Rehabilitating Water and Wastewater Treatment Plants

Selecting the right coatings and linings for severely deterioriated steel and concrete is critical for rehabilitating water and wastewater treatment facilities.

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Many municipalities are discovering that particular process structures and equipment in water and wastewater treatment facilities are subject to severely corrosive environments. However, the need for their protection is often identified only after significant deterioration has occurred.

The primary goals of rehabilitation are returning the structure or equipment to its original degree of integrity and installing a protective lining or coating system that is durable and requires little or no maintenance. Potential coating and linings systems must be identified, and the most suitable material and installation method must be selected for the identified conditions, constraints, and performance requirements. Issues commonly considered include:

- original materials of construction,
- corrosive (service) environment,
- type and extent of deterioration,
- suitability of specific lining systems,
- lining installation requirements,
- plant operating conditions,
- regulatory issues, and
- economics.

This article addresses the above issues and illustrates them with several case histories.

Materials of Construction

The materials used in the construction of water and wastewater treatment facilities include concrete, ferrous metals, plastics,
can be evaluated with adhesion pull test methods. One method follows ASTM D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.3 The minimum recommended surface strength varies by coating manufacturer and specific lining system as well as by the service conditions of the structure. Minimum values are usually 200-300 psi (1.4-1.75 MPa).1,2,4

Concrete inherently contains water. In sufficient quantity at the surface, water sharply reduces adhesion of nearly all restoration coating and lining systems. Additionally, moisture can yield adverse reactions and incomplete cure for some lining materials. The surface moisture depends on the relative porosity of the concrete and the amount of water available from the immediate environment.5 A simple test for excessive moisture is ASTM D 4263-83, Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method.6

The porosity of concrete affects moisture vapor transmission and the ease and depth of contaminant penetration. The capillary action of the concrete draws in moisture or contaminants.

While laitance and efflorescence can affect the performance of linings on new concrete, they are not typically present on older, deteriorated concrete surfaces. They have usually been removed during degradation of the concrete.

Surface uniformity, contamination, and hydrostatic conditions also require consideration.
For concrete structures requiring rehabilitation, surface uniformity is related to the surface roughness or texture from the loss of the cement binder and the exposure of aggregate, rather than bugholes or cavities frequently associated with new concrete. Loss of cement binder and exposed aggregate are more fully discussed below under Type and Extent of Deterioration. Contaminants can also sharply reduce or cause the eventual loss of adhesion of a coating or lining. Contaminants can be acidic, alkaline, organic, or ionic. Concrete surfaces at wastewater treatment facilities can have extensive contamination from greases, fats, and oils. Their removal is addressed under Installation Requirements.

Permeation or hydrostatic conditions occur when groundwater is present on the earth side of the concrete wall or when water is present on the backside of a common concrete wall. The pressure exerted corresponds to the elevation difference between the highest level of the causative water and the interior point of consideration. The lining can disbond and blister if the water pressure exceeds the tensile adhesion of the installed lining.

Ferrous Metals

Ferrous metals in water and wastewater treatment plants include carbon steel, stainless steel, ductile iron, and cast iron. Although grouped with ferrous metals, stainless steels generally resist most treatment plant environments. Therefore, they will not be discussed in this paper.

While carbon steel is used for pressure tanks and some smaller, water-holding structures, it is more frequently used for process mechanisms and piping systems. Ductile and cast iron are generally used for gates as well as piping systems. Removal of acidic, alkali, organic, and ionic contaminants from ferrous metals is the same as their removal from concrete.

Ferrous metal components with edges, angles, and stitch welds more frequently undergo coating breakdown and surface rusting. Therefore, during rehabilitation, these locations as well as surfaces with corrosion pits should be given individual attention. Specific attention for edges and angles can be as simple as brushed stripe coats before planned full surface coats. Seam sealers or caulk can be used to mitigate corrosion at stitch welds or other crevices. Ideally, edges are ground to a radius of 1/4 in. (6 mm), and welded joints are completely self-welded.

