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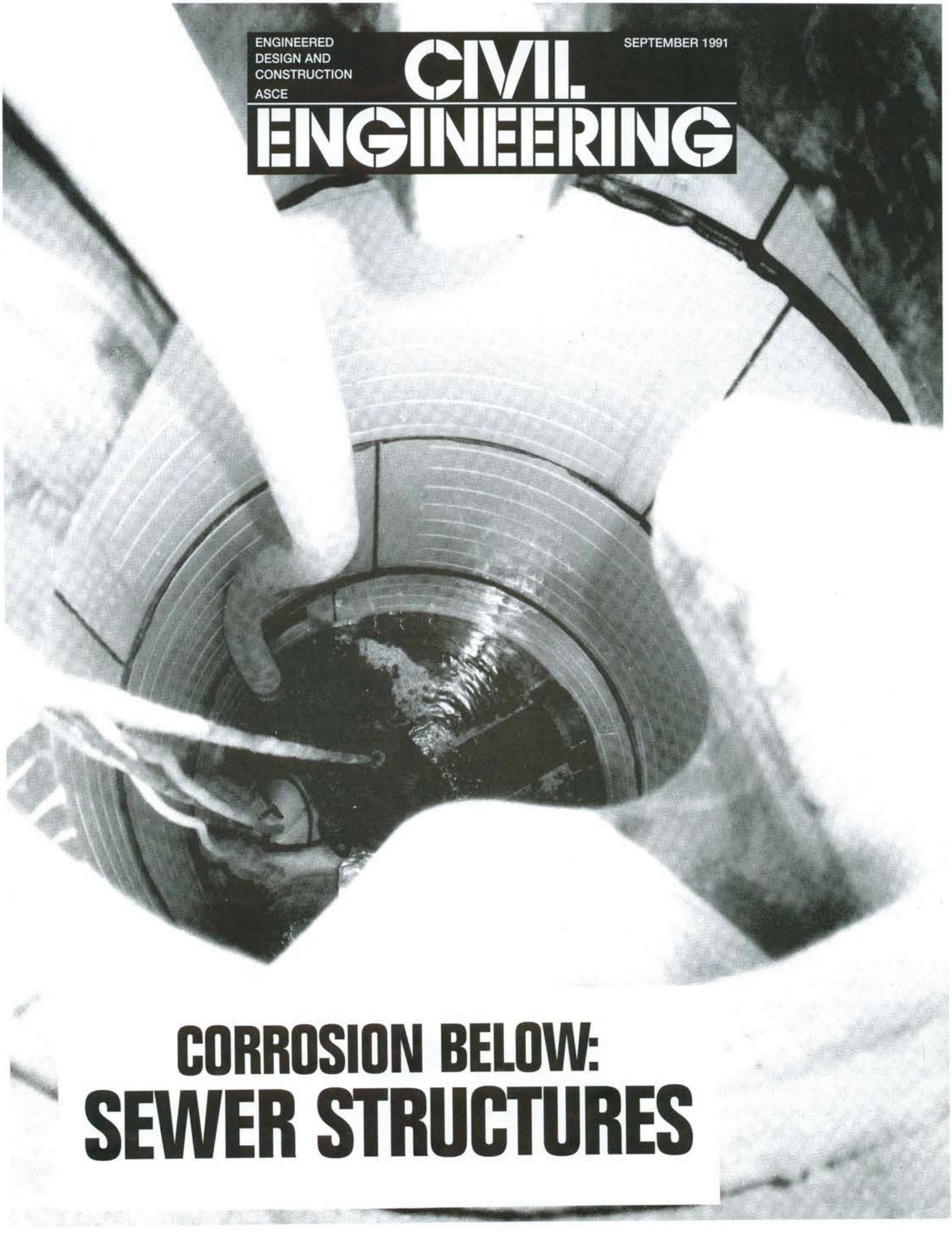

CORROSION BELOW:
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When a sewer system fails, the cause can't always be traced to the pipe. Instead, pipe corrosion can be caused by poorly designed manholes, junctions and other special-purpose structures. Engineers should not ignore the fact that concrete structures can corrode.

Engineers don't go far enough in specifying corrosion protection for sanitary sewers. They will select noncorrodible pipe, corrosion-resistant pipe or some sort of corrosion protection for the pipe, then neglect protection for the structures in the sewer system.

Failure of an inverted siphon inlet or outlet leads to the same type of system failure and expensive rehabilitation as failure of the pipe itself. Other vulnerable structures that must be protected include the conventional access manholes spaced from 300 to 2,600 ft apart, drop structures, junction structures, wet wells and special-purpose structures such as metering stations.

