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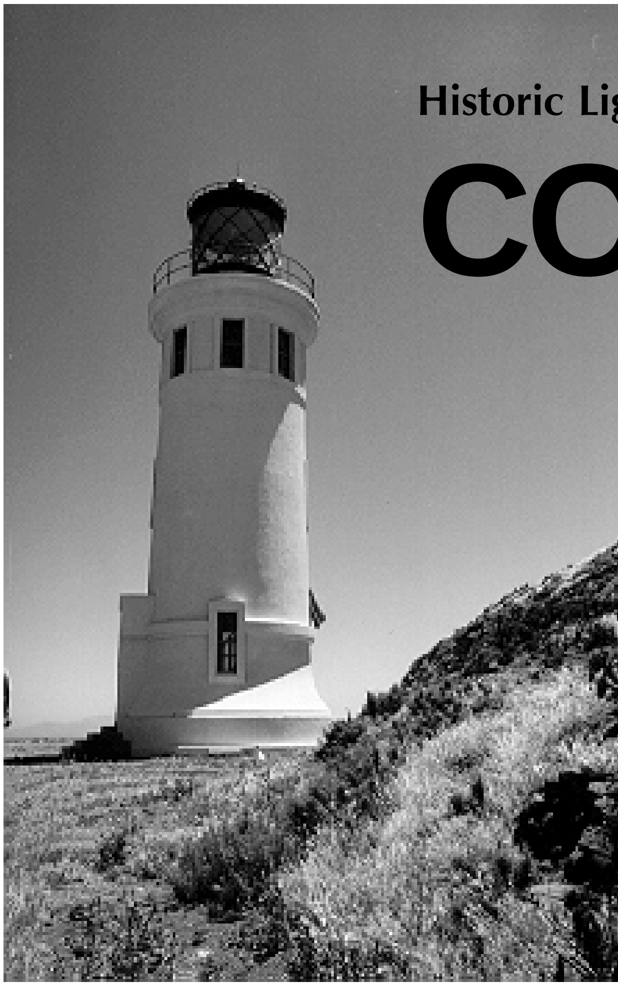

Historic Lighthouse Preservation:

CONCRETE

Figure 1. Anacapa Island Lighthouse is a reinforced concrete lighthouse located on a highly exposed island off the California coast. Concrete was chosen because of its ability to withstand the high winds, harsh climate, and seismic activity of this exposed location.

Concrete[1] is the fourth most common lighthouse construction material. The 1908 Point Arena Lighthouse, the first reinforced concrete lighthouse in the United States was constructed in response to the search for an earthquake-proof construction material. (The Point Arena Lighthouse is located within 10 miles of the San Andreas Fault.) The Point Arena Lighthouse, however, was not the first lighthouse to use concrete in its construction. Caisson-style lighthouses typically used concrete as fill and ballast to help sink the caisson, however, this type of concrete was not reinforced.

Concrete features (such as cast moldings and brackets, poured in-place foundations) as well as concrete surfaces (modeling and tooling, texture and color) are usually important in defining the historic character of a lighthouse and should be retained during any treatment. While concrete is among the most durable of historic building materials, it is still susceptible to damage by improper maintenance or repair techniques and by harsh or abrasive cleaning methods. When performing any treatments on a concrete lighthouse, use the gentlest means possible.

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[1]'Concrete' is a name applied to any of a number of compositions consisting of sand, gravel, crushed stone, or other coarse material, bound together with various kinds of cementitious materials, such as lime or cements. When water is added, the mix undergoes a chemical reaction and hardens. Traditionally, concrete is not referred to as masonry.

WPTC photo

Figure 2. View of the Alcatraz Island Lighthouse. Reinforced concrete was chosen for this lighthouse location for its ability to withstand earthquakes.

WPTC photo

Figure 3. For the construction of this caisson-style lighthouse, unreinforced concrete was used as ballast to sink the cast-iron caisson foundation deep into the mud on the bottom of the Chesapeake Bay in Maryland.

Historical Overview

The Romans found that the mixture of lime putty with pozzolana, a fine volcanic ash, would harden under water. The result was possibly the first hydraulic cement. It became a major feature of Roman building practice, and was used in many buildings and engineering projects such as bridges and aqueducts. Concrete technology was kept alive during the Middle Ages in Spain and Africa, with the Spanish introducing a form of concrete to the New World in the first decades of the 16th century. It was used by both the Spanish and English in coastal areas stretching from Florida to South Carolina. Called 'tapia', or 'tabby', the substance was a creamy-white, monolithic masonry material composed of lime, sand, and an aggregate of shells, gravel, or stone mixed with water.

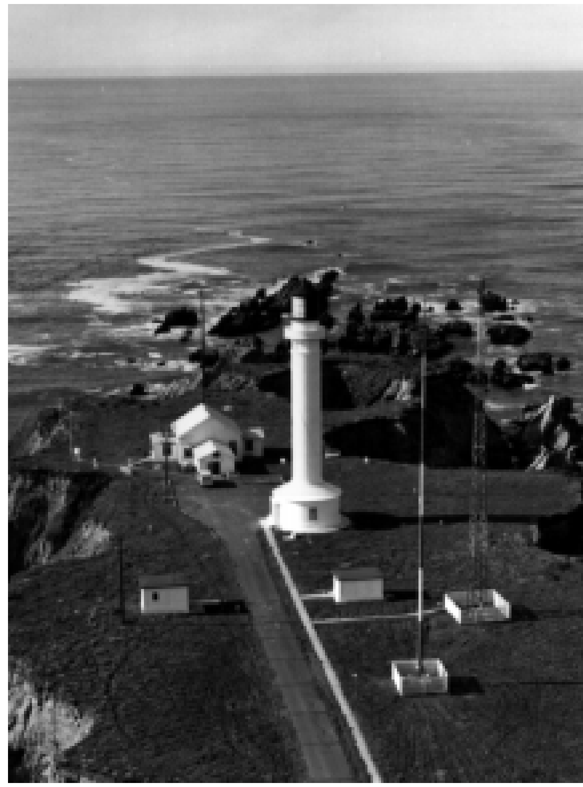
Reinforced concrete in the United States dates from 1860, when S. T. Fowler obtained a patent for a reinforced concrete wall. In the early 1870s William E. Ward built his own house in Port Chester, New York, using concrete reinforced with iron rods for all structural elements. Despite these developments, such construction remained a novelty until after 1880, when innovations introduced by Ernest L. Ransome made reinforced concrete more practical. The invention of the horizontal rotary kiln allowed production of a cheaper, more uniform and reliable cement, and led to the greatly increased acceptance of concrete after 1900. These developments in concrete technology and manufacture ultimately led to the use of reinforced concrete in the construction of lighthouses.

