EVALUATION OF PROTECTIVE COATINGS FOR CONCRETE

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SCOPE

This report summarizes the results of a testing program to evaluate protective coatings for concrete conducted by the County Sanitation Districts of Los Angeles County (Districts). The testing was conducted at the Districts' Compton Field Office in the City of Compton. The program started in 1983 and ended in 2004. Results for 96 protective coating and lining system tests are reported.

INTRODUCTION

Concrete is the most widely used construction material in wastewater collection and treatment systems. Unfortunately, significant corrosion can occur to unprotected concrete when sulfide generation in wastewater is not controlled. Sources of sulfide in wastewater include degradation of sulfur containing organic matter, the microbiological reduction of sulfate or other oxidized forms of sulfur, and unregulated and/or uncontrolled industrial discharges. The construction of regional collection and treatment systems has increased wastewater travel time in collection systems, culminating in anaerobic wastewater and consequently increased sulfide generation. Odors from manholes or wastewater treatment facilities create significant nuisance problems for most agencies. A major cause of odors is hydrogen sulfide, a gas detectable at extremely low concentrations. Hydrogen sulfide is notorious for its toxicity, as well as its ability to corrode a number of materials used in construction of sewers and treatment plants, including concrete. Concrete corrosion is caused by the aerobic microbial oxidation of hydrogen sulfide to sulfuric acid and the subsequent chemical reaction of the acid with the cement binder in the concrete. Most agencies are particularly sensitive to the nuisances created by the odor releases. Many agencies are often unaware of the significant corrosion occurring to their concrete facilities.

The Districts have utilized different types of protective systems in its history to minimize concrete corrosion. In the mid 1920's the use of vitrified clay liner plates in the construction of large poured-in-place concrete sewers and inlet facilities proved unsuccessful. By the mid 1960's many epoxy coating systems were being tried. Inspections documented coating failure wherever exposure to significant sulfuric acid attack occurred, often within just a few years. This same experience was reported in the 1969 Manual of Practice No. 17, Paints and Protective Coatings for Wastewater Treatment Facilities, "... few, if any, coatings have been effective in preventing the corrosion of concrete under highly corrosive conditions... "[1]. A considerable amount of marketing has occurred for high solids, fast cure coating systems. First hand experiences with these coating systems have resulted in widely different opinions from different agencies. One agency reports nothing but success, while another reports nothing but failure. Figures 1A and 1B illustrate the failure that occurred, after only two years of service, to a urethane coating applied to a drop manhole in 1980.

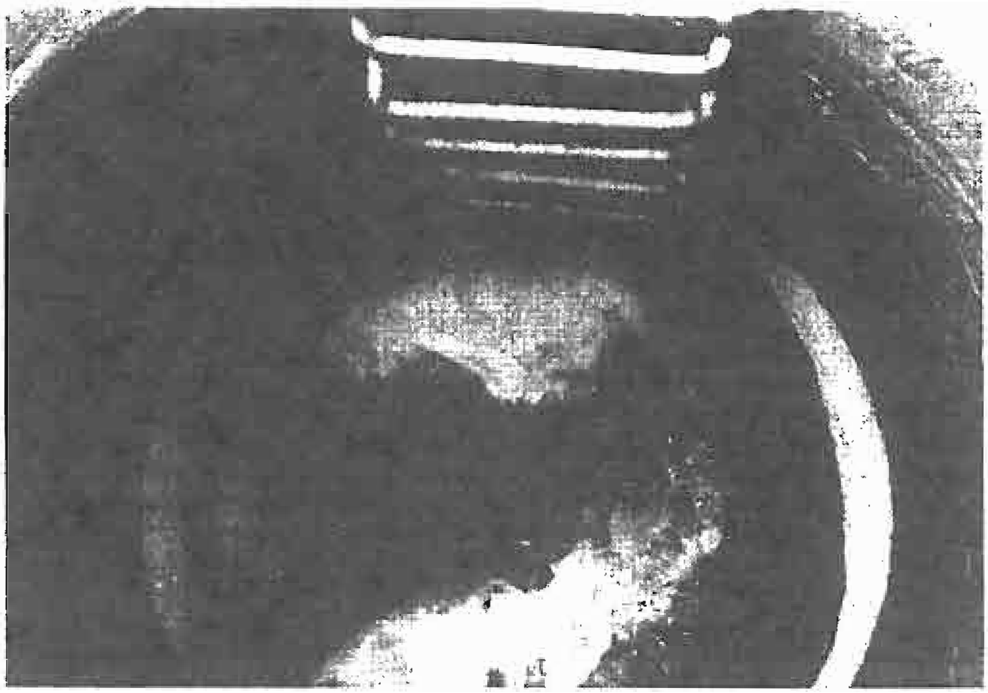

Figure 1A. Urethane coating applied to a drop manhole.

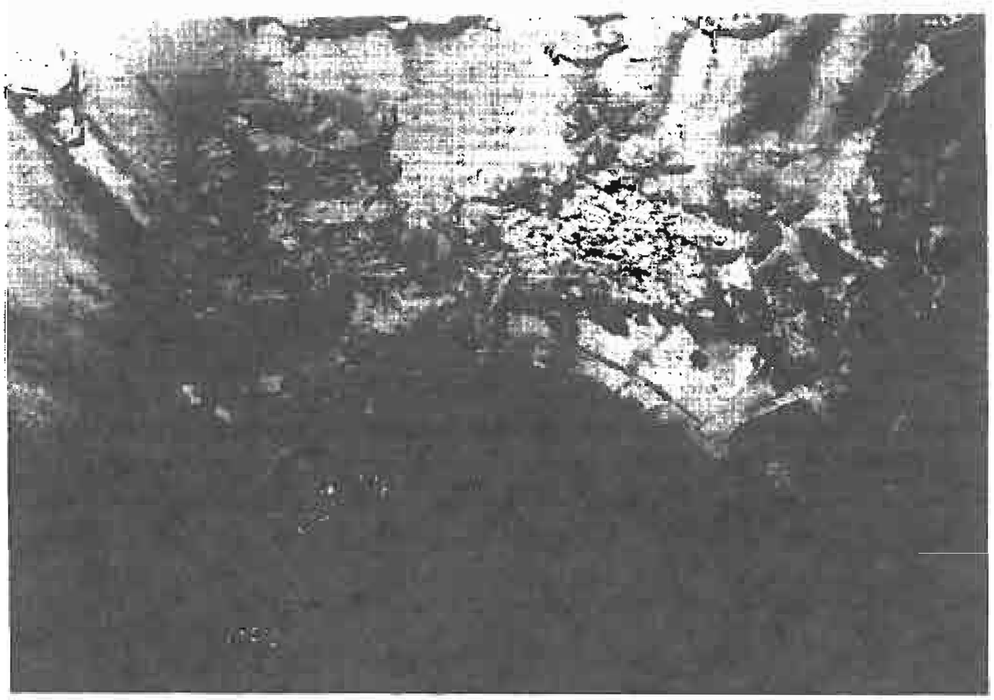

Figure 1B. Urethane coating failure after two years.

The only protective coating system that has developed any consistent degree of success for the Districts has been the application of polyvinyl chloride (PVC) liners to concrete surfaces during construction. While this method of concrete protection has provided 50 years of demonstrated service[2] and has become the standard specification for the Districts for new concrete construction, many questions remain concerning the best method and materials for rehabilitating existing corroded concrete structures. Many rehabilitation projects do not allow sufficient "down" time for conventional concrete surface repairs, using cementitious materials, followed by the application of liners. The application of a coating system that bonds to concrete and provides protection from microbial sulfuric acid would have wide application in the wastewater industry.

The protection of construction materials from corrosive effects of chemicals is a very large industry. The design engineer has a myriad of protective coatings to choose from in designing wastewater facilities. Unfortunately, too much reliance is often placed on the manufacturer's sales representative in deciding which materials to recommend for a given situation. Much laboratory time and money have been spent on evaluating protective coatings on specimens especially prepared for the tests. What was not available were evaluations of the performance of these coating systems in actual applications. How does the coating stand up and what application problems are encountered? What are the proper application specifications? The performance of a design engineer's "favorite" coating system is often inadequately documented. Its use can suddenly run into difficulty when applied in an environment where the corrosion rate is higher, or the application conditions are unfavorable.

The Districts undertook the task of attempting to develop a test to evaluate protective coatings applied to corroded and uncorroded concrete. An accelerated corrosion test that attempts to simulate actual application conditions was designed. The purpose of testing was to develop a list of suitable coatings and the specifications for their applications for both new construction and rehabilitation projects.

