Wastewater treatment plants are among the harshest of environments for high-performance protective coatings. In a wastewater facility, there is never only one cause for a structure to degrade; there are numerous causes, and because of the multiple causes, once a structure starts to degrade, it does so rapidly.

This article gives a basic introduction to, and review of, the chemical and other aggressive exposures within wastewater facilities; how the exposures can cause degradation of a structure; how to diagnose a corrosion or deterioration problem; how to repair the structure; and how to prevent corrosion from recurring. The article will use an example of a wastewater clarifying tank made of hydrated Portland cement concrete to illustrate the above.

Corrosive Environments in Wastewater Treatment Tanks
Wastewater clarifying treatment tanks need to be protected and maintained because their environment exposes them, on a daily basis, to chemical attack, abrasion erosion, chloride ion-induced corrosion, and freeze-thaw conditions, summarized below. (For detailed discussions of causes of deterioration in wastewater treatment structures, see R. A. Nixon, “Deterioration of Wastewater Treatment and Collection System Assets,” JPCL, October 2006, pp. 50–63; and G. Hall, “Out of Sight, Out of Mind, and Often Out of Order,” JPCL, October 2004, pp. 40–48.)

Chemical Attack
Sewage in a wastewater storage tank must receive chemical treatment, biological treatment, or both. The chemicals used are manufactured acids, which, when discharged into the wastewater, lower its pH, causing acid attack of the hydrated Portland cement concrete.

Sewage contains sulfate ions. Sewage traveling through the wastewater systems leaves behind a layer of sludge. The sludge contains sulfate-reducing bacteria (SRB). The SRB react with oxygen in the sulfate ions, forming sulfide ions, which are released back into the wastewater. Through chemical reactions in the wastewater system, the sulfide ions combine with hydrogen to form hydrogen sulfide, which further reacts and forms hydrogen sulfide gas. The gas reduces the pH of the concrete.

Once the concrete pH is reduced from approximately 12 to 9.5, sulfuric acid can be formed. Its formation occurs because at wastewater facilities, the atmosphere around the concrete structures contains moisture and ample oxygen. With the combination of the moisture, oxygen, and lower pH, sulfur oxidizing bacteria (SOB) can colonize on the concrete substrate. The SOB
use the oxygen and hydrogen gas present to form sulfuric acid, which will cause acid attack of Portland cement concrete.

Concrete wastewater storage tanks also undergo sulfate attack and carbonation of the concrete in the headspaces. In sulfate attack, the sulfates react with the hydrated Portland cement paste and form a by-product, which promotes expansion of the concrete through solid volume increases. Carbonation is a natural occurrence in concrete exposed to the atmosphere. Carbon dioxide in the atmosphere reacts with the hydroxide in the hydrated Portland cement paste to form a carbonate, which causes shrinkage of the cement paste. Expansion from sulfate attack and contraction from carbonation weaken concrete tanks.

**Abrasion and Erosion**

Wastewater can also contain suspended solid material, such as sand, rocks, ice, or silt. The solid materials impinge on the surface of a concrete clarifying tank during turbulent water flow conditions, causing an abrasive breakdown of the concrete and leaving a smooth wear pattern on the substrate.

**Chloride-Induced Corrosion**

When concrete is placed around reinforcing bars (rebar), the steel surface initially corrodes. Then, a tightly adherent oxide film forms over the surface to protect it from further corrosion, provided the film remains intact. The highly alkaline environment of hydrated Portland cement paste in the concrete can maintain the passive protection film. But the protective film will be destroyed if moisture, chloride ions, and oxygen penetrate pores or cracks to reach the reinforcing steel surface. Local corrosion cells are then established, and rust forms on the surface of the reinforced steel, increasing the volume of steel, which in turn creates tensile forces within the concrete. Because the tensile strength of concrete is relatively weak, the concrete will crack to relieve the tensile stresses. Once the concrete begins to crack, water, oxygen and aggressive chemicals can freely enter the concrete and further attack the embedded rebar, escalating the deterioration.

**Freeze-Thaw Deterioration**

It is inevitable that concrete will degrade over time when exposed to differential thermal conditions (cold and hot) and humidity cycling (wet and dry) on opposing sides of the structure or to intermittent water immersion along with freezing temperatures.

**When Corrosion Occurs—Steps for Repairing a Wastewater Clarifying Tank**

There are four basic steps in the repair of a deteriorated wastewater clarifying tank.

1. Assess the condition of the concrete structure.
2. Diagnose the problem.
3. Develop the repair specification.
4. Develop an inspection and maintenance program.

