Historic Lighthouse Preservation:

IRON

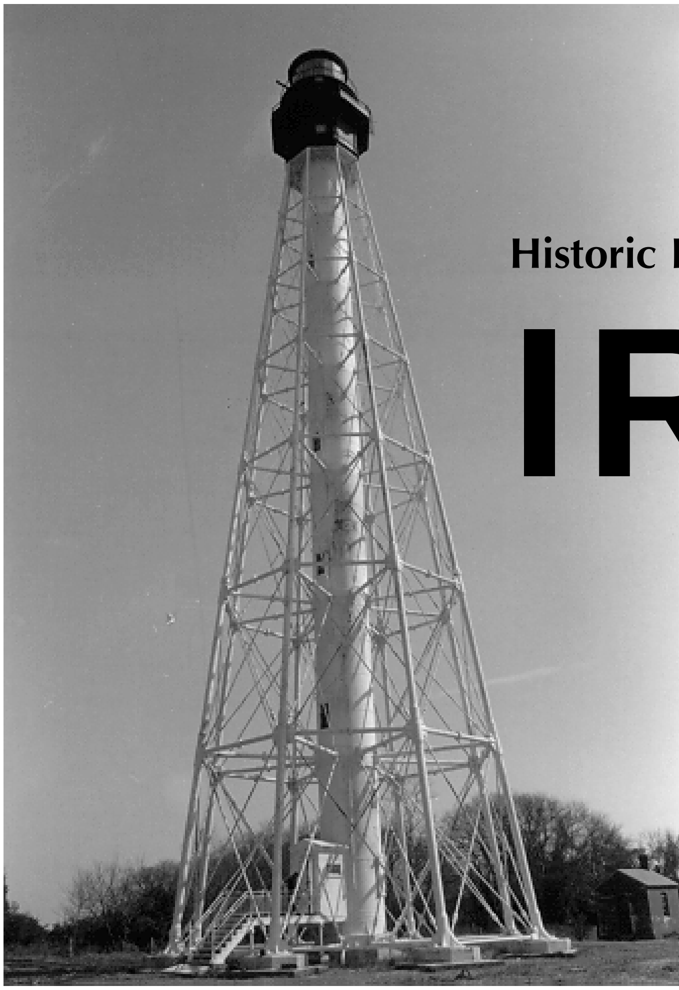

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Figure 1. Cast-iron-and-steel skeletal 191-foot-tall tower at Cape Charles, Virginia

Second to masonry, iron was the most common lighthouse construction material. For lighthouse construction, iron was used in a variety of its commercially manufactured alloys: wrought iron, cast iron, steel, galvanized iron and steel, and stainless steel. In historic lighthouses the most widely used alloy was cast iron. The use of cast iron in lighthouse construction ranged from simple prefabricated lanterns to caisson-style foundations to 190-foot-tall first-order coastal towers. For more on the variety of iron lighthouse construction types refer to Part II., **History of the Lighthouse Service and Lighthouse Construction Types**.

Iron was also used for the production of architectural trim features such as gallery deck brackets, entryway pilasters and pediments, doors, and prefabricated lantern components. These iron features were used on masonry and wood as well as iron lighthouses. Other iron alloys such as steel, galvanized iron and steel, and stainless steel are mostly found in modern additions such as handrails, equipment brackets, security doors, etc.

This section will discuss the preservation of iron alloys used in lighthouse tower construction and decoration. Because of their similar properties, the various iron alloys will be discussed together; special treatments concerning a specific alloy will

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Figure 2. Example of a keeper's quarters fitted with a prefabricated cast-iron-and-steel lantern.

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Figure 3. Example of an all-cast-iron construction "sparkplug" caisson-style lighthouse.

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Figure 4. Double-wall, cast-iron, first-order 163-foot-tall coastal tower at Cape Henry, Virginia.

be discussed accordingly. The use of iron in the construction of lanterns and the special considerations associated with iron in the presence of unlike metal corrosion (galvanic corrosion) will be discussed in the **Lantern** section. Other metals such as brass and bronze will also be discussed in the **Lantern** section.