CORROSION TESTING FACILITY

The evaluations were conducted in shallow concrete tanks constructed by inserting two concentric, precast reinforced concrete manhole shafts into a freshly poured, wet concrete base slab. The inner tank diameter wais 0.9 m (3 ft.) with a depth of approximately 0.8 m (2.5 ft.). The outer tank diameter was 1.2 m (4 ft.) with a depth of approximately 0.9 m (3 ft.). The tanks were constructed of Type II Portland Cement manufactured to meet or exceed the requirements of A.S.T.M. C 478 specification. The annular space between the outer and inner tank was filled with water to simulate moisture from groundwater or from an adjacent process unit. Figure 2 illustrates the construction of a test tank. Figure 3 is a photograph of some test tanks, depicting the concentric inner and outer tanks.

EVALUATION PROCEDURE

The lower half of each tank was allowed to corrode for six to eight weeks, using 265 liters (70 gallons) of a 10% (by weight) solution of sulfuric acid. Approximately 25 mm (1 in.) of corrosion was observed to occur in the unprotected concrete tanks during this period. This rate of corrosion is fifteen to twenty times the highest corrosion rate expected in actual service. The use of 10% acid was arbitrary, but it represents a more corrosive environment than the actual service situation. The observed increased corrosion rate was accounted for by concentration and the volume of acid that was exposed to the concrete surface in the test tank. In the test tank, the corroding concrete was flooded by the 10% acid solution. Figure 4 is a photograph of a test tank showing the corroded lower half and uncorroded upper half.

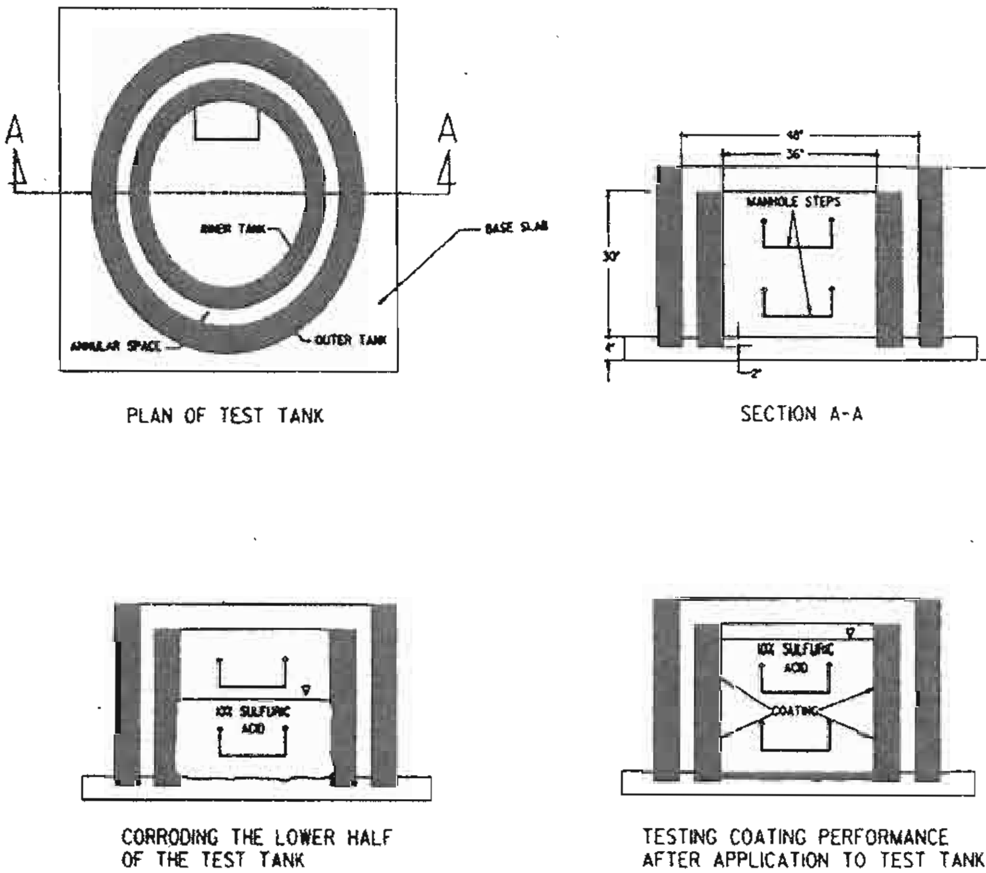

Figure 2. Construction of test tanks and sequence of coating testing.

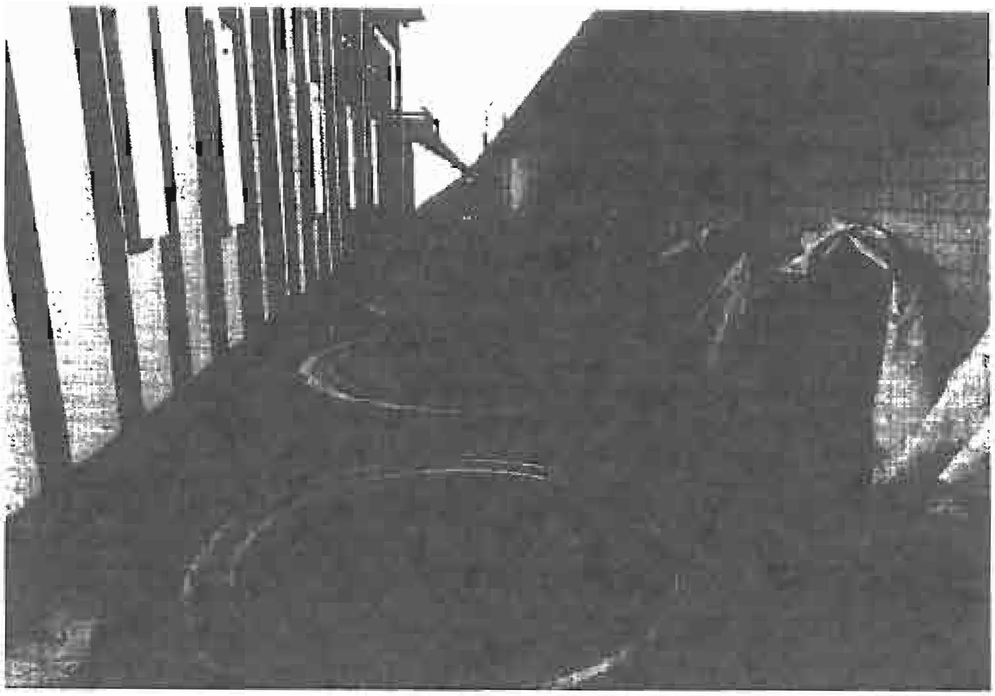

Figure 3. Five test tanks.

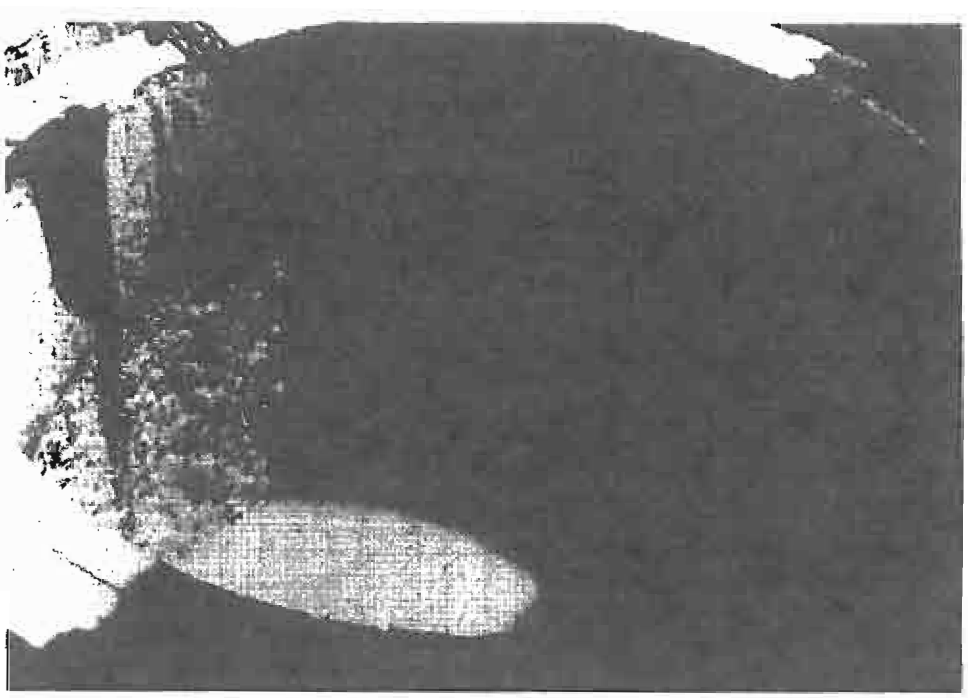

Figure 4. Test tank being waterblasted.