Such failures can happen anywhere. Three cases in point:

- Vero Beach, Fla., 1990. A 12 ft vertical drop was constructed as part of the wastewater-treatment-plant influent channel. Sulfide levels averaged 12-15 mg/L in the sewage, with gaseous H_2S readings in excess of 900 ppm. In the first four months of 1990, 4 in. of concrete disappeared.
- Reno, Nev., 1988. Shutdown of a forced ventilation system in a metering station structure led to serious corrosion. A Parshall flume with a 6 ft drop was part of the meter station design, and because of odor complaints, the ventilation system was shut down, forcing the gas to exit the structure via the upstream pipe. Transfer of H_2S gas into the sewer upstream caused failure of the 10-year-old, unprotected 36 in. concrete pipe and a cave-in at a hotel parking area.

The failure occurred upstream as the H_2S gas was prevented from moving downstream by intentional surcharging of the pipe immediately below the structure. Several hundred feet of 36 in. pipe had to be replaced at a significant cost.

- St. Louis, 1987. A long force main discharged directly into a 54 in. diameter unprotected concrete pipe that then entered a 10 ft vertical drop structure. After 15 years, the drop structure was severely corroded; some interior, 12 in. thick concrete baffle walls virtually disappeared; and 1,200 ft of the 54 in. pipe downstream of the drop structure was reduced to a semicircular channel. The top half of the pipe was entirely gone.

Most of these structures are concrete, either cast in place or precast. Brick manholes have been replaced over the years because of concerns about infiltration and the realization that the mortar holding the bricks together is subject to corrosion. Prefabricated plastic manholes have been introduced, but they are difficult to install, and in high ground-water areas, tend to float out of the hole without proper ballast or anchorage.

PVC LINER PROTECTS A PRECAST CONCRETE PUMP STATION IN FLORIDA. PHOTO COURTESY A-LOK PRODUCTS.

There are two major causes of internal corrosion in a sanitary sewer. One is conventional acid attack caused by low pH industrial waste discharged directly into the sewer system; the other goes by several terms: sulfide corrosion, hydrogen sulfide corrosion or sulfide attack. The types are easy to identify. Sulfide corrosion occurs above the sewage surface while low pH sewage will cause corrosion below the waterline.

"Sulfate attack" is sometimes confused with sulfide corrosion. It occurs when soils with high sulfate levels contact the pipe or structures and deteriorate their outsides. Sulfate attack does not occur inside sewer structure or pipe. Sulfide corrosion of the unwetted upper part of the structure interior is the type of corrosion dealt with in this article.

Sulfide corrosion starts when sulfate in the sewage is converted to sulfide. At normal domestic sewage pH levels, from one quarter to one-third of the dissolved sulfide exists as molecular hydrogen sulfide, H_2S, which is released to the air and deposited on the moist structure wall. Bacteria on the wall convert the H_2S to sulfuric acid, H_2SO_4, which reduces wall moisture pH values to the 1-2 range, the acid corrodes the structure wall above the flow line.

As a matter of interest, there is a third mode, unrelated to concrete corrosion. H_2S reacts directly with metals, corroding fittings and appurtenances. In addition to affecting all forms of iron and steel, this type of corrosion attacks the silver contacts in motor controls and other electronic equipment.

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TABLE 1: RECOMMENDED TCF VALUES

	TCF	DD	DU
Junction Structures			
Turbulence			
Minor	2–2.5	20–25	2–4
Moderate	3–4	30–40	5–6
Severe	5–20	50–200	8–10
Vertical Angle Points (Grade Breaks)			
Change in relative depth			
5%	2	20	2
20%	2.5	25	4
40%	5	50	6
60%	20	200	10
Horizontal Angle Points			
Total angle change (degrees)			
12	2.5	25	4
22.5	3	30	5
45	4	49	6
90	8	100	20
Curves and Structures in Curves			
Radius of curve (ft)			
22.5	4	40	6
45	3.5	35	6
90	3	30	5
180	2.5	25	4

Note DD = distance downstream beyond end curve; and DU = distance upstream from begin curve.

TURBELENCE CORROSION EFFECTS FOR STRUCTURE AND ADJACENT PIPE CORROSION PROTECTION ARE USED IN EQUATION 6-27, ASCE *MANUAL OF PRACTICE NO. 69.*

Design of sewer structures is important. In general, any configuration that results in significant hydraulic energy loss will accelerate corrosion and may also induce serious corrosion of the downstream pipe. Several factors tend to increase the amount of sulfide produced in sewage:

- High sewage temperatures accelerating the sulfate/sulfide conversion process.
- High biochemical-oxygen-demand (BOD) sewage, particularly high-soluble BOD sewage.
- Flat sewer slopes producing oxygen deficient, or "septic" sewage; and the low velocities lengthening detention time and increasing settling of organic solids and grit in the sewer invert.
- Long detention times in wet wells, force mains, inverted siphons or surcharging gravity sewers.