Iron Alloys Found in Historic Lighthouses

Of the iron alloys, cast iron was a perfect choice for lighthouse construction for two principal reasons. First, cast iron is relatively resistant to corrosion because of its microstructure component compounds—graphite and phosphide eutectic. These compounds are not present in steel, which explains why the two materials corrode in different manners. Second, cast iron can be cast into virtually any shape that is required for structural or decorative purposes. To form complex shapes and structural systems, these castings were designed with flanges that made it possible to bolt the component parts together. This prefabricated style of construction facilitated the erection of lighthouses in a timely, economical manner. This method also allowed for the dismantling and relocation of a lighthouse if site conditions were compromised by encroaching erosion.

The various steel alloys were used throughout the structure of a historic lighthouse, but to a lesser degree than cast iron. Most mild steel, stainless steel, and galvanized steel components have been used in modern additions or repairs. These components appear mostly as pre-

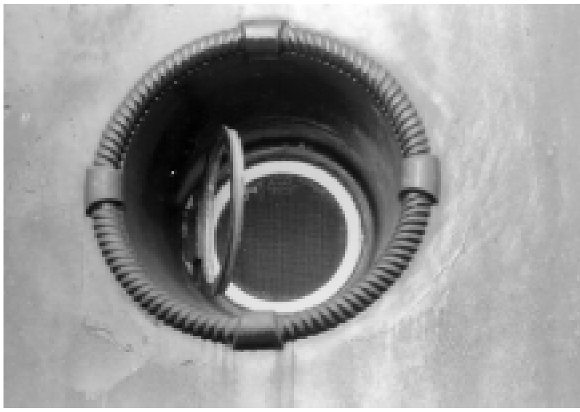

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Figure 5. A view of decorative-rope nautical-style cast-iron window surrounds on Cape Canaveral Lighthouse.

manufactured items such as structural 'I' beams, replacement handrails, equipment brackets, and items that can be fabricated into functional parts of the lighthouse.

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Figure 6. A view of the inner cavity and skeletal structure of the Cape Henry Lighthouse.

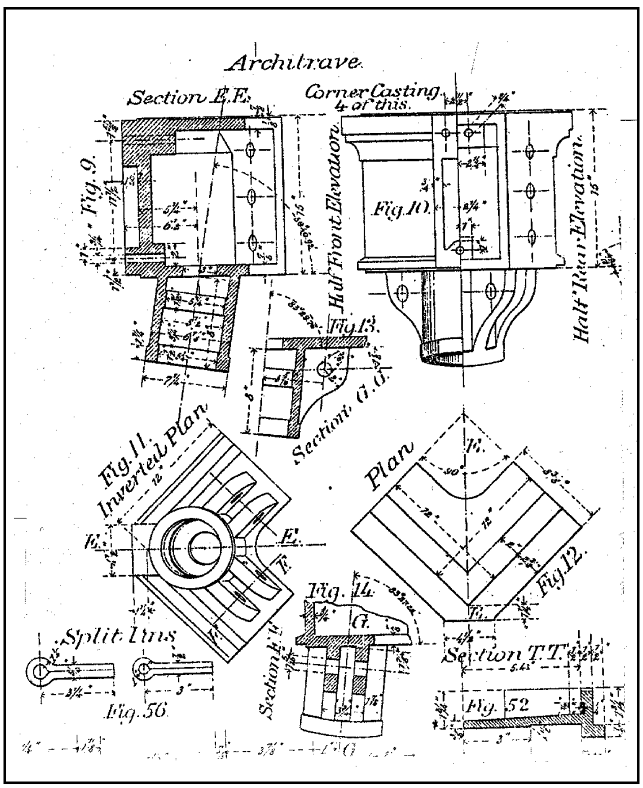

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Figure 7. Shop drawings used for the production of cast-iron lighthouse parts for a screwpile lighthouse.