A coating application to the test tank was scheduled when sufficient aggregate and even some reinforcing steel had been exposed. The manufacturer was requested to apply the coating to both the corroded and uncorroded surfaces inside the test tank. The coating manufacturer was responsible for all surface preparation prior to application of the coating. Generally, the manufacturers chose either sandblasting or high-pressure water blasting for surface preparation. Water blasting is illustrated in Figure 4. If too much aggregate was exposed for proper application of the coating, then the manufacturer was responsible for surface repair as well. Most surface repairs used fast curing cements or a mixture of the coating material and an inert filler, such as sand. The entire application process, including surface preparation, had to be completed within 8 hours. Figure 5 shows surface repair work in progress on a test tank. The spray application of a coating is illustrated in Figure 6.

The coating to be tested had to be able to cure sufficiently so that water could be added to the test tank within 48 hours after the application. A total of 96 hours after the application of the coating, sufficient concentrated sulfuric acid was added to the water in the test tank for a final acid concentration of 10% by weight. The acid level in the coated test tank was set high enough to also submerge a portion of the coated uncorroded concrete. This is illustrated in Figure 2.

The test procedure had been designed to simulate the application of coatings to manholes or pipelines and the return of corrosive conditions. Coating systems that require longer application or cure times are less attractive for most rehabilitation projects, but are still considered for new construction.

The manufacturer was not permitted to perform any pinhole or holiday testing after the application of the coating, even though such testing is used as part of a standard application specification. The existence of coating or application flaws were often apparent after the application and was obvious during the test phase. A coating system that cannot be applied without pinholes or holidays on such a small scale (approximately 3.2 m^2; 35 ft^2) by the manufacturer was not considered a viable system.

The objective of the test was to evaluate the coating's application requirements, concrete bonding characteristics, and acid resistance for a minimum of one year of acid service. Unless coating failure was observed earlier, the acid solution was usually removed on a quarterly or semi-annual basis to allow a physical inspection of the test tank. During the inspection, photographs were taken to document any changes in the coating's appearance. Observations were made of the coating's bonding characteristics and measurements were made of the coating thickness. A cross section of the coating was inspected to evaluate pinholing, air pockets or any gradual deterioration or reaction with the acid. The manufacturer was given the opportunity to repair any areas that are damaged by the inspection.

It is important to consider some of the limitations of this evaluation and the testing procedure. The effects of long term aging and exposure to moisture and any bacterial action was not evaluated. This testing procedure is believed, however, to adequately evaluate the ability of a coating system to be effectively applied and to resist extensive sulfuric acid exposure. The continuation of testing beyond the one year acid service goal, for the successful coating systems, was occasionally done to obtain additional information on long term performance. It should also be noted that some of the coatings that successfully passed this test later failed in actual sewer application. The failures may have been due to permeability of the coating to hydrogen sulfide gas[3], which this testing procedure did not address.

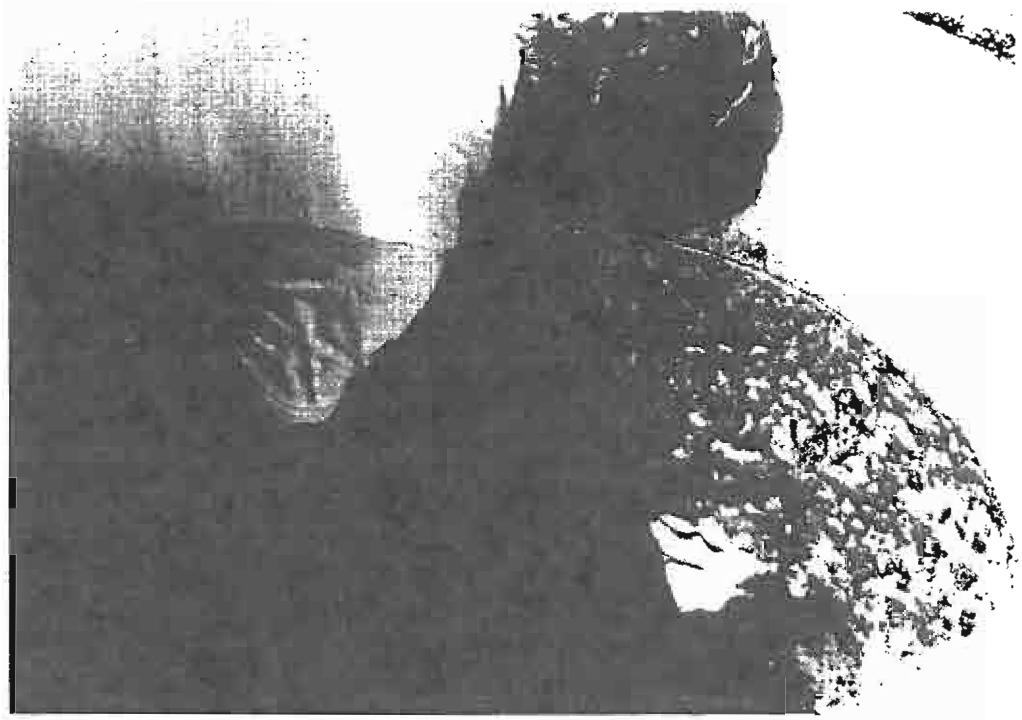

Figure 5. Surface repair to the corroded portion of the test tank.

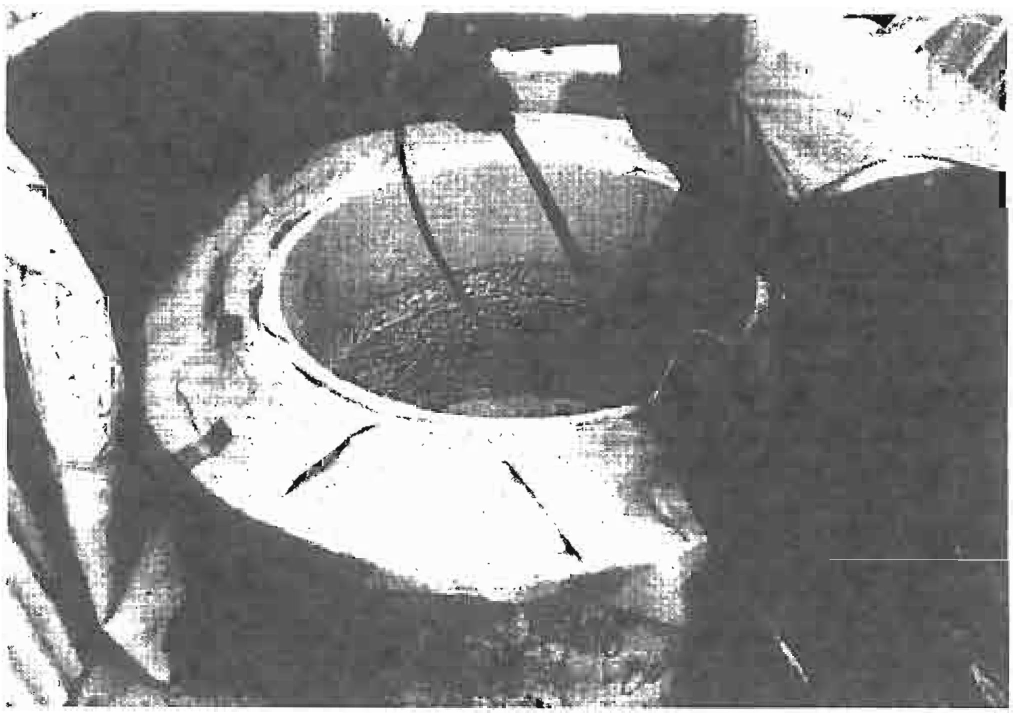

Figure 6. Spraying a coating on a test tank.

RESULTS AND DISCUSSION

Evaluations have been completed on 96 coating and liner system installations. The systems evaluated are identified in Table 1. Each coating is identified by a code number, the generic type of coating, the manufacturer's designation for the coating, and the manufacturer. The types of coatings evaluated have been Coal Tar, Coal Tar Epoxy, Coal Tar Epoxy Mortar, Coal Tar Urethane, Concrete Sealers, Epoxy, Epoxy Mortars, Phenolic, Polyester, Polyester Mortars, Polyurea, Silicone, Specialty Concrete, Urethane, Vinyl Ester, and Vinyl Ester Mortars. The liner systems evaluated include Polyvinyl Chloride (PVC), High Density Polyethylene (HDPE), Glass fiber Reinforced Plastic (GRP), and epoxy resin saturated structural fiberglass with PVC. Manufacturer's brochures for these coatings all recommend application for wastewater collection and treatment facilities.