As mentioned in the introduction, the first reinforced concrete lighthouse was constructed at Point Arena, California in 1908 (see Figure 5). The construction of this lighthouse established a trend of using reinforced concrete for lighthouses on the

West Coast and Alaska. This trend continued into the 1920s and 1930s. The construction of reinforced concrete lighthouses was not limited to the West Coast and Alaska; concrete lighthouses were constructed on the Eastern Seaboard as well. The last one, St. John's River Lighthouse, was constructed in 1954 in Mayport, Florida (Figure 5). The reason for concrete's popularity in lighthouse construction was that it was durable, was cheap compared to traditional masonry construction, and required minimal initial maintenance.

Types of Concrete

- ***Unreinforced concrete*** is a composite material containing aggregates (sand, gravel, crushed shell, or rock) held together by a cement combined with water to form a paste. It gets its name from the fact that it does not have any iron or steel reinforcing bars. It was the earliest form of concrete. The ingredients become a plastic mass that hardens as the concrete hydrates, or 'cures'. This form of concrete is typically used in caisson-style lighthouse construction as ballast to weight the caisson foundation (see Figure 3). Unreinforced concrete, however, is relatively weak, and since the turn of the century has largely been replaced by reinforced concrete.
- ***Reinforced concrete*** is concrete strengthened by the inclusion of metal bars, which increase the tensile strength of concrete. Both unreinforced and reinforced concrete can be either cast in place or precast.
- ***Cast-in-place*** concrete is poured onsite into a previously erected form that is removed after the concrete has set. Lighthouses are typically constructed using cast-in-place construction methods. The advantage to this method of construction is that once the concrete has cured, the lighthouse is a monolithic structure.
- ***Precast concrete*** is molded offsite into building components. This method of construction is seldom used for lighthouses.



USCG photo

Figure 4. The first reinforced concrete lighthouse, Point Arena Light Station in California.

WPTC photo

Figure 5. St. John's River Lighthouse, Mayport, Florida, was constructed of reinforced concrete for its economy and low maintenance.

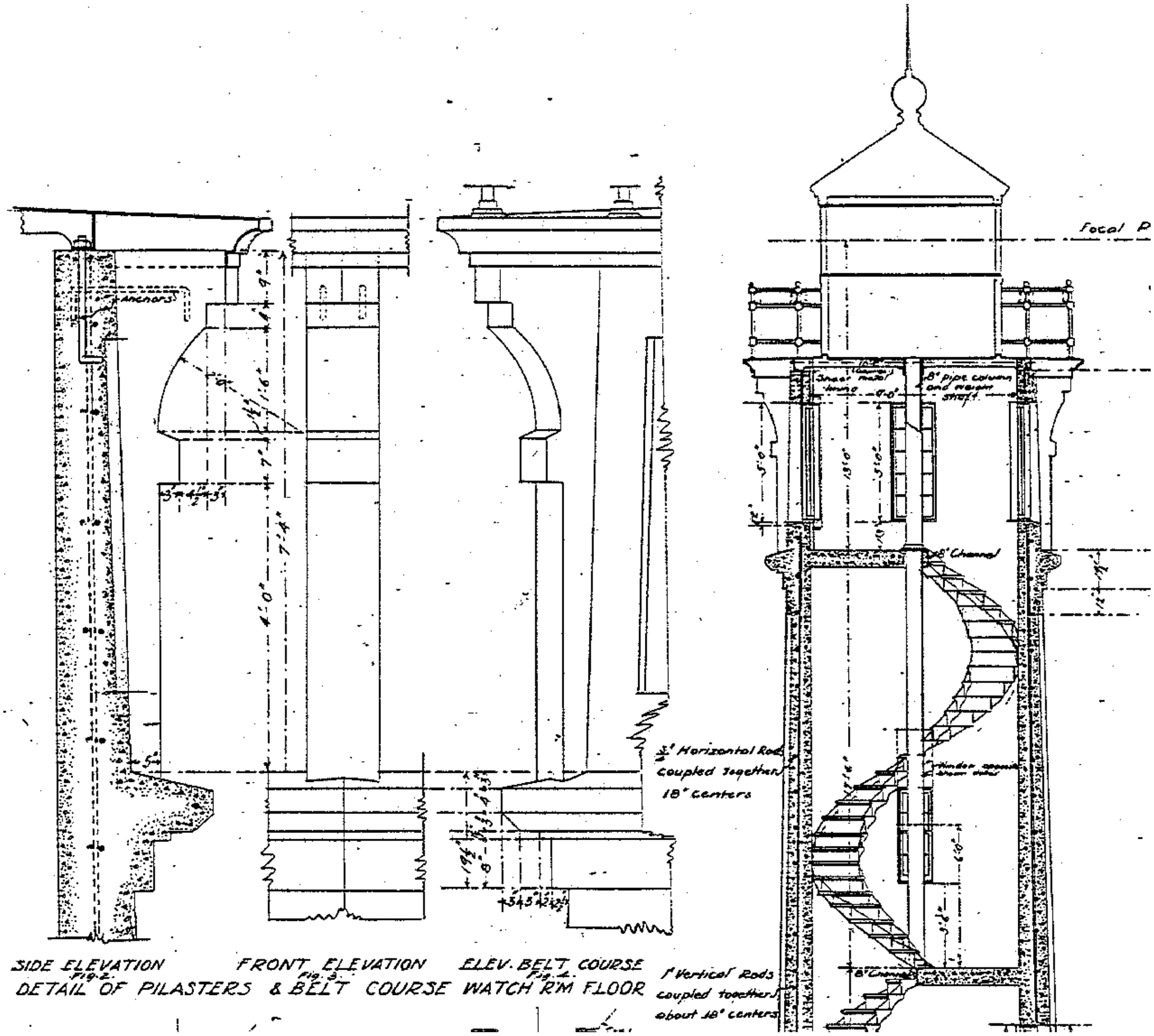


Figure 6. Image showing the placement of reinforcing bars in concrete lighthouse construction. (Image courtesy of CEU Oakland)

Causes of Concrete Deterioration

Deterioration of concrete lighthouses can be caused by environmental factors, inferior materials, poor workmanship, inherent structural design defects, and inadequate maintenance.