Iron Alloys Commonly Found in Historic Lighthouses

- ***Wrought iron*** is relatively soft, malleable, tough, fatigue-resistant, and easily worked by forging, bending, rolling, and drawing. Until steel was available, wrought iron was used structurally for beams and girders as it had strength in both tension and compression. During the late 19th and early 20th centuries, it was not unusual to find a mixture of cast-iron columns and wrought iron or steel beams in the same lighthouse. Currently, very little wrought iron is being produced.
- ***Cast iron*** is an iron-carbon alloy with a high carbon content. It is easily poured while molten into molds, making possible numerous decorative and structural uses. Cast iron is too hard and brittle, however, to be shaped by hammering, rolling, or pressing. Cast iron contains in its microstructure several relatively corrosion resistant components which are mostly absent from the microstructure of steel. Because of this, the two materials corrode in different manners. It is more rigid (highly resistant to buckling) than other forms of iron and can withstand

great compressive loads, which helps account for its ubiquitous use for lighthouse tower structure components such as wall plates, columns, sockets, struts, deck plates, etc. Cast iron does have some drawbacks. There is the potential for inherent flaws in cast pieces such as trapped air pockets or foreign material such as casting sand or slag trapped in the iron during the casting process. These flaws can be avoided if the castings are thoroughly inspected and the casting process is performed to accepted industry tolerances.

- ***Steel*** is an alloy of iron and carbon that contains not more than 2% carbon, and is malleable in block or ingot form. Steel may include phosphorus, sulfur, oxygen, manganese, silicon, aluminum, copper, titanium, molybendum, and nickel. The properties of steel can vary greatly in relation to the chemical composition and the type of heat treatment and mechanical working used during manufacture. Characteristics affected by these differences include strength, hardness, ductility, resistance to abrasion, weldability, machinability, and resistance to corrosion. A grade of medium carbon steel is used for most lighthouse applications today such as handrails, equipment brackets, new light support structures, etc.
- ***Galvanized steel*** and ***iron*** consist of steel or iron with a zinc coating, which makes it highly resistant to corrosion. As in the past, zinc is still widely used as a protective coating for iron and steel. A major advantage of zinc coating on iron is that if the zinc is worn away or broken and the iron is exposed to the atmosphere, galvanic corrosion of the more base zinc occurs, protecting the more noble iron. (The terms *base* and *noble* refer to the relative reactivity of the zinc and iron. A metal that is considered a *base* is more reactive than a metal that is considered *noble.* These properties are directly related to the number of free electrons that exist in the molecular structure of the metal.)
- ***Stainless steel*** is defined as a steel containing sufficient chromium, or chromium and nickel, to render it highly resistant to corrosion. Stainless steel is malleable, hardened by cold working, and resistant to oxidation, corrosion, and heat. It has characteristics of high thermal expansion and low heat conductivity, and can be forged, soldered, brazed, and welded. Because of its relatively inert properties, stainless steel components are mostly found in replacement parts such as bolts where the possibility of galvanic corrosion could occur.

Stainless steel is available in various grades. Given the complexity of the issues and potential application, the selection of the proper grade of stainless steel for use in a marine environment requires careful evaluation by an engineer.

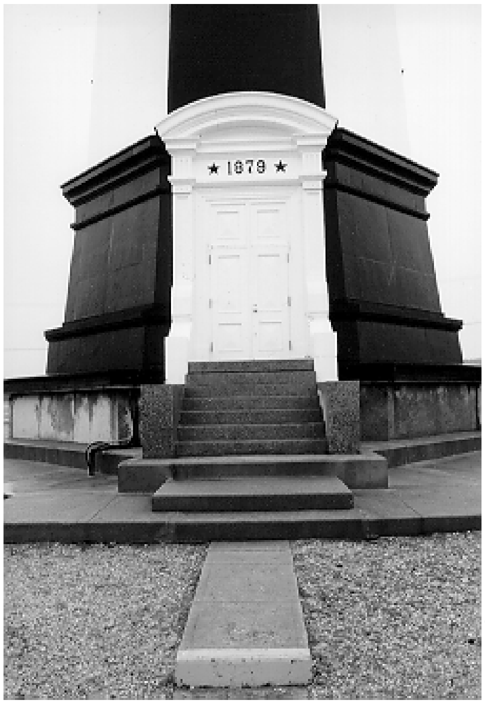

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Figure 8. An example of the level of detail achieved with cast-iron construction.