A summary of the test application data for each coating system evaluated is in Table 2, referenced by code number. The data include the surface preparation method used, surface repair techniques, whether or not a primer was used, coating application method, and average dry coating thickness for the wall and base of each test tank in millimeters and mils. This information is important in evaluating the coatings and preparing specifications for full-scale applications.

All coating systems, bonded lining systems, and most unbonded but anchored lining systems require some form of surface preparation. No coating system can be expected to perform as designed without an adequate surface to adhere to. Prior to application of the coating system for rehabilitation, the existing surfaces must be prepared by either sandblasting or high pressure water blasting (34.5 MPa; 5,000 psi or greater) to firm, sound concrete. Mechanical scraping or scabbling of corroded surfaces can be used, if the surface does not have to be repaired to original dimensions. It is useful to require that preparation provide a concrete surface pH of at least 7 and no visible evidence of corroded concrete.

If the profile of the prepared concrete surface does not exceed 6 mm (1/4 in.) in depth, then no surface repair is normally needed for high build, high solids content coating systems. Surface repair to provide a smoother profile for application of the thinner coating systems is recommended. For areas of greater corrosion, surface repair would be necessary before application of any coating system. Lining systems often do not require surface repair.

Cement mortar can be utilized for surface repair where sufficient cure time can be provided. Where shorter cure periods are necessary, which is typical of most rehabilitation projects, fast setting, high bond strength, polymer cement or epoxy mortar systems, suitable for vertical or overhead surfaces, have to be substituted. Some of these repair materials are able to fill as deep a pocket as 100 mm (4 in.) in one pass. Many coatings can be mixed with fine grades of sand, thickening agents, or other extending agents to produce a trowel or spray grout-like repair material. The use of this type of extended version of the coating system is a recommended repair technique. A final sweep blast of all repaired surfaces may be necessary prior to application of the coating.

TABLE 1
Description of Protective Coating Systems Evaluated

CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
C-1 (1983)	Urethane	Senotex 3005	H.B. Fuller Company Senotex Products 5220 N.E. Main Street Minneapolis, MN 55421
C-2 (1983)	Specialty Concrete	Thorotop HCR (formerly Siloseal)	Degussa Building Systems 889 Valley Park Drive Shakopee, MN 55379 (formerly from Thoro Systems Products)
C-3 (1983)	Urethane	Zebron 386/9000	Reliance Universal Inc. P.O. Box 1113 Houston, TX 77251
C-4 (1983)	Urethane	Torbron	Zebra Management Inc. 10850 Wilshire Blvd. Los Angeles, CA 90024
C-5 (1983)	Urethane	Durathane 100	Sancon Engineering, Inc. 5841 Engineer Drive Huntington Beach, CA 92649
C-6 (1983)	Specialty Concrete	Thoroseal	Refer to C-2 (formerly from Thoro Systems Products)
C-7 (1983)	Epoxy	Engard 460	Engard Corporation 15541 Commerce Lane Huntington Beach, CA 92649
C-8 (1983)	Urethane	PR 318 [1]	Products Research and Chemical Corp. P.O. Box 1800 Glendale, CA 91203
C-9 (1983)	Urethane	PR 319 [1]	Refer to C-8 (Products Research and Chemical Corp.)
C-10 (1983)	Urethane	PR 475 [1]	Refer to C-8 (Products Research and Chemical Corp.)
C-11 (1983)	Specialty Concrete	Deco-Rez PMC 505	General Polymers Corporation P. O. Box 12168 Cincinnati, OH 45212
C-12 (1983)	Specialty Concrete	Thoro Polymer Concrete	Refer to C-2 (formerly from Thoro Systems Products)
C-13 (1983)	Specialty Concrete	All-Crete MP Concrete [1]	Refer to C-2 (formerly from Concrete Products, Inc.)
C-14 (1983)	Epoxy	Sikagard 61	Sika Corporation 875 Valleybrook Avenue Lyndhurst, NJ 07071
C-15 (1984)	Epoxy Mortar	Concresive	Refer to C-2 (formerly from Adhesive Engineering Co.)
C-16 (1984)	Epoxy	Concresive 1305	Refer to C-2 (Degussa Building Systems, formerly from Adhesive Engineering Co.)
C-17	Polyester Mortar	PPC Coating (formerly Quantum)	Polymorphic Polymers Corporation 1775 Broadway, Suite 527

TABLE 1
Description of Protective Coating Systems Evaluated

CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
(1984)			New York, NY 10019-1903
C-18 (1984)	Concrete Sealer	Sinak Sealer, S-101 and S-102	Sinak Corporation 3308 Midway Drive San Diego, CA 92110
C-19 (1984)	Epoxy	Sikagard 62	Refer to C-14 (Sika Corporation)
C-20 (1984)	Coal Tar	Farbertite	Briggs Bituminous Composition Co. 2745 N. Amber Street Philadelphia, PA 19134
C-21 (1984)	Epoxy	Ipanol CH	IPA Systems Inc. 731 N. Market Blvd. Sacramento, CA 95834
C-22 (1984)	Epoxy Mortar	ThoRoc HBS 100 Epoxy Liner (formerly Fosroc)	Refer to C-2 (formerly from Preco Industries Limited)
C-23 (1984)	Epoxy	Plasite 5308	Wisconsin Protective Coating Corporation P.O. Box 216 Green Bay, WI 54305
C-24 (1984)	Phenolic	Phenoline 307	Carboline 350 Hanely Industrial Court St Louis, MO 63144
C-25 (1984)	Epoxy Mortar	AquataPoxy	Raven Lining Systems 1024 N. Lansing Avenue Tulsa, OK 74106 (formerly from American Chemical Corp)
C-26 (1985)	Urethane	Vibraspray PC-100	Uniroyal Inc. World Headquarters Middlebury, CT 06749
C-27 (1985)	Specialty Concrete	Swindress Bond 110	Swindress Bond 101 Fairview Avenue Ontario, CA 91761
C-28 (1985)	Epoxy	Concresive 1305	Refer to C-2 (Degussa Building Systems, formerly from Adhesive Engineering Co.)
C-29 (1985)	PVC Liner	PVC	Southwest Concrete Products 517 S. Benson Avenue Ontario, CA 91761
C-30 (1985)	Coal Tar Epoxy	CTE - 200	Wise Chemical Company Chicago, IL
C-31 (1985)	Silicone	Butec 165-205	Butec Chemical Corporation 2002-1055 W. Georgia Street Vancouver, BC V6E 3P3
C-32 (1985)	Urethane	Sancon - 100	Refer to C-5 (Sancon Engineering Inc.)
C-33 (1985)	Urethane	Carboline L1304-267	Refer to C-24(Carboline)

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Description of Protective Coating Systems Evaluated

CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
C-34 (1985)	Specialty Concrete	Acid Proof Cement No. 54	Sauereisen 160 Gamma Drive Pittsburgh, PA 15238
C-35 (1985)	Polyethylene - Liner	Urethylene Liner [1]	Linabond, Inc. (formerly Allied Coatings Co.) 12960 Bradley Avenue Sylmar, CA 91342
C-36 (1985)	Urethane	GS 1490	Grove International Inc. 826 North Lake Street Burbank, CA 91502
C-37 (1986)	Coal Tar Epoxy Mortar	Mainstay DS-4	Madewell Products Corporation 7561 Industrial Court Alpharetta, GA 30004 (formerly from Mainstay Corp.)
C-38 (1986)	Vinylester Mortar	Series 120 Vinester	Tnemec Company Inc. 6800 Corporate Drive Kansas City, MO 64120-1372
C-39 (1986)	Urethane	Zebron 386/9000	Refer to C-3 (Reliance Universal Inc.)
C-40 (1986)	PVC Liner	Linabond Mastic System	Refer to C-35 (Linabond, Inc.)
C-41 (1987)	Epoxy Mortar	Overkote V	Concrete Protection Systems, Inc. P.O. Box 9545 Tulsa, OK 74157
C-42 (1987)	Epoxy Mortar	Fibre/Crete 2040	Con/Chem, Inc. 12301 Wilshire Blvd. P.O. Box 25577 Los Angeles, CA 90025
C-43 (1987)	Concrete Sealant	Crystal-Lok	Applied Coatings Technology, Inc. 6145 Getty Drive Sherwood, AK 72117
C-44 (1988)	Polyester Mortar	I.E.T. System 3	Integrated Environmental Tech. P.O. Box 40759 Santa Barbara, CA 93140
C-45 (1988)	Epoxy Mortar	Chesterton 798 Polymer Quartz Compound (ARC 791)	A.W. Chesterton Company 225 Fallon Road Stoneham, MA 02180
C-46 (1988)	Specialty Concrete	Hortoncrete 126-6200	The Horton Company P.O. Box 13525 Pensacola, FL 32591-3525
C-47 (1988)	Urethane	Sancon 100	Refer to C-5 (Sancon Engineering Inc.)
C-48 (1988)	Urethane	Senotex 3013	Refer to C-1 (H.B. Fuller Company)