- ***Environmental factors*** are a principal cause of concrete deterioration. Concrete absorbs moisture readily if not coated; this is particularly troublesome in regions of recurrent freeze-thaw cycles. Freezing water produces expansive pressure in the cement paste or in nondurable aggregates. Carbon dioxide, another atmospheric component, can cause the concrete to deteriorate by reacting with the cement paste at the surface.
- ***Materials and workmanship*** in the construction of early concrete buildings are potential sources of problems. For example, aggregates used in early concrete, such as cinders from burned coal and certain crushed brick, absorb water and produce a weak and porous concrete. Alkali-aggregate reactions within the concrete can result in cracking and white surface staining. Aggregates were not always properly graded by size to ensure an even distribution of elements from small to large. The use of aggregates with similarly sized particles normally produced a poorly consolidated and therefore weaker concrete.

Early lighthouse builders sometimes inadvertently compromised concrete by using seawater or beach sand in the mix. A common practice, until recently, was to add salt to strengthen concrete or to lower the freezing point during cold-weather construction. These practices cause problems over the long term.

In addition, early concrete was not vibrated when poured into forms as it is today. More often it was tamped or rodded for consolidation; on floor slabs, it was often rolled with increasingly heavier rollers filled with water. These practices tended to leave voids (areas of no concrete) at congested areas, such as at reinforcing bars at column heads and other critical structural locations. Areas of connecting voids seen when concrete forms are removed are known as 'honeycombs' and can reduce the protective cover over the reinforcing bars.

Other problems caused by poor workmanship are not unknown in later concrete work. If the first layer of concrete is allowed to harden before the next one is poured next to or on top of it, joints can form at the interface of the layers. In some cases, these 'cold joints' visibly detract from the architecture, but are otherwise harmless. In other cases, 'cold joints' can permit water to infiltrate, and subsequent freeze-thaw action can cause the joints to move. Dirt packed in the joints allows weeds to grow, further opening paths for water to enter. Inadequate curing can also lead to problems. If moisture leaves newly poured concrete too rapidly because of low humidity, excessive exposure to sun or wind, or use of too porous a substrate, the concrete will develop shrinkage cracks and will not reach its full potential strength.

- ***Structural design defects*** in historic concrete structures can be an important cause of deterioration. For example, the amount of protective concrete cover around reinforcing bars was often insufficient. Another design problem in early concrete buildings is related to the absence of standards for expansion-contraction joints to prevent stresses caused by thermal movements, which may result in cracking.
- ***Improper maintenance*** of historic lighthouses can cause long-term deterioration of concrete. Water is a principal source of damage to historic concrete (as to almost every other material), and prolonged exposure to it can cause serious problems. Unrepaired roof and plumbing leaks, leaks through exterior cladding, and unchecked absorption of water from damp earth are potential problems. Deferred repair of cracks allowing water penetration and freeze-thaw attacks can even cause a structure to collapse. In some cases the application of waterproof surface coatings can aggravate moisture-related problems by trapping water vapor within the underlying material.

Major Signs of Concrete Deterioration

- ***Cracking*** occurs over time in virtually all concrete. Cracks vary in depth, width, direction, pattern, location, and cause. Cracks can be either active or dormant (inactive). Active cracks widen, deepen, or migrate through the concrete. Dormant cracks remain unchanged. Some dormant cracks, such as those caused by shrinkage during the curing process, pose no danger, but if left unrepaired, they can provide convenient channels for moisture penetration, which normally causes further damage.

  Structural cracks can result from temporary or continued overloads, uneven foundation settling, or original design inadequacies. Structural cracks are active if the overload is continued or if settlement is ongoing; they are dormant if the temporary overloads have been removed, or if differential settlement has stabilized. Thermally-induced cracks result from stresses produced by temperature changes. They frequently occur at the ends or corners of older concrete structures built without expansion joints capable of relieving such stresses. Random surface cracks (also called 'map' cracks because of their resemblance to the lines on a road map) that deepen over time and exude a white gel that hardens on the surface are caused by an adverse reaction between the alkalis in a cement and some aggregates.

Since superficial repairs that do not eliminate underlying causes will only tend to aggravate problems, professional consultation is recommended in almost every instance where noticeable cracking occurs.

- ***Spalling*** is the loss of surface material in patches of varying size. It occurs when reinforcing bars corrode, thus creating high stresses within the concrete. As a result, chunks of concrete pop off from the surface. Similar damage can occur when water absorbed by porous aggregates freezes. Vapor-proof paints or sealants, which trap moisture beneath the surface of the impermeable barrier, can also cause spalling. Spalling may also result from the improper consolidation of concrete during construction. In this case, water-rich cement paste rises to the surface (a condition known as laitance). The surface weakness encourages scaling, which is spalling in thin layers.
- ***Deflection*** is the bending or sagging of concrete beams, columns, joists, or slabs, and can seriously affect both the strength and structural soundness of concrete. It can be produced by overloading, by corrosion, by inadequate construction techniques (use of low strength concrete or undersized reinforcing bars, for example), or by concrete creep (long-term shrinkage). Corrosion may cause deflection by weakening and ultimately destroying the bond between the rebar and the concrete, and finally by destroying the reinforcing bars themselves. Deflection of this type is preceded by significant cracking at the bottom of the beams or at column supports. Deflection in a structure without widespread cracking, sparing, or corrosion is frequently caused by concrete creep.
- ***Stains*** can be produced by alkali-aggregate reaction, which forms a white gel exuding through cracks and hardening as a white stain on the surface. Efflorescence is a white, powdery stain produced by the leaching of lime from Portland cement, or by the pre-World War II practice of adding lime to whiten the concrete. Discoloration can also result from metals inserted into the concrete, or from corrosion products dripping onto the surface.
- ***Erosion*** is the weathering of the concrete surface by wind, rain, snow, and salt air or spray. Erosion can also be caused by the mechanical action of water channeled over concrete, by the lack of drip grooves in belt courses and sills, and by inadequate drainage.
- ***Corrosion,*** the rusting of reinforcing bars in concrete, can be a most serious problem. Normally, embedded reinforcing bars are protected against corrosion by being buried within the mass of the concrete and by the high alkalinity of the concrete itself. This protection, however, can be destroyed in two ways. First, by carbonation, which occurs when carbon dioxide in the air reacts chemically with cement paste at the surface and reduces the alkalinity of the concrete. Second, chloride ions from salts combine with moisture to produce an electrolyte that effectively corrodes the reinforcing bars. Chlorides may come from seawater additives in the original mix, or from prolonged contact with salt spray, or de-icing salts. Regardless of the cause, corrosion of reinforcing bars produces rust, which occupies significantly more space than the original metal, and causes expansive forces within the concrete. Cracking and spalling are frequent results. In addition, the load-carrying capacity of the structure can be diminished by the loss of concrete, by the loss of bond between reinforcing bars and concrete, and by the decrease in thickness of the reinforcing bars themselves. Rust stains on the surface of the concrete are an indication that internal corrosion is taking place.