**Step 1—Assess the Condition of the Concrete Structure**

A basic understanding of causes of concrete corrosion is essential to performing a successful repair of a concrete tank and its lining system. In addition, if available, the history of the wastewater treatment tank may provide clues to causes of the present condition. A review of the plant’s history of operations may reveal periods of high operating temperatures or other aggressive conditions. Answers to questions such as the following may help you diagnose problems.

- When was the tank built?
- What surface preparation method and coating system were used (if any) and when?
- Was there a third party QA inspector during construction or coating of the tank, and is documentation from the inspection available?

If the history of the tank is not available, proceed directly to the next part of assessing the structure, performing a condition survey.

Condition surveys are typically conducted before writing a repair specification. They include comprehensive and systematic visual and analytical analyses of the existing conditions.

There is no one single method or format that may apply for every structure or job; however, the more detailed the survey and the more experienced the surveyor, the more reliable will be the budget and specification prepared from the survey. Some facility owners have their own qualifications and requirements for performing the survey. (Reminder: Though concrete coating assessments and surveys are normally conducted by experienced concrete surveyors, this article is written for those who desire an introduction to, or review of, the survey process.)

The following are two main reasons for periodically conducting surveys of structures in a wastewater facility.

- Detecting early concrete or coating deterioration and gauging its progress
- Determining what maintenance/repair actions may become necessary

In general, two basic types of surveys are used to determine the condition of existing concrete structures to formulate plans for maintenance actions: the visual survey and the detailed survey. Each survey type has its own purpose and limitations. In a visual survey (described in
The principals conducting surveys must have expertise in coatings and must carefully follow standard test method procedures.

One tool that can be used when beginning a survey is the ACI 201.1R, Guide for Making a Condition Survey of Concrete in Service (American Concrete Institute, www.aci.org). It presents a systematic approach for surveying. It defines 10 types of cracking, 31 types of deterioration, and 17 surface defects, and it contains 49 photographs of concrete distress. Summarized from ACI 201.R, the following guidelines for a minimum walk-through (visual survey) are valid for all concrete substrates but are especially important for wastewater treatment tanks and other structures in severe service.

A minimum walk-through consists of a visual assessment of the overall conditions of substrates and coatings on plant structures. Surveyors record the types, extent, and distribution of defects and failures using standard terms and a standard rating system. Surveyors pay attention to special patterns, such as whether deterioration is concentrated on the sunny side of a structure, on the ocean exposure, near the ground, or in hard-to-reach places. The minimum walk-through is intended to provide a benchmark for comparison with later surveys, including a detailed survey. Key components of a minimum walk-through include, but are not limited to, the following.

- Obtaining all relevant information on the structure, coating and past/present exposure conditions, such as physical exposure, chemical exposure, and temperature
- Determining if the structure has aesthetic value (rarely a concern with wastewater treatment tanks), is primarily an industrial structure, or both, and then visually assessing and documenting the exposure and age of the concrete/coating
- Visually surveying the entire layout of the structure. If knowledgeable facility representatives are available, ask them to accompany you on your preliminary investigation and record their known information as well as your own initial observations. (A tape recorder may be useful.)
- Drawing a diagram of manageable sectioned-off zones
- Photographing all pertinent physical conditions and recording them, per zone

A visual walk-through of a wastewater treatment tank will allow the surveyors to see, for example, if there are areas of spalling and pop-outs, indicating chloride-induced distress.

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Step 2—Diagnose the Problem
After condition assessment, a detailed survey is needed to fully diagnose the problem. In a detailed survey, zones of coated areas (diagrammed in the visual survey) are further subdivided, and physical measurements are made of the coating to assess its condition. Detailing the coating condition includes, but is not limited to, the following actions.
1. Determine and record the condition of the substrate/surface, e.g., cracks or delamination per zone. Tests of bond strength, vapor emissions, pH, and other factors may be needed.
2. Determine and record the depth of contamination by taking a concrete core sample.
3. Determine and record the condition of the protective coating system per zone (if applicable). Coating condition assessment also requires various tests to be performed including a concrete/coating bond/cohesive test. Obtain dry film thickness per SSPC-PA 9 (www.sspc.org) on both failed and intact areas of existing coating.
4. Identify and record the environmental conditions, per zone, under which the coating system will be required to protect the substrate.
5. Measure and record the areas of concrete failure per zone for repair.
6. Measure and record areas of coating failure per zone.
7. Measure and record total surface area to be coated.
8. Prioritize repair/coating time lines per zone.
9. Take samples of the substrate, coating, corrosion by-products, and other contaminants per zone if required for laboratory analysis.
10. Write a comprehensive analysis of findings based on all acquired accurate information.