Welds with undercutting or adjacent spatter also cause more rapid deterioration of protective coating and lining systems. Therefore, existing welds with these imperfections should also be corrected before installing rehabilitation lining systems.

Additionally, cathodic protection can be installed to complement the performance of rehabilitation linings on submerged portions of metallic equipment.

Corrosive Environment

Corrosive environments in water and wastewater treatment facilities include those naturally present in incoming flows and those resulting from the application of specific treatment methods or chemicals.

Naturally Occurring Corrosives

Naturally occurring corrosives common to most wastewater facilities include acidic wastewater, hydrogen sulfide, and sulfuric acid. The most severe deterioration from these corrosives occurs on the exposed wall and slab underside surfaces at and above the flow line in enclosed or covered spaces. In these spaces, dissolved sulfides are released from turbulent wastewater as hydrogen sulfide. The hydrogen sulfide is subsequently converted to sulfuric acid by aerobic microbial oxidation. Sulfuric acid aggressively attacks both concrete and fer-
rous metals. Figure 1 shows the walls of a wastewater collection structure with extensive corrosion of concrete and reinforcing steel because of sulfuric acid attack.

Another naturally occurring corrosive is carbon dioxide. In enclosed spaces, it can degrade concrete, creating what is called carbonation. Combined with moisture, carbon dioxide can produce carbonic acid, which can also cause aggressive corrosion of metallic equipment and piping.

For water treatment plants, a naturally occurring corrosive can be raw water itself. Generally, soft water supplies are more corrosive to ferrous metals than hard waters. Hard waters with sufficient calcium ion and alkalinity have the tendency to deposit a protective layer of calcium carbonate. Similarly, waters that have low alkalinity can yield dissolution of calcium from concrete and cause its corresponding degradation.

Other naturally occurring corrosives in water treatment facilities can be dissolved gases such as carbon dioxide and hydrogen sulfide. These gases, where present in water treatment facilities, can cause corrosion similar to that in wastewater treatment facilities discussed above.

Corrosive Treatment Methods and Chemicals
Corrosive conditions in water and wastewater treatment plants can also result from specific treatment methods and chemicals. Granular activated carbon is used for removing organic matter from water and wastewater treatment processes. Contact tanks are generally constructed of steel or concrete, depending on whether the process is pressure or gravity flow, respectively. Steel tank surfaces without protective linings or with holidays in the linings can be subject to aggressive corrosion.

Similarly, treatment chemicals can degrade treatment plant equipment and structures. Most often, this degradation is localized and occurs at the point of concentrated chemical feed (i.e., before dilution within the tank or flow stream). Chlorine solution (hypochlorous acid) added to water and wastewater for disinfection is an example of one such treatment chemical. This treatment can yield both a chlorine residual and acidic conditions, which, when excessive, can corrode concrete and ferrous metals.

Depending on their localized concentration, other treatment chemicals, such as ferric chloride, sodium/calcium hypochlorite, aluminum sulfate (alum), ferrous sulfate, and sulfuric acid, can corrode concrete or ferrous metals.

Type and Extent of Deterioration
Understanding the type and extent of deterioration on equipment or a structure is critical when selecting a rehabilitation coating or lining system.

Concrete
Concrete deterioration can range from slight etching or partial loss of the surface cement binder to complete loss of the cement binder. Complete binder loss yields exposed, coarse aggregate with corroded reinforcing steel. Corroded reinforcing steel...
causes adjacent concrete to crack and spall.

Thus, following removal of contaminants and proper surface preparation, rehabilitation may vary from the application of a relatively thin film lining to an extensive restoration process requiring replacement of reinforcing steel, installation of surface repair mortars to return the surface to its original configuration, and application of a relatively thick coating.

Alternatively, following surface preparation and structural repairs, lining systems with unlimited film build may be suitable to provide corrosion protection without surface repair mortars.