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Figure 9. A modern range finder attached to the gallery deck using modern steel members.

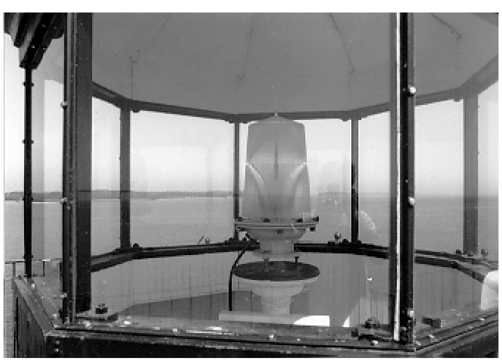

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Figure 10. Close-up of a lantern glass frame: note the use of stainless steel bolts; the lower clamps are also stainless steel that have been painted black.

Figure 11. Detail view of a steel ladder that has been uniformly attacked by corrosion.

Causes of Iron Deterioration and Failure

Iron lighthouse components are subjected to a host of forces associated with a marine environment. How successfully a lighthouse resists these pressures depends on how well it is designed and maintained. Iron lighthouses that are poorly maintained will deteriorate rapidly.

In scientific terms, *deterioration* is generally defined as a decrease in the ability of the material to fulfill the function for which it was intended. It usually refers to the breakdown of a material because of natural causes, although deterioration can also be either directly or indirectly caused by man. Deterioration can also be defined as the changing of a material from a higher to a lower energy state. Although deterioration usually implies a chemical change, under some conditions the change can be physical. There are five possible forces that can act on an iron lighthouse component and cause its failure: corrosion, inherent flaws, mechanical breakdown, weathering, and connection failure.

Corrosion

Corrosion, in one form or another, is the major cause of the deterioration of iron lighthouse components. Often called oxidation, it is the chemical reaction of a metal with oxygen or other substances. The deterioration of iron lighthouse components is a complex process because the type and degree of corrosion is affected by minor variations in environment, contact with other metals and materials, and the composition of the component itself.

Upon exposure to the atmosphere, almost all new or newly cleaned metals become coated with a thin film of metallic oxide, which is a result of the reaction of the metal with oxygen. This film may modify the properties of the metal and make it less susceptible to further corrosion. In the case of rusting iron, however, the oxide does not form a protective coating but rather promotes the continued corrosion of the metal. The three most common types of corrosion experienced by iron lighthouse components are as follows:

- ***Oxidation*** or rusting occurs rapidly when the iron component is exposed to moisture and air. The minimum relative humidity necessary to promote rusting is 65%, but this figure can be lower in the presence of corrosive agents, such as sea water, salt air, acids, acid precipitation, soils, and some sulfur compounds present in the atmosphere, which act as catalysts in the oxidation process. Rusting is accelerated in situations where the shape of the iron details provide pockets or crevices to trap and hold liquid corrosive agents. Furthermore, once a rust film forms, its porous surface acts as a reservoir for liquids, which in turn causes further corrosion. If this process is not arrested, it will continue until the iron is entirely consumed by corrosion, leaving nothing but rust.
- ***Galvanic corrosion*** is an electrochemical action that results when two dissimilar metals react together in the presence of an electrolyte, such as water containing salts or hydrogen ions. The

Figure 12. Close-up of localized corrosion or pitting where the corrosion has eaten through the cast iron.

Figure 13. View of a steel railing where corrosion has occurred in distinct locations either because of variations in composition or localized failure of the coating system.

severity of the galvanic corrosion depends on the difference in potential between the two metals, their relative surface areas, and span of time. If the more noble metal (higher position in electrochemical series) is much larger in area than the baser, or less noble, metal, the deterioration of the baser metal will be more rapid and severe. If the more noble metal is much smaller in area than the baser metal, the deterioration of the baser metal will be much less significant. Iron lighthouse components will be attacked and corroded when they are adjacent to more noble metals such as lead or copper. For more on *galvanic corrosion* refer to the **Lantern**.