A detailed survey of a wastewater clarifying tank may, for example, indicate that moisture is present (to be expected), that degradation from an acidic environment due to an acidic pH has taken place in the headspace area, and that the existing coating on the structure is an epoxy (could be determined by laboratory analysis of a paint chip sample from the site). Core samples from each deteriorated area may give further diagnostic information, such as the quality of the adhesion of the existing coating and the porosity of the concrete matrix.

Step 3—How to Repair a Deteriorated Structure?
Once the cause of corrosion is known, a repair method can be developed. Below is a summary of general steps for surface preparation of the substrate and substrate repair (which includes installing repair materials and protective coatings). The sidebar describes measures for repairing deterioration caused by rebar corrosion.

Repairing Chloride-Induced Rebar Corrosion
Chloride-induced corrosion of rebar is a common cause of concrete degradation and must be addressed before further repair measures can be taken. This form of corrosion is usually displayed as spalling on the concrete surface. Spalling is the chipping or fragmenting of a surface or surface coating caused by differential thermal expansion or contraction. Rebar corrosion is often found in wastewater clarifying tanks. To repair concrete and rebar after chloride-induced corrosion, follow ICRI Guideline No. 310.1 (International Concrete Repair Institute, www.icri.org), summarized below.
1. Remove all concrete that is loose or delaminating.
2. Undercut exposed corroded rebar by creating a minimum ¾-inch clearance between the exposed rebar and surrounding concrete.
3. Extend concrete removal along the rebar until an area is reached that is free of bond-inhibiting corrosion and is well bonded to surrounding concrete.
4. Take care to not disrupt non-corroded rebar exposed during undercutting.
5. Secure loose reinforcement to secured bars.
6. Remove corrosion from rebar by abrasive blasting.
7. Repair concrete using an appropriate material that also contains an inhibitor for chloride-induced corrosion.

One class of inhibitors—penetrating corrosion inhibitors—can be used in several ways to slow chloride-induced rebar corrosion. For example, a liquid amino alcohol-based penetrating corrosion inhibitor additive can be incorporated into the concrete aggregate, sprayed directly onto the finished concrete surface, or drilled into an existing structure to effectively decrease the rebar corrosion.

For the drilling method, a hole is drilled into the cured concrete structure and the additive is inserted into the hole. The hole is then repaired using a cementitious mortar. When the penetrating corrosion inhibitor reaches the rebar, it forms a protective layer around the steel.

It should also be noted that the effectiveness of chloride-induced corrosion inhibitors is dependent upon the permeability of the concrete and the amount of inhibitor reaching the rebar. This corrosion prevention method is fairly new; therefore, only a small amount of published literature on its effectiveness is available.
essential to secure functionality. To achieve proper adhesion and prevention of corrosion of a substrate, several surface cleaning and preparation methods should be chosen, based on the condition of the concrete and the requirements of the coating system to be applied. (All prepared concrete surfaces need to be repaired to the level required by the coating system in the intended service condition.)

One of the first steps when preparing a concrete surface is removal of protrusions such as burrs, sharp edges, fins, and concrete spatter. All concrete that is not sound must be removed. All contamination, form-release agents, efflorescence, curing compounds, and existing coatings determined to be incompatible with the coating to be applied must be removed. Detergent water cleaning and steam cleaning are used to remove oils and grease from concrete. Power tool methods, including circular grinding, sanding, and wire brushing, can remove existing coatings, laitance, other weak concrete, and protrusions in concrete. Impact-tool methods are also used to remove existing coatings, laitance, and weak concrete. These methods include scarifying, planing, scabbling, and rotary peening.

Dry or wet abrasive blasting, vacuum-assisted abrasive blasting, shot blasting, and water jetting are also among the methods that can be used to remove contaminants, laitance, and weak concrete, to expose subsurface voids, and to produce a sound concrete surface with adequate profile and surface porosity.

The acceptance criteria for concrete surfaces after surface preparation should be specified, but SSPC-SP 13/NACE No. 6 provides some guidance.

Where concrete deterioration is severe, structural integrity may need to be restored prior to application of protective lining barriers.

• Repair Basics: To improve a porous concrete matrix in a deteriorating wastewater clarifying tank, filler compounds are used to fill voids, irregularities, and air pockets in the concrete. A filler compound is a viscous material that has the consistency of a “putty” and is applied using a smooth plasterer’s rubber float trowel. Once the material is applied, any excess material is removed using the edge of the rubber float trowel.

Once the voids, irregularities and air pockets are filled, creating a (relatively) smooth surface, it is necessary to fill in any cracks that would allow water infiltration. This is accomplished by use of rapid-setting mortar or hydroactive grouts. The material is mixed and immediately applied.