Other factors tend to increase the amount of H_2S escaping from the wastewater and accelerate corrosion rates:

- Steep slopes and high flow velocities.
- Turbulence caused by inadequate or poor design of structures. Examples are junction structures with colliding flows, and drop structures and intercepts or force mains that discharge significantly above the wastewater surface in the main line.
- Slope changes that produce hydraulic jumps, abrupt flow direction changes (angle points) and short radius curves.

PROTECTION METHODS

Corrosion protection methods commonly used for structures include modification of the concrete mix design; coatings that are sprayed, painted or rolled onto the concrete surface; and liners that have integral locking projections cast into the concrete.

Modifying the concrete mix usually involves increasing the alkalinity, since the corrosion rate is inversely related to concrete alkalinity. The ASCE *Manual of Practice No. 69, Sulfide in Wastewater Collection and Treatment Systems,* discusses concrete modification and sacrificial concrete in Chapter 10. Turbulence corrosion factors (TCFs) used in Equation 6-27 of Chapter 6 (a design example illustrating the use of Equation 6-27 is included in Chapter 10) is listed in Tables 1 and 2.

Some mix design modifications should be avoided, as they have little or no effect on structure corrosion rates:

- Use of Type V rather than Type II cement, or Type II low alkali cement rather than Type II is not a factor in sulfide corrosion.
- Addition of fly ash or pozzolanic materials as cement replacements increase the sulfide corrosion rate by decreasing concrete alkalinity.
- Addition of microsilica to precast concrete sewer pipe doubles the corrosion rate of conventional concrete pipe when exposed to acid.
- High-alumina cement increases corrosion rates at typical pH moisture levels of 1-2 on structure walls.
- Absorption or porosity of the concrete is not a factor, except as it influences density.
- So-called "waterproofing" and other admixtures have no appreciable effect on sulfide corrosion rates.

Concrete density is a minor factor in corrosion protection. Precast manhole or pipe-production methods that increase the density of the concrete will reduce corrosion rates by the same percentages as the relative change in density.

Manual 69 includes equations for calculating the *Az* value, the alkalinity *(A)* and thickness *(z)* required for a desired design life and given sulfide condition. Incorporating a turbulence corrosion factor for nonuniform flows, the equations give *Az* factors for structures. When the *Az* value is higher than 3.0 or 4.0, some type of inert lining or coating should be specified.

Coatings depend on adhesion rather than mechanical locking to stay in contact with the concrete. Coating performance is sensitive to proper surface preparation, adequate applicator training and supervision, and proper inspection of the finished product. Weather conditions, particularly rain and high humidity, may adversely affect application and bonding.

The final dry film must be at least 40 mils thick and at least two coats in addition to a primer coat. Specifications should include a spark test of the completed coated structure, with clearly stated requirements for repair of pinholes or other defects. Even well-specified coatings may not perform well, however. A study of 53 coating systems, conducted by the Sanitation Districts of Los Angeles County, showed that a very low percentage performed well (Table 3).

Among the disadvantages of many coating systems are the environmental considerations: confined space entries; clothing and respiration requirements for worker protection; proper and adequate ventilation; and disposal of containers and other waste materials, which are often considered a hazardous waste. The 1985 EPA design manual *Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants* states, "Many different types of linings and coatings have been used in attempts to protect pipe for corrosion due to wastewaters containing sulfides. Unfortunately, success with these materials has been quite variable."

LINERS

Lining materials are defined as those protective materials that depend on mechanical locking, as opposed to adhesion, to maintain their position on the surface being protected. Polyvinyl chloride (PVC) and high-density polyethylene (HDPE) liners have been used in the U.S. for protecting both precast concrete pipe and cast-in-place concrete tunnel sewers.

An HDPE liner material, which fastens to mechanical locking devices installed in the concrete after casting, has been used in the U.S. There has been at least one major failure: In Houston, January 1991, several hundred feet of lining tore loose from the fastening system and clogged the 11 ft diameter sewer. This caused a 30 million gal. sewage spill. A second failure occurred in April.