TABLE 1
Description of Protective Coating Systems Evaluated

CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
C-49 (1988)	Epoxy Mortar	Semstone 140S	Refer to C-2 (Carboline Company, formerly from Sentry Polymers and Plasite)
C-50 (1988)	Epoxy Mortar	Magma Quartz or Belzona 4111	Belzona, Inc. 2000 NW 88th Court Miami, FL 33172
C-51 (1988)	Epoxy Mortar	CR Barrier	Refer to C-50 (Belzona, Inc.)
C-52 (1988)	Urethane	Crandal SHB 1000	RenDel Corporation 1900 MacArthur Blvd. Suite 1217 Irvine, CA 92715
C-53 (1988)	Epoxy Mortar	I.P.I. Crystal Quartz	Integrated Polymer Industries, Inc. 3029 S. Harbor Blvd. Santa Ana, CA 92704-6448
C-54 (1988)	Vinylester	Plasite 4300	Refer to C-23 (Wisconsin Protective Coating Corp.)
C-55 (1988)	Coal Tar Urethane	Bitumastic Coal Tar Urethane Type I	Kopcoat, Inc. 5431 District Blvd. Vernon, CA 90040
C-56 (1988)	Epoxy Mortar	Nu-Klad 100A	Ameron Protective Coatings 201 N. Berry Street Brea, CA 92621
C-57 (1989)	Polyester	Quantum	Refer to C-17 (Polymorphic Polymers Corporation)
C-58 (1989)	Specialty Concrete	Hortoncrete 126-6200	Refer to C-46 (The Horton Company)
C-59 (1989)	Specialty Concrete	Hortoncrete 126-6200	Refer to C-46 (The Horton Company)
C-60 (1989)	Urethane	P.R.-2331	Refer to C-8 (Products Research and Chemical Corp.)
C-61 (1990)	Epoxy Mortar	Sauereisen 210	Refer to C-34 (Sauereisen)
C-62 (1990)	PVC Liner	Con-plast Plastic Liner System	Southwest Concrete Products 519 S. Benson Avenue Ontario, CA 91762-4002
C-63 (1990)	PVC Liner	Danby PVC Liner	Danby of North America, Inc. P.O. Box 5127 Cary, NC 27512-5127
C-64 (1990)	PVC-Liner + Urethane Foam	Linabond Foam & PVC	Refer to C-35 (Linabond, Inc.)
C-65 (1990)	Sulfur Concrete	Chempruf	F. E. Ward Constructors 2710 Northeast 78th Street Vancouver, WA 98665
C-66 (1992)	Epoxy	Hydro-Pox 204 (formerly Hydro-Pox 193)	Con-Tech of California 2211 Navy Drive Stockton, CA 95206

TABLE I
Description of Protective Coating Systems Evaluated

CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
C-67	Epoxy Mortar	Sauereisen-210	Refer to C-34 (Sauereisen)
C-68 (1992)	Polyurea	Structural Seal Polyurea (formerly Sprayseal)	Structural Seal Polyurea Manholes 2652-D North Southport Avenue Chicago, IL 60614
C-69 (1992)	Epoxy Mortar	Raven 405	Refer to C-25 (Raven Lining Systems)
C-70 (1993)	PVC-Liner + Urethane Foam	Linabond Structural Polymer System	Refer to C-35 (Linabond, Inc.)
C-71 (1993)	Urethane	Endura-flex EF1988	Global Eco Technologies P.O. Box 767 Pittsburgh, CA 94565-0767
C-72 (1994)	PVC Liner	Danby PVC Liner	Refer to C-63 (Danby of North America, Inc.)
C-73 (1994)	Fiberglass and PVC Liner	Poly-Triplex Liner	Poly-Triplex Technologies, Inc. 1701 Wynkoop, Suite 250 Denver, CO 80202
C-74 (1994)	Epoxy Mortar	AquataPoxy A-6	Refer to C25 (formerly from American Chemical Corp.)
C-75 (1994)	Polyurea	ThoRoc IC-2480 and Sonneborn TF30 (formerly Polyquick P300)	Refer to C-2 (Degussa Building Systems, formerly from Willamette Valley Company)
C-76 (1995)	Polymer Concrete	Meyer Polycrete	Meyer Rohr + Schacht GmbH http://www.meyer-polycrete.com/en/
C-77 (1996)	Polymer Concrete	iNTERpipe (formerly ICOM)	Polymer Pipe Technology, LLC 500 E. Locust, 5th Floor Des Moines, IA 50309
C-78 (1997)	PVC Liner	PVC 500	Roundeau Phelps Ventures 6603 San Leandro Street Oakland, CA 94621
C-79 (1998)	Polyethylene-coated CMP	SRP (Steel Ribbed Polyethylene Pipe)	Pacific Corrugated Pipe Co. P.O. Box 2450 Newport Beach, CA 92658-8972
C-80 (1998)	PVC Liner	Arrow-Lock	Refer to C-56 (Ameron Protective Coatings)
C-81 (1998)	HDPE Liner	Agru Sure Grip	Agru www.agru.at
C-82 (1999)	HDPE Liner	GSE StudLiner	GSE Lining Technology, Inc. 19103 Gundle Road Houston, TX 77073
C-83 (2000)	GRP Liner	Channeline GRP Liner	Channeline Sewer Systems (N.A.) Inc. 125 Half Mile Road, Suite 200 Red Bank, NJ 07701
C-85 (1999)	Fiberglass and PVC Liner	Multiplexx Liner System	Terre Hill Composites 485 Weaverland Valley Road Terre Hill, PA 17581

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CODE NUMBER (Yr tested)	GENERIC TYPE	COATING DESIGNATION	MANUFACTURER
C-86 (1999)	Fiberglass and PVC Liner	Multiplexx Type PVCP Liner	Refer to C-85 (Terre Hill Composites)
C-87 (2000)	HDPE Liner	GSE StudLiner	Refer to C-82 (GSE Lining Technology, Inc.)
C-88 (2000)	Epoxy	Warren Epoxy Spray	Warren Environmental, Inc. P.O. Box 1206 Carver, MA 02330
C-89 (2000)	Epoxy	Warren Epoxy Laminate	Refer to C-88 (Warren Environmental, Inc.)
C-91 (2001)	Fiberglass and PVC Liner	Multiplexx Type PVCP Liner	Refer to C-85 (Terre Hill Composites)
C-92 (2001)	Urethane	SprayWall	Sprayroq, Inc. 4707 Alton Court Birmingham, AL 35210
C-93 (2002)	Urethane	CIM 1000	C.I.M. Industries, Inc. 23 Elm Street Peterborough, NH 03458
C-94 (2002)	Polyurea	EnviroLastic AR425	The Sherman-Williams Company 17500 South Main Street Gardena, CA 90248
C-95 (2003)	Epoxy Mortar	Tnemec Series 434 Chembloc	Refer to C-38 (Tnemec Company Inc.)
C-96 (2003)	Polyurea	EnviroLastic AR425	Refer to C-94 (The Sherman-Williams Company)
C-97 (2003)	Epoxy	NeoPoxy NPR-5300 Series	NeoPoxy Corporation 27057 Industrial Blvd., Ste. 208 Hayward, CA 94545
C-98 (2003)	Fiberglass and PVC Liner	Poly-Triplex Liner PTLS-5600	Refer to C-73 (Poly-Triplex Technologies, Inc.)

Note: 1. Reported to be discontinued.