Inspecting for Concrete Problems

In order to develop an effective treatment plan for concrete problems, an in-depth inspection must be made of the 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 Concrete Lighthouses	
THE SITE	
Look For:	*Possible Problems:*
Environment	
Typical climatic conditions, including average temperatures, wind speeds and directions, humidity levels, average snow accumulation, ice, wave action, salt spray, and blown sand	Severe conditions can lead to concrete deterioration, including cracking, spalling, surface erosion, and efflorescence. Concrete lighthouse features can be broken or damaged by the weight of excessive ice buildup or by the impact of violent wave action or wave-carried debris.
Number of freeze-thaw cycles	Severe cycles can produce damage from frost action if moisture is trapped in concrete walls or there is a lack of total structure ventilation. Daily freeze-thaw cycles may also cause excessive condensation buildup within the tower, promoting fungal growth and rot as well as causing iron components such as stairs, landings, and hatches to rust and deteriorate.
Location near sea	Salt in the air can lead to efflorescence forming on the concrete.
Acid rain in the region or from nearby industry or from automobile exhaust	Acid rain can cause damage to concrete.
Location in the flood plain of a river, lake, or sea	Prolonged immersion in floodwater can bring damaging moisture to foundations and walls.
Exposed or sheltered locations/elements of a lighthouse	Exposure to the sun and elements affects moisture evaporation and rain penetration. Portions of the lighthouse that do not receive sunlight are susceptible to mildew and other forms of biological attack.
Terrain	
Soil type—clay, sand, rock	The type of soil influences water drainage around the structure. Excessive water in the soil can cause rising damp, leading to structural problems.
Slope away from lighthouse on all sides	If no slope exists, puddles will form at the base of the lighthouse during heavy rains. This may lead to localized ground saturation and to water penetration. Localized ground saturation may cause soil around the lighthouse to shift, possibly resulting in uneven settlement.

Look for:	*Possible Problems:*
Earth covering part of a concrete wall or foundation	Moisture accumulation or penetration is possible.
Asphalt or other impervious paving touching the lighthouse foundation (if exposed) or walls	Detrimental water accumulation and rain splash-back onto the walls can result. Splash-back can saturate the concrete, which may cause premature failure of exterior coatings (if present).
Trees and Vegetation	
Species of trees within 50 feet of lighthouse	Elms and some poplars dry up clay soil, possibly leading to foundation failure.
Branches rubbing against a wall or roof	Branches may abrade surfaces.
Ivy or creepers on walls	Leaves prevent proper drying of the concrete surface.
THE LIGHTHOUSE	
Exterior Walls	
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 structure members or caused excessive moisture infiltration.
Construction method—solid or cavity wall	Knowing how a tower wall is constructed will help in analyzing problems and selecting appropriate treatments.
Embedded iron (steel) anchors, structural members, reinforcement bars, etc.	As iron (steel) rusts, it expands; this expansion can damage the surrounding concrete.
Evidence that parts of the lighthouse were constructed at different times or of different materials	Similar problems with various parts may need different treatments because of different materials.
Attached antennas, range finders, auxiliary or replacement lights, etc.	Heavy devices which are cantilevered off the side of the tower wall may cause eccentric loading. If this load is improperly distributed, severe cracking and possible localized failure may result.
Cracks	Cracks indicate that movement has occurred within the wall. Small cracks may be patched; large cracks may require reconstruction of the affected area.
Enlarging cracks	Active cracks indicate a continuing problem. The cause must be dealt with before the crack itself is repaired.
Spalling of concrete surface	Spalling indicates that the internal reinforcing bars have corroded, causing high stresses within the concrete. As a result, the concrete ‘pops’ off in chunks, exposing the corroded reinforcing bar.

Look for:	*Possible Problems:*
Windows and Doors	
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 lighthouse wall.
Sealed window and door frames	If caulking is missing or deteriorated around window and door frames, moisture can penetrate into the wall cavity and cause deterioration of the window or door frame, as well as of the concrete.
Foundation	
Uneven settlement	This may cause the leaning tower effect and possibly result in collapse of the lighthouse.
Composition of foundation walls	Stone or brick are more likely than concrete to allow water to infiltrate.
Undermining of the foundation caused by erosion	Undermining may cause a catastrophic failure of the foundation and may result in total lighthouse collapse. The remedy is to address the cause of the erosion. Minor undermining should be back-filled with a stable, graded fill material containing a range of aggregate sizes for good compaction. For major undermining a structural engineer should be consulted.
Interior	
Cracked plaster, signs of patching, stairs and landings askew	These may be signs of lighthouse settlement.
Damp walls, mold or mildew stains on walls, efflorescence, 'bubbling' or blistering plaster or painted finish, rotting wood	These indicate water infiltration or severe condensation or moisture buildup within the tower.
Concrete Components	
Materials	
Composition, including secondary materials; characteristics—color and color variation; texture—smooth or patterned surfaces	Types of materials indicate the susceptibility or resistance to damage and should be matched if the concrete component is repaired or replaced.
Areas of delicate moldings or fine castings	These sections may need special attention or protection during rehabilitation.
Missing or spalled patches of concrete	Missing material may allow water penetration, as well as indicate corrosion of the concrete reinforcement.
Evidence of previous patches	Patches are signs of past damage or deterioration. If the repair was not made properly, the patch may cover a potential source of future deterioration. Any patched areas should be monitored and inspected regularly for signs of deterioration.