- ***Graphitization*** of cast iron, a less common problem, occurs in the presence of acid precipitation or seawater. As the iron corrodes, the porous graphite (soft carbon) corrosion residue is impregnated with insoluble corrosion products. As a result, the cast-iron element retains its appearance and shape but is weaker structurally. Graphitization occurs where cast iron is left unpainted for long periods or where caulked joints have failed and acidic rainwater has corroded pieces from the backside. Testing and identification of graphitization is accomplished by scraping through the surface with a knife to reveal the crumbling of the iron beneath. Where extensive graphitization occurs, usually the only solution is replacement of the damaged element.

Inherent Flaws

Castings may also be fractured or flawed as a result of imperfections in the original manufacturing process, such as air holes, cracks, and cinders, or cold shuts (caused by the "freezing" of the surface of the molten iron during casting because of improper or interrupted pouring). Brittleness is another problem occasionally found in old cast-iron elements. It may be a result of excessive phosphorus in the iron, or of chilling during the casting process.

The corrosion of iron lighthouse components takes several forms:

- ***Uniform attack*** is where the iron component corrodes evenly where exposed to corrosive agents.
- ***Pitting*** is the localized corrosive attack on the iron component.
- ***Selective Attack*** can occur where an iron component's composition is not homogeneous and certain areas are attacked more than others.

- ***Stress corrosion cracking*** can occur where stresses were induced into the iron component in the pulling or bending process of metalworking and the component later subjected to a corrosive environment. For example, stainless steels can crack in environments containing chloride, and carbon steels in nitrate, cyanide, or strong caustic solutions.
- ***Erosion*** occurs when the corrosion-resistant film or oxide or layer of protective corrosion product is removed by abrasion, exposing fresh metal to the corrosive agents.

Mechanical Breakdown

Iron lighthouse components can also fail from purely physical causes such as abrasion, or a combination of physical and chemical attack, such as weathering and stress corrosion cracking.

- ***Abrasion*** is the erosion of the iron component caused by moving dirt, dust, sand, grit, sleet, and hail, or rubbing by another lighthouse component or human element. Abrasives can also encourage corrosion by removing the protective coating (paint) from the iron lighthouse component.
- ***Fatigue*** is failure of an iron component by the repeated application of cyclic stresses below the elastic limit—the greatest stress a material can withstand without permanent deformation after removal of the load. It results from a gradual or progressive fracture of the crystals.


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Figure 14. Nearly 30% of this ventilation shroud has been lost to two forms of abrasion: first, sand or grit blasting abraded away a majority of the material; second, human touch has smoothed the once rough surface.


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Figure 15. As corrosion attacked this steel handrail, wind and airborne sand eroded the loose and flaking surface rust.

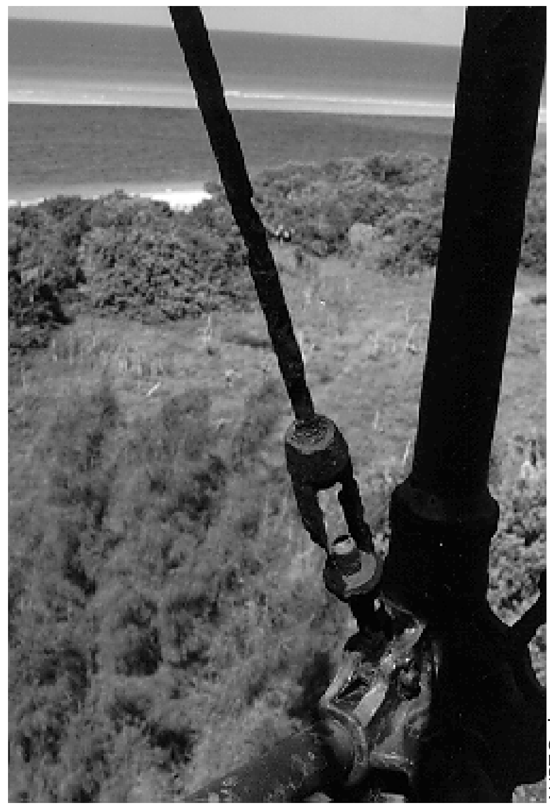
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Figure 16. As corrosion attacked this steel turnbuckle, wind and airborne sand eroded away the flaking rust.