TABLE 2
Application Data - Protective Coating Systems Evaluated

Code No.	Surface Preparation [1]	Surface Repair	Primer	Application Method	Coating Thickness Tank Walls mm (mils)	Coating Thickness Tank Base mm (mils)
C-1	WB	No	Yes	Spray	1.5 (60)	2.5 (100)
C-2	WB	No	No	Trowel	3.2 (125)	3.2 (125)
C-3	WB	No	No	Spray	2.5 (100)	6.3 (250)
C-4	WB	No	Yes	Spray	2.5 (100)	-
C-5	WB	No	Yes	Spray	2.5 (100)	-
C-6	SB	No	No	Trowel	3.2 (125)	6.4 (250)
C-7	SB	Yes [2]	Yes	Brush	0.6 (24)	0.6 (24)
C-8	SB	No	No	Brush	0.5 (20)	-
C-9	SB	No	No	Brush	0.6 (24)	-
C-10	SB	No	Yes	Spray	0.8 (30)	0.8 (30)
C-11	WRB	No	No	Trowel	3.2 (125)	3.2 (125)
C-12	WRB	No	No	Trowel	1.5 (60)	6.4 (250)
C-13	[3]	[3]	[3]	[3]	-	-
C-14	SB	No	No	Brush	1.5 (60)	1.5 (60)
C-15	SB	No	No	Trowel	3.2 (125)	6.4 (250)
C-16	SB	No	[4]	Brush/Roll	0.8 (30)	1.5 (60)
C-17	SB	No	Yes	Trowel/Roll	1.5 (60)	3.2 (125)
C-18	SB	No	No	Spray	-	-
C-19	SB	Yes [2]	No	Brush	0.4 (16)	0.4 (16)
C-20	WB	Yes [2]	No	Brush	0.5 (20)	0.5 (20)
C-21	WB	Yes [2]	No	Brush	0.8 (30)	0.8 (30)
C-22	SB	No	No	Trowel	3.2 (125)	3.2 (125)
C-23	[5]	[5]	[5]	[5]	-	-
C-24	[5]	[5]	[5]	[5]	-	-
C-25	SB	Yes	No	Brush	7.6 (300) Gel 0.8 (30) Top Coat	9.1 (360) Gel 0.8(30) Top Coat
C-26	SB	No	Yes	Spray	5.1 (200)	15.2 (600)
C-27	[6]	[6]	[6]	[6]	-	-
C-28	SB	Yes [2]	No	Spray	0.4 (16)	1.0 (40)
C-29	-	-	-	Manufactured liner	3.2 (125)	3.2 (125)
C-30	[7]	[7]	[7]	Spray	1.3 (50)	-
C-31	WB	Yes [2]	No	Brush/Roll	0.2 (8)	0.4 (16)
C-32	R, G	No	Yes	Spray	2.5 (100)	3.2 (125)
C-33	WB	Yes [2]	Yes	Spray	1.8 (70)	1.8 (70)
C-34	SB, WRB	No	No	Spray urethane underlayment & form concrete	1.5 (60) urethane underlayment 25(1000)concrete	1.5 (60) urethane underlayment 25(1000)concrete
C-35	SB	No	No	Trowel mastic and hand lay up of liner	3.2 (125) Mastic 0.3 (10) PE	3.2 (125) Mastic 0.3 (10) PE
C-36	SB	No	Yes	Spray	1.0 (40)	2.0 (80)
C-37	SB	No	No	Brush	2.5 (100)	2.5 (100)
C-38	SB	Yes	No	Brush	0.8 (30)	0.8 (30)
C-39	SB	No	Yes	Spray	2.5 (100)	2.5 (100)
C-40	SB	No	Yes	Spray mastic and hand lay up of liner	3.8 (150) Mastic 0.8 (30) PVC	3.8 (150) Mastic 0.8 (30) PVC
C-41	SB	No	No	Trowel	3.2 (125)	12.7 (500)

TABLE 2
Application Data - Protective Coating Systems Evaluated

Code No.	Surface Preparation [1]	Surface Repair	Primer	Application Method	Coating Thickness Tank Walls mm (mils)	Coating Thickness Tank Base mm (mils)
C-42	WB	No	Yes	Spray	3.2 (125)	9.6 (375)
C-43	WB	No	No	Spray	3.8 (150)	3.8 (150)
C-44	SB	No	Yes	Spray	3.2 (125)	3.2 (125)
C-45	SB	No	Yes	Trowel	6.4 (250)	9.6 (375)
C-46	CH, WRB	No	Yes	Form	85 (3350)	85 (3350)
C-47	WB	Yes [2]	[8]	Spray	3.8 (150)	3.8 (150)
C-48	SB	No	Yes	Spray	2.3 (90)	2.3 (90)
C-49	SB	No	Yes	Trowel/Brush	3.2 (125)	9.6 (375)
C-50	SB	No	Yes	Trowel	3.2 (125)	9.6 (375)
C-51	SB	No	Yes	Trowel/Brush	1.6 (60)	1.6 (60)
C-52	SB	No	Yes	Spray	3.3 (130)	3.3 (130)
C-53	SB	No	Yes	Trowel	-	-
C-54	SB	Yes	[9]	Spray	1.0 (40)	1.0 (40)
C-55	SB	No	No	Spray	1.6 (60)	1.6 (60)
C-56	WB	No	Yes	Trowel	3.8 (150)	15.9 (625)
C-57	SB	No	Yes	Brush/Roll	1.0 (40)	1.0 (40)
C-58	SB	No	Yes	Shot	12 (480)	25 (1000)
C-59	SB	No	Yes	Form	60 (2400)	60 (2400)
C-60	SB	No	Yes	Spray	2.0 (80)	2.0 (80)
C-61	WB	No	No	Trowel	3.3 (130)	4.0 (160)
C-62	-	No	No	Manufactured liner	2.0 (80)	2.0 (80)
C-63	WB	No	No	Interlocking PVC liner	1.5 (60)	1.5 (60)
C-64	WB	No	Yes	Spray foam and hand lay up of liner	20 (800) Foam 0.8 (30) PVC	20 (800) Foam 0.8 (30) PVC
C-65	-	No	No	Manufactured pipe	-	-
C-66	WB	No	No	Brush	1.5 (60)	1.5 (60)
C-67	WB	No	No	Trowel	2 (80)	3 (120)
C-68	WB	No	No	Spray	1.5 (60)	1.5 (60)
C-69	WB	No	No	Spray	1.5 (60)	1.5 (60)
C-70	SB	No	No	Spray foam and hand lay up of liner	3.2 (125) Foam 0.8 (30) PVC	3.2 (125) Foam 0.8 (30) PVC
C-71	SB	No	No	Spray	10 (400)	10 (400)
C-72	WB	No	No	Interlocking PVC liner	1.5 (60)	1.5 (60)
C-73	WB	No	No	Cured in place	1.5 (60)	2 (80)
C-74	WB	Yes [10]	No	Spray	1.5 (60)	1.5 (60)
C-75	WB	No	No	Spray	2.5 (100)	2.5 (100)
C-76	-	-	-	Manufactured pipe	-	-
C-77	-	-	-	[11]	-	-
C-78	WB	No	No	Interlocking PVC liner	1.5 (60)	1.5 (60)
C-79	-	-	-	Manufactured pipe	-	-
C-80	SB	No	Yes	Trowel epoxy gel, hot air weld liner	12.7 (500) gel 1.6 (62) PVC	12.7 (500) gel 1.6 (62) PVC

TABLE 2
Application Data - Protective Coating Systems Evaluated

Code No.	Surface Preparation [1]	Surface Repair	Primer	Application Method	Coating Thickness Tank Walls mm (mils)	Coating Thickness Tank Base mm (mils)
C-81	WB	No	No	Welded liner, grouted in place	28.6 (1125) grout 2.0 (80) liner	28.6 (1125) grout 2.0 (80) liner
C-82	WB	No	No	Welded liner, grouted in place	25.4 (1000) grout 2.0 (80) liner	25.4 (1000) grout 2.0 (80) liner
C-83	WB	No	No	Factory fabricated, grouted in place	25.4 (1000) grout 6.35 (250) liner	25.4 (1000) grout 6.35 (250) liner
C-85	WB	Yes [2]	No	Cured in place	4.4 (175)	4.4 (175)
C-86	WB	Yes [2]	No	Cured in place	3.8 (150)	3.8 (150)
C-87	WB, WRB, CH	No	No	Welded liner, grouted in place	38.1 (1500) grout 2.0 (80) liner	38.1 (1500) grout 2.0 (80) liner
C-88	SB, WB	No	Yes	Spray	5.0 (200)	20.3 (800)
C-89	SB, WB	No	Yes	Trowel & spray	15.2 (600)	25.4 (1000)
C-91	WB	No	No	Cured in place	5.0 (200)	2.5 (100)
C-92	CH, WB	Yes [2]	No	Spray	7.6 (300)	7.6 (300)
C-93	WB, WRB	Yes [2]	No	Rolled on	not measured	not measured
C-94	SB, G	Yes [2]	Yes	Spray	not measured	not measured
C-95	WB	No	No	Trowel	6.0 (240)	6.0 (240)
C-96	CH,G,R,SB	No	Yes	Spray	3.8 (150)	1.0 (40)
C-97	WB	No	No	Hand-applied	6.3 (250)	17.8 (700)
C-98	WB	No	No	Cured in place	5.0 (200)	5.0 (200)