Look for:	*Possible Problems:*
Dirt or stains	Surface stains usually cause few problems other than being unpleasant to look at. Streaking on the surface of the lighthouse tower, however, may be an indicator of deteriorating materials that are not readily visible, such as rust streaks from embedded iron anchors or reinforcement rods, etc.
Moisture	
Water penetration through joints between concrete and other lighthouse components, through expansion joints or, rarely, through the concrete itself	Moisture can lead to deterioration of the concrete and other parts of the structure.
Staining or white deposits (efflorescence), mold and mildew stains on walls	White deposits are evidence of excessive dampness.
Location and type of salt deposits on surface; standing water	Deposits can indicate a source of dampness, such as rainwater or ground water, inside the lighthouse materials.
Coatings	
Applied coating type: stucco, lime mortar wash, or paint	Applied stucco is common lighthouse coating; the surface should be inspected for cracks that could allow water infiltration. Lime mortar wash or whitewash is another common concrete lighthouse coating. This coating is considered a sacrificial coating. The lime mortar wash protects the lighthouse by wearing away over time. This coating is meant to be reapplied periodically like paint.
Paint; type of paint	A paint that does not breathe can trap moisture within the concrete and cause the surface to spall.
Blistering, flaking and peeling paint, failure of plaster or stucco and interior painted finishes	These conditions indicate the paint does not breathe.
Waterproof or water-repellent coating	Such coatings often trap moisture within the concrete.

PRESERVATION TREATMENTS

WARNING: Many of the maintenance and repair techniques described in this text, particularly those relating to cleaning and painting, are potentially dangerous and should be carried out only by experienced and qualified workmen using protective equipment suitable to the task. It may be necessary to involve a USCG engineer or architect, preservation architect, or building conservator familiar with lighthouse preservation to assess the condition of the concrete and prepare contract documents for its treatment.

Many of the maintenance and repair techniques described in this text, if not properly performed, can cause potentially irreversible damage to the character-defining features and historic fabric of the concrete lighthouse. Therefore, if the tasks to be performed are beyond the skills of onsite personnel, they should be carried out by experienced and qualified workmen. In the **Beyond Basic Preservation** section of this Handbook, examples of treatments that are considered rehabilitation and restoration are illustrated and discussed.

Protection and Stabilization (Mothballing)

Despite their inherent durability, concrete lighthouses are still susceptible to accelerated decay. A historic concrete lighthouse that receives only minimal routine maintenance is highly vulnerable to decay if it is not protected and stabilized properly. A thorough inspection and diagnosis should be performed using the inspection chart in the preceding section as a guide; the results of which can then be used to develop a protection and stabilization plan. The following recommended protection and stabilization guidelines for vacant historic concrete lighthouses are minimum treatment requirements to prevent any further damage from occurring.

Weatherization

To protect a historic concrete lighthouse, the exterior envelope should be completely weathertight. When moisture penetrates into concrete walls and foundations, it can be exceedingly detrimental to the integrity of the concrete. Moisture in a wall or foundation may cause various types of damage: reinforcement bars may rust, expansion caused by freezing may crack surrounding concrete, efflorescence (the leaching of salts out of the concrete) may appear, adjacent wood elements may rot, adjacent metal elements may rust or corrode, or fungal growth may occur.

To prevent moisture penetration, be sure the following moisture infiltration points are weathertight or functioning properly:

- ***Lantern glass:*** Lantern glass, frames, and roofs must be weathertight before mothballing. Refer to the **Lantern** section for more information concerning the weatherproofing of the lantern components. (See Figures 7 and 8 in the **Masonry** section which illustrate a broken glass panel and a temporary repair using a metal plate and caulking.)

  A temporary patch repair will prevent water from entering the lantern and therefore help avoid incurring further damage. This fix should be considered only as an interim treatment until the glass can be replaced. For more on lantern glass replacement refer to **Lantern** section.

- ***Built-in gutter systems:*** All rainwater gutter systems (lantern roofs, or other tower roof forms) should be cleaned and checked for holes. All holes and non-functioning gutter system components should be repaired. For more information refer to the discussion on roofing in the **Lantern** section.

- ***Gallery decks:*** In most concrete lighthouses gallery decks are cast iron, stone, or concrete. These decks are generally laid directly on top of the concrete wall structure. The decking should be sloped away from the lighthouse to shed the water away from the structure. If the decking material is not weathertight, moisture can enter the interior of the lighthouse or saturate the concrete wall. See Figure 7 for signs that a gallery deck is failing. Refer to the **Lantern** section for more information concerning the weatherproofing of gallery decks.
- ***Door and window frames:*** The joints along the perimeter of doors and windows where a wood or metal frame is fitted into a concrete opening should be caulked to prevent moisture from entering the walls. See the **Windows** section for the proper caulk for this application.
- ***Protective coatings:*** Lighthouses were often painted as a protective measure and for identification as a daymark. As part of a protective treatment, the exterior coating should be checked for loose and flaking paint. Any deteriorating areas should be scraped and repainted to match the existing color.

WPTC photo

Figure 7. The concrete gallery deck on this concrete lighthouse has been covered with a rubber membrane. This covering should be checked regularly for leaks.

WPTC photo

Figure 8. Close-up view of a glass-block window in a concrete lighthouse. The joint where the glass block meets the concrete wall should be caulked to prevent moisture infiltration.

Ultimately, the entire lighthouse should have all loose and flaking paint removed and a new coating applied according to the manufacturer's specifications. If the overall condition of the coating system is sound and there are only a few bare spots, however, the lighthouse can be spot-painted to provide a weatherproof coating. Either of these actions will result in a coating system that will require minimal interim maintenance. For more information refer to the discussion on repainting in the following repair section.

If the lighthouse was historically protected by a stucco coating, the surface should be checked for loose or delaminating patches. Any sections that are loose could trap moisture and cause premature deterioration of the concrete structure. The repair of damaged stucco coatings is covered in the following section on concrete repair.