**Ferrous Metals**
Degradation of ferrous metals can vary from coating breakdown and uniform surface rusting to deep pitting and broad metal loss. In extreme conditions, where hydrostatic loading or pressure is a concern, pits in basin or pipe walls with depths exceeding one-third of the original wall thickness should be reviewed for structural integrity by competent persons. When necessary, repair commonly involves filling the pits with weld metal or structural polymer material. Similarly, structural members with significant metal loss should be evaluated by a structural engineer to determine the extent of repair or metal replacement required before application of protective coatings and linings.

**Suitable Lining Systems**

**Limitations of Coal Tar Epoxy**
At one time, coal tar epoxy was considered the standard of the industry for water and wastewater treatment facilities. However, in recent years, its use has lessened because of regulations and an increased awareness of its limitations.

Potable water structures now require protection with lining systems certified to Standard 61 of the American National Standards Institute/NSF International (ANSI/NSF). The standard is entitled Drinking Water System Components—Health Effects. To the author's knowledge, no coal tar epoxies have achieved this certification. Health concerns about coal tar itself have similarly reduced its use in some locations.

Also, the performance limitations and installation requirements of coal tar epoxy are well known, resulting in less frequent usage. Severe acid conditions generated in some treatment plant exposures exceed the capabilities of many thin film materials.

For satisfactory performance, installed coal tar epoxy linings need to be holiday-free. However for new concrete structures, a holiday-free lining requires opening and sealing all bugholes. Many early installations did not follow these procedures, and as a result, failed prematurely.

Today, lining systems for rehabilitating structures and equipment at water and wastewater treatment facilities must provide long-term protection with little or no maintenance. Often, because of the considerable effort needed to remove the structure or equipment from service, only systems proven in the field should be considered.

**Wastewater Treatment Facilities**
More recently, systems for the rehabilitation of concrete at wastewater treatment facilities have been fairly well defined by test programs and field experience.

Generic lining systems that have demonstrated varying performance from testing or field experience include:

- polyester,
- vinyl ester,
- epoxy,
- coal tar epoxy,
- polyurea,
- polyvinyl chloride (PVC) liner/PVC liner with mastic or urethane,
- urethane,
- sulfur concrete,
• potassium silicate concrete, and
• calcium aluminum concrete.

Many of the organic resin linings systems have shown enhanced performance when installed in a mortar form. That is, they are sand-extended or filled. Several can be reinforced with fabric or mat.

Metals in similar wastewater environments can be suitably protected with many of the organic resin lining systems above.

**Water Treatment Facilities**

As discussed in the Regulatory Issues section below, the lining systems for water conveyance, storage, and treatment facilities require ANSI/NSF 61 certification. However, because of this certification requirement, the number of lining systems available for the rehabilitation of water treatment plants is notably lower than those available for wastewater facilities.

The bulk of the certified lining systems are thin film in nature, 8-24 mils dry (200 to 600 micrometers) maximum dry film thickness. These are more suited for new, smooth surfaces rather than the rough, textured surfaces of structures to be rehabilitated. These systems must fully cover any surface repair products that are not certified and therefore cannot come in contact with the potable water.

The majority of the lining materials with ANSI/NSF 61 certification are epoxy-based. However, some certified lining materials are based on polyurethane, vinyl, asphalt, or chlorosulfonated polyethylene. Similarly, several proprietary sheet lining materials of PVC, polypropylene, and ethylene propylene terpolymer, as well as cementitious-based materials, are certified.

**Installation Requirements**

**Surface Preparation**

Both concrete and metallic surfaces, where submerged in water or wastewater, can be exposed to surface contaminants. These contaminants can be organic, acidic, or alkali, and can result from incoming flow or from treatment chemicals. Surface contaminants can sharply reduce lining performance.

Surfaces at the front end of wastewater treatment plants are often contaminated with organic substances, such as greases, fats, and oils. These contaminants require cleaning with detergents, steam, or commercial degreasing products. All surfaces should be thoroughly rinsed with clean water following contaminant removal.