Notes:

1. Surface preparation letter designation: CH - chipping hammer; G - mechanical grind; R - water rinse; SB - sandblast; WRB - wirebrush; and WB - water blast.
2. Fast cure mortar.
3. A 1.3 kg sample was suspended in the acid solution in a test tank.
4. Primer applied to one-half of tank only.
5. Coated concrete ingots were suspended in the acid solution in a test tank.
6. Two concrete ingots were suspended in the acid solution in a test tank.
7. Manufacturer prepared and coated a 14-inch diameter pipe specimen. It was shipped to the test site and attached to a plexiglass base. The specimen was placed inside an unused test tank. The acid solution was placed inside the specimen. Water was placed outside the specimen.
8. Manufacturer applied 0.1 mm (5 mils) of a water proof epoxy primer sealer. A top coat of 2 mm (80 mils) was applied to one-half of the tank. A felt pad, saturated with the primer sealer and 3 mm (124 mils) thick, was applied to the second half of the tank and coated with 1.5 mm (60 mils) of top coat.
9. Primer applied to the lower half of test tank only.
10. High-build or gel version of coating applied extensively for surface repair and to patch bugholes.
11. Polymer concrete coupons were placed in acid solution.

As stated earlier, the objective of the test is to evaluate the coating's application requirements, concrete bonding characteristics, and acid resistance for one full year of acid service. For each coating system evaluated, data was obtained for the exposure time to failure or completion of the test, and in categories dealing with the relative ease or difficulties of application, the acid resistance, and bonding characteristics demonstrated. The following numerical score (rating system) is used to classify the results for ease and speed in interpretation:

1. No application problems; excellent resistance to acid; and good bond to concrete.

2. Some application problems that are attributed to the applicator and not a reflection of a coating material problem; some reaction with the acid, such as a color change or surface sheen change, but no coating failure; and an adequate, but not necessarily tenacious, bond to the concrete substrate. None of these problems are judged to be significant during the evaluation.

3. Significant problems developed during the application or during the evaluation phase; the material did not bond adequately to the concrete, indicating that the coating could not reliably protect the concrete.

4. A failure in the coating system as a result of serious application problems; a reaction of the acid with the coating; or failure of the coating to protect the concrete during the evaluation period.

Two additional abbreviations are also used:

N/E: Not evaluated due to early failure in other categories.

N/A: This category is not applicable to the particular product being tested.

Table 3 contains the evaluation results. Data include: the coating or lining system's code number; the exposure time in days; the assigned numerical score for relative ease of application, acid resistance (concrete protection), and concrete bond; and the total score for each coating system that progressed well into or completed the one year evaluation period. Comments are also included in Table 3 in an effort to pinpoint specific problems and to describe the coating's ability to protect concrete from sulfuric acid attack.

The total score is simply the sum of the category scores. The lower the "application" score, the easier the system is to apply. The lower the "acid resistance" score, the more acid resistant the system is. The lower the "concrete bond" score, the stronger the system bonds to the concrete substrate. The lowest assigned score for each component is one; therefore, the lowest possible total score for a coating system that is assigned a score in all categories is 3, unless one or more of the scores are not applicable to a coating system. For instance, if a liner is applied in the manufacturers' facilities and is subsequently transferred to the Districts' testing facilities, we are unable to score this system for ease of application. Consequently, such a system is not assigned a score for the ease of application category. This may lead to a total score of less than 3. A total score of "Failed" is assigned to those products that either received a total score of 6 or greater, and/or received a score of 3 or 4 in any of the categories.

TABLE 3
Test Results for Protective Coating Systems Evaluated

Code No.	Exposure Time (Days)	Application	Acid Resistance	Concrete Bond	Total Score	Comments
C-1	427	2	1	3	Failed	Improved primer required.
C-2	0.1	1	4	1	Failed	Immediate reaction with acid.
C-3	369	2	1	3	Failed	Primer needed.
C-4	98	4	N/E	3	Failed	Pinholes/blowholes formed in coating following application.
C-5	98	4	N/E	3	Failed	Pinholes/blowholes formed in coating following application; bond to concrete inadequate.
C-6	4	1	4	1	Failed	Reaction with acid.
C-7	15	1	4	N/E	Failed	Acid attack to concrete.
C-8	14	1	4	N/E	Failed	Acid attack to concrete.
C-9	14	1	4	N/E	Failed	Acid attack to concrete.
C-10	620	2	2	1	5	Surface repair is necessary; color change to coating.
C-11	21	1	4	1	Failed	Reaction with acid.
C-12	488	3	3	1	Failed	Slow reaction with acid; application difficult to vertical and overhead surfaces.
C-13	1	N/A	4	N/A	Failed	Reaction with acid.
C-14	183	2	4	3	Failed	Acid attack to concrete; color change progressed through coating; poor bonding.
C-15	0	3	-	3	Failed	Would not bond to concrete during application; moisture sensitive.
C-16	232	2	4	1	Failed	Pinholes due to roller application; acid attack to concrete; color change to coating; refer to C-28.
C-17	1429	1	1	1	3	No problems observed; no detrimental effects due to long term exposure to acid were observed.
C-18	30	1	4	N/E	Failed	Acid attack to concrete uninhibited.
C-19	35	2	4	1	Failed	Acid attack to concrete.
C-20	1	1	4	1	Failed	Acid attack to concrete uninhibited.
C-21	4	1	4	1	Failed	Acid attack to concrete uninhibited.
C-22	605	3	3	1	Failed	Small failure spots where coating thickness was 0.8 mm (30 mils) or less; color change through cross section; improved application technique is necessary.
C-23	144	N/A	1	N/A	1	Ingots showed no acid attack; full-scale test not pursued by mfr.
C-24	32	N/A	3	N/A	Failed	Ingot showed some acid attack to concrete; no longer marketed.

TABLE 3
Test Results for Protective Coating Systems Evaluated

Code No.	Exposure Time (Days)	Applica-tion	Acid Resistance	Concrete Bond	Total Score	Comments
C-25	320	2	1	1	4	Surface repair or extensive use of gel is necessary.
C-26	156	4	1	2	Failed	Application problems include blowhole formation and disbonding between coats.
C-27	20	N/A	3	N/A	Failed	Acid attack to ingots; fullscale test not pursued.
C-28	710	1	2	1	4	Refer to C-16. Spray application; color change to coating; no detrimental effects due to long term exposure to acid were observed.
C-29	276	3	1	N/A	Failed	Jointing system for cast in place PVC panels allowed acid migration behind panel.
C-30	63	N/A	4	1	Failed	Acid attack to concrete.
C-31	7	4	4	2	Failed	Pinholes; acid attack to concrete.
C-32	272	4	4	3	Failed	Pinholing/blowholing upon application; acid attack to concrete through pinholes; poor bonding.
C-33	412	3	3	1	Failed	Problems with pinholes/blowholes; coating porous; acid attack to concrete.
C-34	699	2	2	N/E	4	Cement top layer is porous; acid is able to penetrate to underlying membrane; underlayment membrane failed when exposed to acid alone but protected the concrete when combined with cement top layer.
C-35	598	1	2	3	Failed	Bond of liner to mastic deteriorated with exposure to sunlight and contamination by dust and dirt; problems occurred in the bonding of mastic to a patch area of liner.
C-36	157	4	N/E	3	Failed	Test failure was result of poor application technique; coating does not bond adequately to concrete.
C-37	589	1	1	1	3	No problems observed.
C-38	548	1	1	1	3	Extended cure time requirements may limit application to new construction.
C-39	-	4	N/E	1	Failed	Primer greatly improved bond (see C-3); numerous pinholes/ blowholes during application; manufacturer agreed test application was a failure.