### Table 1: Repair Products

<table>
<thead>
<tr>
<th>Material</th>
<th>Fast Set</th>
<th>High Strength</th>
<th>High Elasticity</th>
<th>Application Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement and Modified Calcium Aluminate</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>Gunite, trowel, cast-in-place</td>
<td>Resurfacer</td>
</tr>
<tr>
<td>Portland-based Cementitious</td>
<td></td>
<td>✓</td>
<td></td>
<td>Pumpable for wet-spray application</td>
<td>Resurfacer</td>
</tr>
<tr>
<td>Hydraulic Water Plug</td>
<td>✓</td>
<td></td>
<td></td>
<td>Hand</td>
<td>Waterproofing</td>
</tr>
<tr>
<td>Catalyzed Hydrophobic Injection Liquid</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Injection</td>
<td>Waterproofing</td>
</tr>
<tr>
<td>Elastomeric Asphalt Modified Urethane Lining</td>
<td></td>
<td></td>
<td>✓</td>
<td>By hand using a glove</td>
<td>Waterproofing</td>
</tr>
</tbody>
</table>
by injection to the area displaying leakage.

Table 1 lists some repair products used for the interior of a wastewater tank. [Editor’s note: For a detailed study of surface preparation of repair materials before lining application in wastewater environments, see the article by V. O’Dea in this issue on pp. 32–45.]

One approach to repairing and resurfacing a wastewater clarifying tank is to use a Portland cement and modified calcium aluminate material. This fast-set material might be chosen if a quick return to service is needed. The material can be applied by trowel and can cure within 5 hours. Once the resurfacer cures, the tank should be checked for areas of water infiltration. If water infiltration is found, the affected areas can be corrected by injecting a catalyzed hydrophobic liquid. For the headspace of the tank, an elastomeric asphalt-modified urethane lining can be applied by hand using a glove. Because the headspace is prone to deterioration from hydrogen sulfide gas, the urethane system could be chosen for its strong resistance to this gas.

Once a proper substrate barrier exists, it is time to apply a protective coating system. Depending on the coating system chosen, application can be accomplished by trowel, airless spray, or plural-component spray. The coating system should be applied per the manufacturer’s product data sheet (PDS) to ensure optimum physical properties and a uniform surface without pinholes or holidays.

For wastewater clarifying treatment tanks, the chemical resistance of the coating is extremely important. Epoxy coatings offer a high degree of chemical resistance and ease of application if the surface is prepared and the coating is applied appropriately. For example, two to three coats of a polyamide epoxy might be suitable for lining a wastewater tank.

Other coating technologies such as polyureas, urethanes, and vinyl esters also offer a high degree of chemical resistance, but often are not environmentally friendly or easily applied. You can consult
coating manufacturers and other experts for all commonly recommended protective coatings for concrete substrates and wastewater treatment facilities, in particular. Be sure to ask about the advantages and disadvantages of each system.

Step 4—Develop an Inspection and Maintenance Program
To reduce costly and timely repairs, it is important to develop an inspection and maintenance program for the structure. Again, such a program is relevant to any structure but is particularly important for structures in severe service such as wastewater treatment tanks.

The inspection and maintenance program should include a procedure for conducting surveys of structures in a wastewater facility periodically to enable early detection of concrete or coating deterioration.

A tool that can be used to help develop a quality inspection and maintenance program is the SSPC Guide for Planning Coatings Inspection (www.sspc.org). It is intended to assist coating and lining inspection companies, contractor quality control (QC) personnel, and owners in developing a key tool to ensure that coating and lining inspection is the best it can be. This tool will provide the contractor with guidance on how to plan to do comprehensive QC, which will provide a record of objective evidence that the work has met contract requirements.

The quality inspection and maintenance program should consist of inspection hold points, which are critical periods during the project when work is stopped until the work-to-date has been inspected and the contractor has been authorized to proceed. Hold points will vary, but the ones listed here should be considered as basic for most work, including wastewater treatment tank jobs.

- Pre-Surface Preparation
- Post-Surface Preparation
- Coating Conditions for Application
- Coating Application
- Post-Application of Coating
- Post-Curing

Summary
Wastewater treatment creates severely corrosive environments that call for protection of all structures at wastewater plants. This article gave an overview of concrete deterioration, diagnosis of its causes, repair, and prevention, using a concrete clarifying tank to illustrate key points. If corrosion is detected on a structure, it is important to determine what the cause of corrosion is and create a repair method to stop corrosion from continuing or recurring. There are steps that can be taken to prevent corrosion or detect it in its early stages to reduce structural problems and the costs of their repair.
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