- ***Overloading*** is the stressing of an iron lighthouse component beyond its yield point so that permanent deformation, fracturing, or failure occurs. It can fail through the application of static loads, dynamic loads, thermal stresses, and settlement stresses either singly or in combination. "Buckling" is a form of permanent deformation from overloading which is usually caused by excessive weight but can also be caused by thermal stresses. Members can also be overloaded if their support is removed and loads are redistributed to other members which can become overstressed and deformed. An iron lighthouse component can fail or become permanently deformed by the phenomenon known as rust-jacking. The failure or deformation is the result of the expansion of the iron component as it oxidizes. This expansion "jacks" the two members apart.

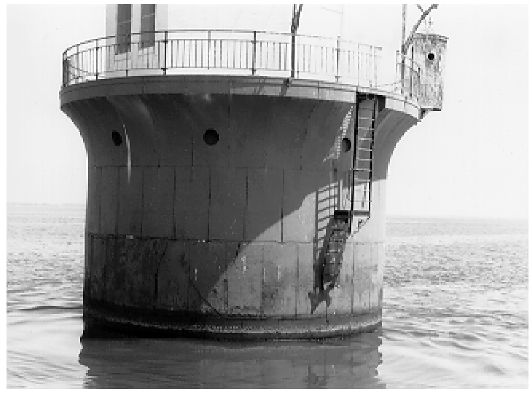

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Figure 17. The cyclic pressure of the different rates of expansion and contraction of the exterior cast-iron plates and the interior brick lining of the caisson-style lighthouse has caused the cast-iron plates to fatigue and crack.

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Figure 18. The internal structural skeleton of this lighthouse is cracked because of overloading possibly during assembly.

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Figure 19. This handrail has been damaged by rust-jacking; rusting began between the two pieces of flat bar stock that formed the rail.

Weathering

An iron lighthouse component subjected to the weather is exposed to various chemical and physical agents singly and in combinations of several at one time. The result is a kind of synergism where the total effect is greater than the sum of the individual effects taken separately. For example, the rate of corrosion accelerates with increases of temperature, humidity, and surface deposits of salts, dirt, and pollution.

Connection Failure

The failure of the connections of iron lighthouse components, especially structural members, can also be caused by a combination of physical and/or chemical agents. The most common type of connections used for iron structural elements of historic lighthouses include bolting, riveting, pinning, and welding. These connections can fail through the overloading, fatiguing, or corrosion of the connectors. Common examples of this type of failure include the corrosion, usually by concentration cells (or battery affect caused by dissimilar metals), of bolt heads, rivets, and areas covered by fastening plates. The effective cross-sectional area of the connectors is often reduced by corrosion, making the connectors more susceptible to stress failure.

Inspecting for Possible Problems

In order to develop an effective treatment plan for iron lighthouse problems, an in-depth inspection must be made of the iron lighthouse and its immediate surroundings. The following chart is a listing of locations that should be inspected regularly. Associated with these locations are the possible problems to look for during the inspection.