- ***Open cracks in walls:*** Cracks in exterior concrete walls indicate that movement has

Figure 9. Patches of spalled concrete: familiar with lighthouse preservation the one pictured here should be repaired to protect the underlying concrete structure.

occurred, either movement caused by shrinkage (in the case of stucco) or by settlement or mechanical impact. Cracks should be monitored to determine if movement is still occurring and structural stabilization is necessary before the crack is filled. Refer to the following repair section for more information concerning wall repair.

Stabilization

If funds are insufficient to make repairs, structural stabilization should be performed as a less expensive temporary alternative. Temporary blocking in of window and door openings and installation of interior or exterior shoring or bracing are all stabilization methods. The stabilization treatment utilized should not permanently damage historic character-defining features and should be easily reversible so that when the budget allows, the structure can be properly repaired. Refer to the following

Figure 10. Cracks like the one here, extending down from the belt course of this concrete lighthouse, should be monitored for movement before any patching is performed.

repair section for more information on structural concrete repairs.

Ventilation

Much like masonry lighthouses, concrete lighthouses are difficult to ventilate without resorting to extensive louvering and/or mechanical exhaust fan systems. During the summer months concrete lighthouses will need to have maximum air exchange to eliminate damaging condensation on the interior walls and woodwork and iron components. In order to achieve this, almost every window opening will need to be fitted with some type of passive louvered ventilation. Installation of window-mounted passive louver systems is covered in the **Windows** section of this handbook. For more information on lighthouse ventilation refer to the **Interiors** section.

Figure 11. These replacement lighthouse doors have screened louvers that cover approximately 25% of the door opening to maximize air exchange.

Fire Protection

Despite the fact that concrete lighthouses are constructed of noncombustible materials, fire can still be a threat to their preservation. The impacts of a fire are devastating and will often cause serious irreversible damage and loss to historic interior fabric. For guidance on these issues, refer to "Fire Protection and Protection Objectives" under **Related Activities** in Part VI.

Planning for Concrete Repair

Whatever the causes of deterioration, careful analysis, supplemented by testing, is vital to the success of any historic concrete repair project. Undertaken by experienced engineers or architects, the basic steps in a program of testing and analysis are document review, field survey, testing, and analysis.

- ***Document review:*** While plans and specifications for historic concrete lighthouses are rarely extant, they can be an invaluable aid, and every attempt should be made to find them. They may provide information on the intended composition of the concrete mix, or on the type and location of reinforcing bars. Old photographs, records of previous repairs, documents for lighthouses of the same basic construction or age, and news reports may also document original construction or changes over time.
- ***Field survey:*** A thorough visual examination can assist in locating and recording the type, extent, and severity of stress, deterioration, and damage.
- ***Testing:*** Two types of testing, onsite and laboratory, can supplement the field condition survey as necessary. Onsite, nondestructive testing may include use of a calibrated metal detector or sonic tests to locate the position, depth, and direction of reinforcing bars. Voids can frequently be detected by "sounding" with a metal hammer. Chains about 30 inches long attached to a 2-foot-long crossbar, dragged over the slabs while listening for hollow reverberations, can locate areas of slabs that have delaminated. In order to find areas of walls that allow moisture to penetrate to the lighthouse interior, areas may be tested from the outside by spraying water at the walls and then inspecting the interior for water. If leaks are not readily apparent, sophisticated equipment is available to measure the water permeability of concrete walls.

  If more detailed examinations are required, nondestructive instruments are available that can assist in determining the presence of voids or internal cracks, the location and size of rebars, and the strength of the concrete. Laboratory testing can be invaluable in determining the composition and characteristics of historic concrete and in formulating a compatible design mix for repair materials. These tests, however, are expensive. A well-equipped concrete laboratory can analyze concrete samples for strength, alkalinity, carbonation, porosity, alkali-aggregate reaction, presence of chlorides, and past composition.
- ***Analysis:*** Analysis is probably the most important step in the process of evaluation. As survey and test results are revised in conjunction with available documentation, the analysis should focus on determining the nature and causes of the concrete problems, on assessing both the short-term and long-term effects of the deterioration, and on formulating proper remedial measures.

Repair

Repairs should be undertaken only after the planning measures outlined above have been followed. Principal concrete repair treatments are discussed below. While they are presented separately here, in practice, preservation projects typically incorporate multiple treatments. When performing any of the following treatments, the gentlest means possible should be used.

The following general guidelines should be followed when performing any treatment on a concrete lighthouse.

- Identify, retain, and preserve concrete features that are important in defining the overall historic character of the lighthouse.
- Identify finished surface texture, color, and coatings. Some walls bear the impression of wooden form boards used during construction. Any repairs made to surfaces with such impressions should reproduce the same finish to disguise the repaired area.
- When determining the best treatment for coating removal, coating application, or applied patches, test panels should be prepared using the proposed treatments in inconspicuous locations.
- Identify the age and potential inherent preservation problems in original materials or construction methods, which may require laboratory analysis. Any rehabilitation plan must be based on a thorough knowledge of the properties of the original materials.
- Identify type and location of reinforcing bars.
- Be sure to evaluate and treat the various causes of deterioration, such as leaking roofs or gutters, differential settlement of the lighthouse, capillary action (such as rising damp), or chloride contamination.
- Do not remove or radically change concrete features that are important in defining the overall historic character of the lighthouse.

Cleaning

Clean concrete only when necessary to halt deterioration. Heavy soiling, bird debris, ferrous stains, graffiti, and biological growth can trap moisture and damaging chemicals against the surface of the concrete, initiating and sustaining deterioration. Consider the following guidelines to prevent soiling and to determine the most effective cleaning methods.

- Cover areas where pigeons roost with specially manufactured and sensitively installed bird netting.
- Conduct concrete cleaning tests if cleaning is appropriate. Tests should be observed over a sufficient period of time to assess both the immediate and the long-range effects of cleaning. Clean concrete surfaces with the gentlest method possible, such as a low-pressure water rinse using a mild detergent applied with natural bristle brushes. Chemicals applied as a poultice may be necessary to remove tenacious stains without abrading surface texture or detail. After treatment, thoroughly rinse the surface of all residual chemicals.
- Do not use a cleaning method that involves water or liquid chemical solutions when there is any possibility of freezing temperatures.
- Do not clean with chemical products that will damage concrete. When using chemical cleaning products, be sure to rinse the surface clean of chemicals.
- Do not apply high-pressure water cleaning methods that will damage historic surface treatment or coating and drive water into the wall, causing corrosion of the steel reinforcing bars.