Contamination by acids can also be present at the front end of wastewater treatment facilities where hydrogen sulfide is released from the incoming flow. They can also be present on surfaces near the point of application of acids used for pH adjustment. Acid contamination is usually neutralized and cleaned with alkaline products and then rinsed with clean water.

Similarly, alkali and ionic contamination can be present in water and wastewater treatment facilities from the addition of treatment chemicals. Alkali contaminants are generally removed with detergent or by steam cleaning. All surfaces should be thoroughly rinsed with clean water following contaminant removal.

Following removal of contaminants by any cleaning method, the surfaces should be rinsed with clean water, and the...
surface cleanliness should be verified by the site inspector.

After washing, deteriorated concrete is typically prepared using high-pressure waterjetting, wet abrasive blasting, or dry abrasive blasting. All existing coatings, deteriorated concrete, and loose aggregate should be removed until only sound, gray concrete remains. Most lining manufacturers want the prepared concrete to have a minimum texture of coarse sandpaper. Often, lining manufacturers also require that the prepared concrete have a prescribed surface pH as an indicator that contaminants and deteriorated concrete have been sufficiently removed. The recommended surface pH can vary from 5-10, depending on the individual lining manufacturer. However, recognizing that concrete without deterioration or contamination commonly has pH values from 10-14, surfaces with pH values of greater than 10 are recommended for optimum lining performance.

Following removal of contaminants, ferrous metals are generally abrasive blasted to remove existing corrosion products and deteriorated paints and to provide the surface with an anchor pattern or surface profile. Although the extent of surface preparation is generally specified by the coating manufacturer for individual exposures, White Metal (SSPC-SP 5) is commonly specified for severe, immersed environments, and Near-White Metal (SSPC-SP 10) for less severe conditions.

Installation of Lining Materials
Lining systems can have widely varying installation requirements, including environmental conditions, degree of surface dryness, equipment specifics, and application criteria. Most lining systems require an application temperature between 50 and 100 F (10 and 38 C) and at least 5 F (3 C) above the dew point; relative humidity should be below 85 percent. These values may vary according to generic system and individual manufacturer. Similarly, the surface to be lined should be dry and free of contaminants.

However, rehabilitation must sometimes occur in structures with active flow conditions. In many cases, the relative humidity is above 85 percent, and surface moisture is present. Where these conditions cannot be corrected, moisture-tolerant lining systems are recommended.

The equipment requirements for installation vary with the individual lining system. Organic lining systems may require installation by conventional airless or plural component equipment, or by trowel methods. Concrete-type linings are most commonly installed using gunite-type equipment, formed casting, or trowel methods.

Application criteria for liquid-applied linings include mixing, induction times, the number and thickness of each coat, spray pattern, and recoat times.

Plastic sheet linings for rehabilitating concrete structures usually require applying an adhesive to the prepared surface and operating heat guns at prescribed temperatures to weld the seams and corners and to patch identified holidays.

Cure
The method of cure and the amount of time required for cure of a lining system are very important for water and wastewater structures or equipment rehabilitation. Unless the system is 100 percent solids, the method of cure for most rehabilitation lining materials is chemical reaction with solvent evaporation. Frequently, these systems have cure times ranging from 7 to 10 days.

Some lining materials such as epoxy, polyurethane, and polyurea can be formulated at 100 percent solids. These materials cure by chemical reaction without solvent evaporation. Most set rapidly and have short cure times ranging from 1 hour to 2 days. The materials with shorter, minimum
cure times are recommended for structures or equipment with very limited outages.

Plant Operating Conditions

Often, one of the biggest challenges of rehabilitating water and wastewater treatment facilities is the difficulty of removing the process equipment or treatment structures from service. Difficulties include isolating flow or diverting it from the structure and the corresponding amount of time available to complete the rehabilitation effort.

Wastewater treatment plants, for example, receive their wastewater by gravity flow and usually have no built-in means, such as valves or gates, to bypass or halt the incoming flow. Similarly, there is typically no provision for temporary storage of such waste flows, which frequently are above a million gallons (3.8 million liters) a day.