Inspection Chart for Iron Lighthouses	
THE SITE	
Look For:	*Possible Problems:*
Environment	
General climatic conditions, including average temperatures, wind speeds and directions, humidity levels, and average snow accumulation	Severe conditions can lead to deterioration of the masonry foundation, which in turn could lead to differential settlement that could ultimately damage the iron lighthouse structure.
Number of freeze-thaw cycles	Severe cycles can cause damage to iron lighthouse components from frost action.
Location near sea	Salt (chloride) in the air can lead to accelerated corrosion of exposed iron surfaces.
Acid rain in the region or from nearby industry	Acid rain can lead to accelerated corrosion of exposed iron lighthouse components.
Proximity to a major road highway or railroad	Vibrations are harmful to masonry foundation mortar joints as well as iron lighthouse parts. Repetitive vibration can cause premature failure in iron components if the oscillation cycles fatigue the metal to the point of failure.
Location in the flood plain of a river, lake, or sea	Floodwaters can bring damaging moisture to foundations and walls; such damage can result in differential settlement that could ultimately damage the iron lighthouse structure.
Exposed or sheltered sections of a lighthouse	Exposure to the sun and elements affects moisture evaporation and rain penetration into the joints between iron members. Sheltered areas such as the underside of an iron gallery deck are highly susceptible to corrosion and rust pitting because of a tendency to accumulate moisture and the slow drying rate without direct sunlight.
Terrain	
Soil type—clay, sand, rock	The type of soil influences water drainage around the structure. Excessive water in the soil could lead to differential settlement that could ultimately damage the iron structure. This is a minimal concern for most iron lighthouses. Most iron lighthouses were constructed on sites that had been chosen for their soil and/or underlying strata stability.

Look For:	*Possible Problems:*
Slope away from lighthouse on all sides	If no slope exists, puddles will form at the base of the lighthouse walls during heavy rains, causing water penetration and possible damage to foundation systems that could lead to differential settlement and ultimately to damage of the iron structure.
Earth covering part of a brick or stone wall or foundation	Moisture accumulation or penetration is possible and could lead to differential settlement and ultimately to damage of the iron structure.
Concrete or other impervious paving touching walls	Water accumulation and rain back-splash onto the walls which could lead to accelerated corrosion of the iron wall structure.
Trees and Vegetation	
Species of trees within 50 feet	Elms and some poplars dry up clay soil, leading to foundation failure and differential settlement that could ultimately damage the iron lighthouse structure.
Branches rubbing against a wall	Branches abrade surfaces, possibly exposing bare iron surfaces to the elements and accelerating corrosion of the iron lighthouse structure.
Ivy or creepers on walls	Leaves prevent proper drying of the painted iron surface resulting in possible accelerated corrosion of the iron surface. Tendrils from some species can penetrate joints and can literally break the iron lighthouse members.
THE LIGHTHOUSE	
Overall Condition	
General state of maintenance and repair	A well maintained lighthouse should require fewer major repairs.
Evidence of previous fire or flooding	Such damage may have weakened the lighthouse structural members or caused the introduction of excessive moisture.
Signs of settlement	Uneven settlement can crack foundations and lead to differential settlement that could ultimately damage the iron lighthouse.

Look For:	*Possible Problems:*
Lantern	
General condition	A well maintained lantern should require fewer major repairs. A leaking lantern may leave stains under the gallery deck on the exterior of the lighthouse as well as streaks on the interior walls of the tower spaces below. This condition can introduce excessive moisture into the interior of the lighthouse and possibly cause accelerated deterioration of interior features and structure.
Roof drains (usually associated with larger first-order lights) and covering	Clogged roof drains can hold water in the built-in guttering system and accelerate deterioration of the roof covering. Small holes in the roof covering can be moisture infiltration points.
Gallery decks, copings, and structural seams	Gaps in gallery decking can allow water to penetrate in the interior cavities of an iron tower wall.
Condition of storm panels	Cracks and holes in storm panel glazing can provide an infiltration point for moisture into the lantern.
Humidity level within the lantern	Non-functioning lantern vents can inhibit the release of humid air from within the tower. The water vapor will ultimately condense on the surfaces inside the tower and lantern and possibly cause accelerated corrosion of iron lantern components.
Windows and Doors	
Straight and square openings	Deformed openings in the lighthouse structure may be a sign of structure settlement.
Door and window sills sloped to shed water; drips under sills to prevent water from running back underneath; caulking	If any of these is inadequate, water can penetrate into the wall and start corrosion from the inside out.
Foundation	
Composition of foundation walls	Stone or brick is more likely than concrete to allow water to infiltrate.
Water condensation or other signs of moisture	Wood joists or iron structural members resting on masonry foundation walls may begin to rot or corrode at the ends. Termites or algae, mold, mildew, or moss may be present, causing damage to the wood or masonry.
Damp proof course	This can impede rising damp, lessening deterioration of the masonry wall.