Coatings

As a protective measure and for identification as a daymark, most concrete lighthouses had an external coating. The external coating was the first line of defense against the elements. Typically this was either a paint, stucco, or in some cases whitewash or lime-mortar-wash coating. As part of preserving the lighthouse, all coatings must be maintained.

Each type of coating protected the lighthouse in a slightly different manner. Paint provides a film over the concrete that prevents water from penetrating. Stucco is a three-layer mortar-and-sand shell that bonds to the concrete to prevent water from penetrating. Whitewash and lime mortar wash are lime-and-water-based "sacrificial" coatings that protect the lighthouse by slowly deteriorating as they weather.

The key to the preservation of an external coating system, especially a lighthouse coating that is subjected to severe marine environment conditions, is a complete understanding of the mechanics of the system. Whether simply touching up the coating or following through with a complete restoration of the external coatings, it is wise to seek the advice of paint manufacturers' technical representatives.

All external coatings, especially paints which may date from the early 20th century, should be tested for lead and asbestos content. If lead or asbestos is present, local codes on health, life safety, and environmental requirements must be met. Lead or asbestos found in otherwise sound paint layers, does not dictate the removal of that paint. In most cases it is far safer and more cost-effective to leave intact paint areas in place. For further information refer to NPS *Preservation Briefs 37: Appropriate Methods of Reducing Lead-Paint Hazards in Historic Housing.*

Refer to the **Masonry** section for more information on the repair of stucco and lime-mortar-wash coatings.

When performing coating removal and reapplication on a historic concrete lighthouse, consider the following general guidelines:

- Inspect painted and stuccoed concrete surfaces to determine whether recoating is necessary. Failed coatings are characterized by flaking or loss of adhesion.
- Locate areas of delaminated stucco and incipient concrete spalls by sounding. Spalled concrete or delaminated stucco will reverberate with a distinctly hollow sound.
- Remove damaged or deteriorated coating only to the next sound layer using the gentlest method possible (e.g., hand scraping) before recoating.
- Evaluate the overall condition of the concrete to determine if protection and maintenance are sufficient, or if material analysis and repairs are necessary.

Coating Removal

When there is extensive failure of the protective coating, most or all of the paint must be removed to prepare the surfaces for new protective coatings. The selection of an appropriate technique depends upon how much paint failure and concrete deterioration has occurred. Local environmental regulations may restrict the options for cleaning and paint removal methods, as well as the disposal of materials.

Many of these techniques are *potentially dangerous* and should be carried out only by experienced and qualified workers using proper personal protective equipment such as full-face respirators, eye protection, protective clothing, and optimum workplace safety conditions. Before selecting a process, test panels should be prepared on the concrete to be cleaned to determine the relative effectiveness of various techniques. The cleaning process will very likely expose additional coating defects, cracks, and deterioration that may not have been obvious before.

The following are guidelines to consider when removing coatings from historic concrete lighthouses:

- Proven paint removal methods include: water based paint strippers designed for concrete use, *low* pressure needle guns, and hand scraping.

(For more information on the use of needle guns refer to the case study on the rehabilitation work performed at Anacapa Island Lighthouse in Part V., **Beyond Basic Preservation**.)

- Do not sandblast concrete surfaces using dry or wet abrasives. This treatment will permanently erode the surface of the material and accelerate deterioration.
- Do not remove paint or stucco from a historically coated concrete lighthouse and not recoat, thus changing the appearance.
- Do not remove sound stucco, then recoat the entire lighthouse only to achieve a uniform appearance.
- Do not remove paint or stucco by methods that destroy concrete, such as sandblasting, application of caustic solutions, or high-pressure water blasting.

Recoating

A thorough study of materials is recommended before starting any coating program. An understanding of the substrate, or base material, must also be had. This can best be achieved by a thorough inspection of both the substrate and the existing coating system. Any areas of deteriorated substrate should be examined and repaired before recoating.

Coatings applied to masonry surfaces should 'breathe'. This means the coating should allow the transpiration of moisture at the microscopic level. Modern paint coatings are able to do this. A successful coating system for exterior concrete surfaces is to use an acrylic primer with an elastomeric acrylic top coat with mold and fungus inhibitors, mineral oxide pigments, and freeze-thaw stabilizers. A successful coating system for interior concrete is to use an acrylic primer and a 100% acrylic emulsion top coat with a minimum 55% permeability rating. This coating system will allow the concrete to breathe, thus allowing moisture in the concrete to escape.

- Apply compatible coating systems following proper surface preparation. Testing is mandatory to ensure that replacement material is compatible with the aesthetic and physical properties of the existing fabric and to determine short- and long-term adverse effects.
- Recoat with materials, textures, and colors that are historically appropriate to the lighthouse.
- Follow the manufacturer's specifications for surface preparation and application of paint. This will ensure that the coating will perform as designed. For more information on types of masonry paints currently being used in the field, refer to the case study on Anacapa Island Lighthouse in Part V., **Beyond Basic Preservation**.
- Use brushes to apply coatings. Brush application will provide the best coverage as well as be historically accurate. The use of brushes will also eliminate the need to contain overspray that is associated with spray applications.
- Do not apply paint or other coatings such as stucco to concrete in a manner that creates a new appearance.

Damaged Concrete Repair

Repair of historic concrete may consist of either patching the historic material or filling in with new material worked to match the historic material. If replacement is necessary, duplication of historic materials and detailing should be as exact as possible to assure a repair that is functionally and aesthetically acceptable. The correction and elimination of concrete problems can be difficult, time-consuming, and costly. Yet the temptation to resort to temporary solutions should be avoided, since their failure can expose a lighthouse to further and more serious deterioration, and in some cases can mask underlying structural problems that could lead to serious safety hazards.

The following are guidelines to consider when repairing damaged or deteriorated historic concrete.