Thus, coating and lining rehabilitation work at wastewater treatment facilities is commonly completed in 1 of 2 scenarios:

• special provisions such as temporary pumps and piping or diversion plates are used to take a structure or process partially or fully out of service (Fig. 2); or
• the work is completed sequentially, often at night, during low flow, and only surfaces above the flow are prepared and coated.

In general, water treatment plants have similar shutdown constraints but for different reasons. The shutdown constraints at water treatment plants are tied to consumer demand for potable water. While water municipalities generally have some storage capacity to respond to peak demands, coating and lining rehabilitation work at their facilities is typically timed to the months with lower water demand.

At water treatment plants, the water being treated in adjacent basins must also be protected during surface preparation and painting activities. Thus, for many plants with open top basins, dust, debris, and overspray must be confined to the work area with tarps and other containment equipment to prevent contamination.

Regulatory Issues

Confined Spaces

Many of the basins, tanks, and structures at water and wastewater treatment facilities are classified as confined spaces and are subject to the Occupational Safety and Health Administration (OSHA) rule, Permit-Required Confined Spaces (29 CFR 1910.146). Classification depends on meeting any of the following characteristics:

• contains or has the potential to contain a hazardous atmosphere;
• contains a material that has the potential for engulfing an entrant;
• has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross-section; or
• contains any other recognized serious safety or health hazard.

At wastewater treatment sites, the floors of wet wells, headworks structures, and grit basins are often sloped to enhance collection and removal of grit. Although to a lesser degree, numerous other treatment basins often have sloped floors to enhance
the removal of sludge. The basins can include primary and secondary clarifiers.

Additionally, in recent years, an increasing number of these structures are enclosed or covered to prevent the release of foul odors from gases such as hydrogen sulfide. Similarly, an increasing number of water treatment plants are covered to minimize entrapment of air-borne contaminants.

Because many of the corrosive conditions of treatment plants are associated with the release of gases in enclosed structures, the rehabilitation of such structures involves a confined space.

**Potable Water Coatings**

Rehabilitation lining systems contacting potable water must be certified in accordance with ANSI/NSF Standard 61. This standard provides minimum requirements for controlling potentially adverse health effects from products in contact with potable water. Of concern is preventing hazardous metals or organic chemicals from leaching into the water and contaminating it. The standard covers “indirect water additives” or products including “protective (barrier) materials,” or tank linings.

Particular attention must be given to mixing, application, and cure of certified lining materials. The proper components of the correct proportions should be thoroughly mixed, with only approved thinners, accelerators, or retarders added as necessary to maximum allowed quantities. The mixed coating should also achieve the required induction time before application.

Similarly, the water contact size restriction (number of gallons or liters) and the total number and thickness of each coat should meet the coating manufacturer’s instructions to ensure compliance with the standard. Adherence to defined environmental parameters of temperature and humidity during application is also necessary.

Following application, suitable temperature, humidity, and ventilation are required to ensure complete reaction, solvent release, and cure.

**Economics**

The costs for rehabilitating concrete and steel at water and wastewater treatment facilities depend on several factors, including

- project location,
- size of the project (sq ft or sq m),
- degree of surface contamination,
- extent of surface preparation,
- extent of surface repair before lining, and
- type and thickness of lining.

The magnitude of surface repair before lining application for concrete projects includes, as necessary, replacing reinforcing steel and installing surface repair mortars. For metallic structures, it includes repair as required for deep pits by welding or structural polymers and replacement of excessively thinned components.

Additional significant factors related to project costs are the ability to remove the structure or equipment from service and the time available for completing the project. These factors can more than double the project cost.

The costs for a limited number of concrete rehabilitation projects of the County Sanitation Districts of Los Angeles County, California, ranged from $9.83 to $23.08 per sq ft ($106 to $248 per sq m).
Selected Restoration Projects

The following projects illustrate the considerations described above.