Look for:	*Possible Problems:*
Interior	
Damp walls, stains on walls, rotting wood	These indicate water infiltration.
Walls	
Construction method—iron plate, sheet iron double wall, iron plate with masonry infill, wood frame interior walls, etc.	Knowing how a tower wall is constructed will help in analyzing problems and selecting appropriate treatments.
Masonry-lined iron lighthouses	Rust-jacking of iron members captured by masonry infill may cause cracking of the infill. If the masonry infill becomes wet, the different rates of expansion and contraction of the masonry infill and the iron sheathing during a freeze-thaw cycle can cause the iron and masonry both to crack.
Sheet iron cavity walls	Water infiltration will show as rust forms on the interior of the cavity and appears as blistering on the exterior of the panels. Rust streaks known as 'rust weep' or 'rust bleed' appearing on interior wall surface plate seams may indicate water infiltration has occurred.
Iron Components	
Materials	
Type of iron—wrought, cast, steel, galvanized steel, or stainless steel	Types of materials indicate the susceptibility or resistance to damage and proper repair method.
Areas of intricate castings or moldings	These sections may need special attention or protection during treatment.
Missing or broken iron components	Missing material may allow water penetration.
Evidence of sandblasting, such as a pitted surface; evidence of erosion, flaking, scaling, or other form of corrosion.	Surface deterioration is not only aesthetically displeasing but can lead ultimately to the complete deterioration of the lighthouse.
Dirt or stains	Surface stains usually cause few problems other than being unpleasant to look at. Accumulated dirt or debris in built-in gutters or other 'pockets', however, may trap water and cause accelerated corrosion.
Moisture	
Water penetration through joints between iron components and between iron and other lighthouse components	Moisture can lead to deterioration of the iron and other parts of the lighthouse structure through corrosion and rot. Water that has entered a cavity may go unnoticed until extensive corrosion has occurred.

Look for:	*Possible Problems:*
Location and type of corrosion on surface	The type of corrosion may indicate the source of the deterioration; refer to the following section on corrosion for more information.
Rust streaking or 'rust weep' present on interior or exterior wall surfaces near seams or construction joints in the iron structure	This condition indicates that moisture has penetrated the joint or interior cavity of the iron wall. The water entry point should be identified and sealed or the damaged area repaired.
Coatings	
Paint; type of paint	Various paint types require different treatment methods and safety precautions, i.e., lead-based paint hazards, etc.
Blistering, flaking, and peeling paint	These conditions indicate the paint is at or near the end of its effective life span.
Rust streaks or rust weep	This indicates localized failure of the coating system which has caused the exposed iron to begin to rust. The rust scale should be removed and the area spot painted in the interim until the next repainting of the lighthouse.
Construction Joints	
Joints between iron lighthouse components were typically sealed with white lead mixed with linseed oil	The white lead/linseed oil mixture hardens and becomes brittle over time and eventually falls out, thus allowing open joints for water infiltration.
Concrete or mortar used as a seam or cavity filler	The concrete and mortar are very hard and can easily break and thus allow for water infiltration; cavities in an iron lighthouse that have been filled with concrete or mortar are susceptible to corrosion because of the alkalis present in the concrete and mortar and the possible trapping of water between the filler and the iron.
Iron copings over masonry portions of the lighthouse such as watertables and window and door surrounds.	The alkali nature of the mortar used in the masonry may cause the iron to prematurely rust. These areas are prone to rust weep and should be thoroughly cleaned of rust scale and painted during the scheduled lighthouse repainting.