- ***Repair of Cracking***

  Hairline, nonstructural cracks that show no sign of worsening normally need not be repaired. Cracks larger than hairline cracks, but less than approximately one-sixteenth of an inch, can be repaired with a mix of cement and water. If the crack is wider than one-sixteenth of an inch, fine sand should be added to the mix to allow for greater compatibility, and to reduce shrinkage during drying. Field trials will determine whether the crack should be routed (widened and deepened) minimally before patching to allow sufficient penetration of the patching material. To ensure a long-term repair, the patching materials should be carefully selected to be compatible with the existing concrete as well as with subsequent surface treatments such as paint or stucco.

  When it is desirable to reestablish the structural integrity of a concrete lighthouse involving dormant cracks, epoxy injection repair should be considered. An epoxy injection repair is made by sealing the crack on both sides of a wall or a structural member with an epoxy mortar, leaving small holes, or 'ports' to receive the epoxy resin. After the surface mortar has hardened, epoxy is pumped into the ports. Once the epoxy in the crack has hardened, the surface mortar can be ground off, but the repair may be visually noticeable. (It is possible to inject epoxy without leaving noticeable patches, but the procedure is much more complex and is beyond the scope of this text.)

  Other cracks are active, changing their width and length. Active structural cracks will move as loads are added or removed. Thermal cracks will move as temperatures fluctuate. Thus, expansion-contraction joints may have to be introduced before repair is undertaken. Active cracks should be filled with sealants that will adhere to the sides of the cracks and will compress or expand during crack movement. The design, detailing, and execution of sealant-filled cracks require considerable attention, or else they will detract from the appearance of the historic lighthouse.

  Random (map) cracks throughout a structure are difficult to correct, and may be unrepairable. Repair, if undertaken, requires removing the cracked concrete. A compatible concrete patch to replace the removed concrete is then installed. For some lighthouses without significant historic finishes, an effective and economical repair material is probably a sprayed concrete coating, troweled or brushed smooth. Because the original concrete will ultimately contaminate new concrete, lighthouses with map cracks will present continuing maintenance problems.

- ***Repair of Spalling***

  Repair of spalling entails removing the loose, deteriorated concrete and installing a compatible patch that dovetails into the existing sound concrete. In order to prevent future crack development after the spall has been patched and to ensure that the patch matches the historic concrete, great attention must be paid to the treatment of rebars, the preparation of the existing concrete substrate, the selection of compatible patch material, the development of good contact between patch and substrate, and the curing of the patch.

  Once the deteriorated concrete in a spalled area has been removed, rust on the exposed rebars must be removed by wire brush or sandblasting. An epoxy coating applied immediately over the cleaned rebars will diminish the possibility of further corrosion. As a general rule, if the rebars are so corroded that a structural engineer determines they should be replaced, new supplemental reinforcing bars will normally be required, assuming that the rebar is important to the strength of the concrete. If not, it is possible to cut away the rebar.

  Proper preparation of the substrate will ensure a good bond between the patch and the existing concrete. If a large, clean break or other smooth surface is to be patched, the contact area should be roughened with a hammer and chisel. In all cases, the substrate should be kept moist with wet rags, sponges, or running water for at least an hour before placement of the patch. Bonding between the patch and substrate can be encouraged by scrubbing the substrate with cement paste, or by applying a liquid bonding agent to the surface of the substrate. Admixtures such as epoxy resins, latexes, and acrylics in the patch may also be used to increase bonding, but this may cause problems with color matching if the surfaces are to be left unpainted.

  Compatible matching of patch material to the existing concrete is critical for both appearance and durability. In general, repair material should match the composition of the original material (as revealed by laboratory analysis) as closely as possible so that the properties of the two materials, such as coefficient of thermal expansion and strength, are compatible. Matching the color and texture of the existing concrete requires special care. Several test batches of patching material should be mixed by adding carefully selected mineral pigments that vary slightly in color. After the samples have cured, they can be compared to the historic concrete and the closest match selected.

Contact between the patch and the existing concrete can be enhanced through the use of anchors, preferably stainless-steel hooked pins, placed in holes drilled into the structure and secured in place with epoxy. Good compaction of the patch material will encourage the contact. Compaction is difficult when the patch is 'laid-up' with a trowel without the use of forms; by building up thin layers of concrete, however, each layer can be worked with a trowel to achieve compaction. Board forms will be necessary for large patches. In cases where the existing concrete has a significant finish, care must be taken to pin the form to the existing concrete without marring the surface. The patch in the form can be consolidated by rodding or vibration.

Because formed concrete surfaces normally develop a sheen that does not match the surface texture of most historic concrete, the forms must be removed before the patch has fully set. The surface of the patch must then be finished to match the historic concrete. A brush or wet sponge is particularly useful in achieving matching textures. It may be difficult to match historic concrete surfaces that were textured, as a result of exposed aggregate for example, but it is important that these visual qualities be matched. Once the forms are removed, holes from the bolts must also be patched and finished to match adjacent surfaces.

Regardless of size, a patch containing cement binder (especially Portland cement) will tend to shrink during drying. Adequate curing of the patch may be achieved by keeping it wet for several days with damp burlap bags. Note that although greater amounts of sand will reduce overall shrinkage, patches with a high sand content normally will not bond well to the substrate.

- ***Repair of Deflection***

  Deflection can indicate significant structural problems and often requires the strengthening or replacement of structural members. Because deflection can lead to structural failure and serious safety hazards, its repair should be left to engineering professionals.

- ***Repair of Erosion***

  Repair of eroded concrete will normally require replacing lost surface material with a compatible patching material (as outlined above) and then applying an appropriate finish to match the historic appearance. The elimination of water coursing over concrete surfaces should be accomplished to prevent further erosion. If necessary, drip grooves at the underside of overhanging edges of sills, belt courses, cornices, and projecting slabs should be installed.

Limited Replacement In Kind

If repair by stabilization, consolidation, and conservation proves inadequate, the next level of intervention involves the *limited replacement in kind* of extensively deteriorated or missing *parts* of features when there are surviving prototypes (for example, concrete cornices and door pediments, window architraves, gallery brackets, etc). The replacement material needs to match the old both physically and visually, i.e., gray, portland-cement-based concrete needs to be replaced with gray, portland-cement-based concrete. Thus, with the exception of hidden structural reinforcement and new mechanical system components, substitute materials are not appropriate in the treatment *preservation*. Again, it is important that all new material be identified and properly documented for future research.

If prominent features are missing, then a *rehabilitation* or *restoration* treatment may be more appropriate.