Wastewater Treatment Facilities

• Headworks, Splitter Boxes, and Primary Clarifiers: The headworks inlet chamber, the splitter boxes, and the primary clarifiers at an Austin, TX, wastewater treatment plant had been corroded considerably by sulfuric acid. These concrete structures had exposed aggregate and occasionally corroded reinforcing steel on walls and ceilings in vapor spaces at and above the flow.

  The headworks inlet chamber at this facility posed the greatest difficulty for installing the rehabilitation lining system because the structure could not be removed from operation. Therefore, the rehabilitation was completed in halves after installation of a temporary flow diversion plate.

  Rehabilitation of the walls and slab undersides of the primary clarifier launders was less difficult. Painters installed surface repair mortar on deteriorated concrete to return it to the original configuration.

  More than 25,000 sq ft (2,300 sq m) of surfaces were cleaned with detergent wash, abrasive blasted, restored to their original configuration with mortar repair, and topcoated with a 100 percent solids, fiber-reinforced epoxy lining (minimum thickness of 80 mils [2 mm]).

• Sludge-Holding Tanks: Sulfuric acid had severely deteriorated the concrete sludge-holding tanks of a treatment facility in Virginia. The original system, a surface repair mortar and thin film epoxy, swelled from the permeation of and reaction with sulfuric acid and began sloughing off the walls in the vapor zone (Fig. 3). When the system was removed, severely corroded concrete and steel reinforcement were found.

  Particular concerns were the need for a long-term, durable lining system with proven resistance to hydrogen sulfide and sulfuric acid exposures as well as potential hydrostatic conditions. The hydrostatic conditions resulted from groundwater on exterior walls and from stored sludge on a common wall in an adjacent holding tank, which had to remain in service.

  The tank walls were prepared with chipping hammers. All original rehabilitation lining materials, contaminants, and deteriorated concrete (white acid reaction products) were removed, leaving only sound, gray concrete with a surface pH above 10. Corroded steel reinforcement bars were replaced if corrosion loss exceeded 25 percent of their original diameter.

  All new and existing reinforcement was abrasive blasted and coated with a rust-inhibitive epoxy. The wall surfaces were rebuilt to their original dimensions with a structural-grade, shotcrete mortar. Anchors were installed in the shotcrete mortar and coated with an elastomeric urethane. The coated mechanical anchoring arrangement was topcoated with 2 in. (50 mm) of potassium silicate cement, an acid-resistant lining.

Water Treatment Plants

• Clarifier Mechanisms: The steel mechanisms of clarifiers at an Austin water treatment plant showed coating breakdown, surface rusting, accumulated lime solids, and aggressive pitting (Fig. 4). The clarifiers at the plant were sequentially removed from service, covered with tarp, and abrasive blasted to White Metal (SSPC-SP 5).

  Immediately after surface preparation, the mechanisms were recoated with a three-coat, ANSI/NSF 61-certified epoxy polyamide system, installed at a minimum of 12 mils (300 micrometers).

• Lime Softening Treatment Unit: The lime softening treatment unit at a Florida water treatment plant displayed breakdown of a lead-based paint system and surface rusting. The unit was 85 ft (26 m) in diameter;
it consisted of a carbon steel mixing well, rake mechanism, and side walls (Fig. 5).

After abatement of the lead-based coatings and surface preparation to Near-White (SSPC-SP 10), the unit was coated with a three-coat polyamide epoxy system with ANSI/NSF 61 certification. The specification required an overall minimum dry film thickness of 12 mils (300 micrometers), but some areas required additional film thickness for adequate coverage.

Conclusion
The deteriorated concrete and ferrous metals in treatment plant facilities can be rehabilitated with protective coatings and linings. Selection and specification of effective coating and lining systems require consideration of many factors, including

- original materials of construction,
- corrosive environment,
- type and extent of deterioration,
- suitability of specific lining systems,
- lining installation requirements,
- plant operating conditions,
- regulatory issues, and
- economics.  

References