A flexible PVC liner has been used successfully since the early 1950s. Manufactured by Ameron Corp., Protective linings Division, the "T-Lock" liner takes its name from T-shaped locking-rib extensions that are cast into the pipe and structure concrete as they are formed. PVC joint weld strips are hot air welded in the field, joining the PVC liner in adjacent manhole or pipe sections. A similar liner, "Poly-Tee," made of polyethylene (PE) rather than PVC, has recently entered the market. The new PE product is manufactured by Poly-Tee, Inc., of Fullerton, Calif. Field welds are made with a hot-melt PE bead-welding system.

EPA reports in its manuals that PVC liners that are mechanically attached to cast-in locks are "one of the few lining systems that have been used successfully for long term protection of concrete." The oldest installations, EPA notes, have been in service since the early 1950s "with no evidence of significant deterioration."

A rigid PVC liner is manufactured specifically for structure lining by A-Lok Products, Inc., Tullytown, Pa. Sold under the trade name "Dura Plate 100," the liner is vacuum formed at the factory to the contour of the structure interior; the locking ribs are cast into the concrete. The Dura Plate system has a butyl rubber sealant in the joints between precast manhole sections. These eliminate the need for a person to enter the structure to weld the liner on the job site.

Both HDPE and PVC liners have excellent sulfide corrosion resistance, and plastic-lined concrete structures combine the structural advantages of reinforced concrete with the acid resistance of the plastic. Environmental stress cracking, which can occur in HDPE sewer pipe in the presence of detergents, is not a problem since the HDPE liner itself is not subjected to stress or strain.

RECOMMENDATIONS

Proper attention to hydraulic design, minimizing turbulence and energy losses, and some design effort focused on protection of sanitary sewer structures will prevent deterioration and early failure of both structures and downstream piping. The result will be structures that function as intended for the design life of the collection system. Some specifics:

1. Where corrosion prediction calculations indicate that a corrosion-proof liner is required for sewer pipe, the structures in the system should also be protected. A mechanically locked PVC liner is preferable to a coating.

2. Where conditions tend to exacerbate sulfide corrosion, concrete sewer structures should be protected. These include flat slopes, high ambient temperatures and/or long detention times.

3. Where conditions tend to increase the amount of hydrogen sulfide gas released to the sewer atmosphere, concrete sewer structures should be protected. These include steep slopes, turbulence and presence of sulfide in the sewage.

4. Pump-station wet wells, drop structures, inverted siphon inlet and outlet structures, force main discharge structures, metering-station structures, and structures where hydraulic jumps or other significant flow disturbances will occur should be protected with a mechanically locked PVC lining as a routine design procedure. Pipe in the vicinity of such structures should be lined as well. The exception is where it can be demonstrated that sulfide will not be present in the sewage. ❑

TABLE 2: RECOMMENDED TCF VALUES—DROP STRUCTURES

	Total Flow Dropped				
Height	100% TCF	25% TCF	10% TCF	DD	DU
1 D	15	12	10	150 D	10 D
2 D	20	17	15	200 D	20 D
3 D	30	37	25	300 D	30 D

Note: Distance in pipe diameters.

TABLE 3: COATING STUDY

		Performance		
Coating	Test Number	Application	Corrosion Resistance	Bond
Senotex 3005	C-1 (Urethane)	2	1	3
Zebron	C-3 and C-39 (Urethane)	3	1	2
PR475	C-10 (Urethane)	2	2	1
Quantum	C-17 (Polyester)	1	1	1
Fosroc	C-22 (Epoxy mortar)	3	3	1
Aquata-Poxy	C-25 (Epoxy)	2	1	1
Vibrabond 500	C-26 (Urethane)	4	1	2
Concresive 1305	C-28 (Epoxy)	1	2	1
PVC Panels	C-29 (Liner)	3	1	–
Acid Proof Cement No. 54	C-34 (Liner)	2	2	–
Allied Urethylene	C-35 (Liner)	2	2	–
GS1490	C-36 (Urethane)	4	–	3
Mainstay DS-4	C-37 (Epoxy)	1	1	1
120 Vinester	C-38 (Vinyl/ester (long cure time)	1	1	1
Allied Vinylthane	C-40 (Liner)	1	1	–
Overkote V	C-42 (Epoxy mortar)	2	2	1
IET System 3	C-44 (Polyester)	2	1	1
Sancon 100	C-47 (Urethane)	2	2	2
Semstone 140S	C-49 (Epoxy)	1	1	1
Magma Quartz	C-50 (Epoxy mortar)	2	1	1
IPI Crystal Quartz	C-53 (Epoxy mortar)	1	1	1

Each coating was ranked for application, corrosion resistance and bonding: 1 = good; 2 = some problems, but not significant; 3 = significant problems; and 4 = failure.

COATINGS WERE RATED BY THE LOS ANGELES COUNTY SANITATION DISTRICTS.

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