoin Post.

Thrust Diaphragm Stiffener: Plate located at each side of the Thrust Diaphragm to provide stiffness and support.

Walkway: Platform provided at the top of the gate that provides continuous access across the gate in its closed position.

Wall Quoin: A bearing block with a concave surface that matches with the Quoin Block to provide bearing between the Quoin Contact and wall and is attached to the wall through an embedded anchorage.
## C.2 Details

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### C.3 Condition states

#### C.3.1 Metal protective systems

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C.3.2 Corrosion and section loss
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### C.3.3 Fatigue and fracture

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C.4 Miter gate sketches

Figure C.1. Miter Gate Horizontally Framed Elevation.
Figure C.2. Horizontally framed miter gate-general elevation and section.
Figure C.3. Miter gate-gudgeon hood.
Figure C.4. Miter gate-embedded anchorage.
Figure C.5. Miter gate-top anchorage assembly.
Figure C.6. Miter gate-fixed pintle assembly.
Figure C.7. Miter gate-fixed pintle assembly.
Figure C.8. Miter gate-quoin and miter blocks.
Figure C.9. Miter gate-walkway and miter guide.
Figure C.10. Miter gate-miter guide.
Figure C.11. Miter gate-sill angle and seal.
Figure C.12. Miter gate-gate latches.
Figure C.13. Miter gate-upper and lower latching devices.
Figure C.14. Miter gate-upper and lower latching devices.
Figure C.15. Miter gate-operating strut connection.
Figure C.16. Lock 22 – gudgeon hood assembly.
A System for Collecting and Compiling Condition Data for Hydraulic Steel Structures for Use in the Assessment of Risk and Reliability and Prioritization of Maintenance and Repairs; Report 1: Miter Gates

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This report presents a new Inspection, Reporting, and Evaluation System for Hydraulic Steel Structures that provides a systematic approach to identifying, documenting, and tracking deficiencies in a consistent, objective, and repeatable manner. This approach will serve as the basis to assess the current and future conditions of the structural system. The report also describes the deterioration states for navigation structures and defines the corresponding quantitative values for the different deterioration states. This approach will serve to identify when and how the structure will exhibit an unsatisfactory performance level that may become severe if the structure is not maintained properly. A new inspection form to record detailed inspection information for each member using condition state procedures is also presented and discussed. The approach presented in this report will assist those in charge of maintenance and repair to take a proactive rather than a reactive approach by which a significant amount of dollars can be saved. Therefore, it will serve in the decision-making process to make risk and reliability evaluations possible.

Civil works structures whose partial or complete failure could jeopardize the operational integrity of the project, endanger the lives and safety of the public, or cause substantial property damage shall be periodically inspected and evaluated to ensure their structural stability, safety, and operational adequacy. The risk of a navigation structural failure is usually evaluated by the economic consequences from loss of the navigation pool, instead of by the significantly more extreme criterion of risks to human life in downstream communities associated with the loss of a flood control reservoir.

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14. ABSTRACT

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15. SUBJECT TERMS

Condition states
Deterioration
Hydraulic steel structures
Inspections
Deficiencies
Risk and reliability
Maintenance and repairs
Standardization

16. SECURITY CLASSIFICATION OF:

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