TABLE 3
Test Results for Protective Coating Systems Evaluated

Code No.	Exposure Time (Days)	Applica-tion	Acid Resistance	Concrete Bond	Total Score	Comments
C-40	646	1	1	2	4	No problems observed.
C-41	406	4	4	1	Failed	Coating allowed acid penetration and attack of concrete substrate, possibly through areas of inadequate thickness.
C-42	388	2	4	1	Failed	Concrete substrate on floor was corroded due to acid penetration.
C-43	14	1	4	N/E	Failed	Acid attack to concrete.
C-44	378	2	1	1	4	During application some solvent was spilled on bottom of tank; these areas blistered upon exposure to acid; areas patched. No problems observed.
C-45	381	1	2	1	4	Slight discoloration of coating. No other problems were observed.
C-46	168	3	4	N/E	Failed	Inferior material application; large air pockets allowed acid to deteriorate concrete substrate.
C-47	418	2	2	2	Failed	Several areas of delamination due to improper metering during application which resulted in incomplete curing.
C-48	720	3	1	3	Failed	Problems with pinholes during application; areas of delamination have formed on bottom half of tank, found to be separated between coating and primer.
C-49	419	1	1	1	3	No problems observed.
C-50	383	2	1	1	4	No problems observed.
C-51	383	2	3	1	Failed	Pinholes throughout; acid attack to concrete.
C-52	592	1	2	3	Failed	Delamination on floor of tank; traces of corrosion on bottom half of tank; minimal pinholes; problems with adhesion.
C-53	632	1	1	1	3	No problems observed.
C-54	236	3	3	2	Failed	Pinholes on both upper half, where primer not used, and lower half; penetration of acid and concrete corrosion.
C-55	223	3	2	3	Failed	Pinholes allowed acid attack of concrete; blisters in coating.
C-56	83	2	4	1	Failed	Coating reacted with acid.
C-57	56	2	4	4	Failed	Thin coat applications allowed penetration of acid through thin spots and pinholes.

TABLE 3
Test Results for Protective Coating Systems Evaluated

Code No.	Exposure Time (Days)	Applica-tion	Acid Resistance	Concrete Bond	Total Score	Comments
C-58	539	2	2	3	Failed	Bonding problems in uncorroded surfaces of the test tank.
C-59	539	1	2	3	Failed	Blistering of the coating; coating separated from concrete; bonding problems; pinholes.
C-60	106	4	N/E	33	Failed	Corroded concrete found underneath coating in bottom half of tank; pinholes; separation of coating from concrete.
C-61	393	2	3	1	Failed	Acid penetration.
C-62	369	N/A	1	N/A	1	No problems observed.
C-63	371	2	1	N/A	3	No problems observed.
C-64	414	3	4	2	Failed	Reaction with acid.
C-65	2223	N/A	1	N/A	1	No problems observed.
C-66	375	2	1	2	5	No problems observed.
C-67	369	2	1	1	4	No problems observed.
C-68	385	1	1	2	4	No problems observed.
C-69	375	2	1	1	4	No problems observed.
C-70	365	2	1	1	4	No problems observed.
C-71	365	2	1	1	4	No problems observed.
C-72	394	1	1	N/A	2	No problems observed.
C-73	410	2	2	1	5	Acid penetrated the outer layer of fiberglass. Middle PVC layer prevented acid penetration to concrete.
C-74	463	2	1	2	5	Poor adhesion of the coating to the bottom of the tank. No acid penetration.
C-75	404	1	1	1	3	No problems observed.
C-76	445	N/A	1	N/A	1	No problems observed.
C-77	503	N/A	1	N/A	1	Coupons are acid resistant. Pipe product currently available.
C-78	127	4	N/A	N/A	Failed	Acid penetrated joints above grout level due to faulty installation.
C-79	373	N/A	1	N/A	1	Pipe is corrosion resistant.
C-80	363	1	1	1	3	No problems observed.
C-81	349	1	1	N/A	2	No problems observed.
C-82	369	3	1	2	Failed	Acid penetrated welded joint.
C-83	364	1	1	1	3	No problems observed.
C-85	390	1	4	2	Failed	Acid penetrated liner at seam.
C-86	390	1	4	2	Failed	Acid penetrated liner at seam.
C-87	383	2	1	1	4	Liner not embedded at bottom.
C-88	365	2	2	1	5	Slight discoloration, pinholes but no acid penetration.
C-89	365	1	2	1	4	Slight discoloration.

TABLE 3
Test Results for Protective Coating Systems Evaluated

Code No.	Exposure Time (Days)	Application	Acid Resistance	Concrete Bond	Total Score	Comments
C-91	365	2	2	1	5	Poor surface prep at bottom. Liner slightly discolored & sticky.
C-92	370	1	2	2	5	Variable bond. Shallow pinholes, but no acid penetration.
C-93	180	1	4	1	Failed	Corrosion at pinhole. Odorous brown liquid emitted by coating.
C-94	99	2	N/E	3	Failed	20% disbonded in large bubbles.
C-95	430	1	2	1	4	No problems observed except surface discoloration.
C-96	365	3	4	2	Failed	Coating delaminated. Coating over aggregate broke at several locations and allowed concrete corrosion.
C-97	365	1	1	1	3	No problems observed.
C-98	366	1	2	1	4	No problems observed except slight surface discoloration.

Explanation of Rating System:

1. No application problems; excellent resistance to acid; and good bond to concrete
2. Some application problems that are attributed to the applicator and not a reflection of a coating material problem; some reaction with the acid, such as a color change or surface sheen change, but no coating failure; and an adequate, but not necessarily tenacious, bond to the concrete substrate. None of these problems are judged to be significant during the evaluation.
3. Significant problems developed during the application or during the evaluation phase; the material did not bond adequately to the concrete, indicating that the coating could not reliably protect the concrete.
4. A failure in the coating system as a result of serious application problems; a reaction of the acid with the coating; or failure of the coating to protect the concrete during the evaluation period.

N/E: Not evaluated due to early failure in other categories.
N/A: This category is not applicable to the particular product being tested.
Failed: A total score of "Failed" is assigned to those products that either received a total score of 6 or greater, and/or received a score of 3 or 4 in any of the categories.

For discussion purposes, the coatings are grouped into the following categories: Coal Tar, Coal Tar Epoxy Mortar, Concrete Sealer, Epoxy, Epoxy Mortar, Liner, Phenolic, Polyester, Polyester Mortar, Polyurea, Silicone, Specialty Concrete, Urethane, Vinyl Ester, and Vinyl Ester Mortar.

Coal Tar

One coal tar (C-20), one coal tar epoxy with a polyamide curing agent (C-30), and one coal tar urethane (C-55) coating system were evaluated. There are probably more coal tar epoxy coatings on concrete in wastewater collection and treatment systems than any other type of coating. The Districts' experience has been that the coatings fail in a period of just a few years when they are subjected to sulfuric acid attack. The failure of all three coating systems during the testing supports this observation.

Coal Tar Epoxy Mortar

The only system evaluated (C-37) has shown excellent results in acid testing. This system uses the application of a mixture of the coating and a sand filler to build thickness, and has a multi-component polyamine curing system. A top coat (0.5mm, 29mils) of the neat coating completes the system. This system was exposed to acid for 589 days. It showed no signs of deterioration due to acid exposure.

Concrete Sealer

Two concrete sealers (C-18 and C-43) were tested. These were advertised as providing chemical resistance. Neither concrete sealer provided any acid resistance.

Epoxy

Eleven tests of ten different epoxy coating systems have been completed (C-7, C-14, C-16, C-19, C-21, C-23, C-28, C-66, C-88, C-89, and C-97). Only five systems (C-28, C-66, C-88, C-89, and C-97) survived the test. These five systems are all 100% solids systems. One system failed when brush applied (C-16), but was successful when spray applied (C-28). A minimum of 1-mm (40 mils) dry film thickness of the coating is required to provide adequate protection. To provide this thickness, most of the stand alone-epoxy systems will require application of four or more coats. C-66 was brush and roller applied to a minimum thickness of 60 mils in two coats. It took 8 hours to apply this coating to the test tank. A minimum of one hour of cure time is necessary for each coat. C-88 was sprayed on in four coats to a minimum thickness of 200 mils. C-88 had numerous blowholes. A core sample cut through a blowhole showed that a thin layer of coating less than 10 mils thick protected the concrete at the bottom of the hole. C-89 was troweled on in three coats with one spray coat to a minimum thickness of 600 mils. C-97 was hand-applied in two coats to a minimum thickness of 250 mils.

Figure 7 illustrates the coating failure that occurred after only a short time period to one epoxy coating (C-7). Preliminary tests with ingots of one system (C-23) looked promising, but the manufacturer decided to use a non-epoxy coating system in the evaluation. Lack of sufficient acid resistance and inability to protect the concrete from corrosion plagued the other systems (C-14, C-19, and C-21).

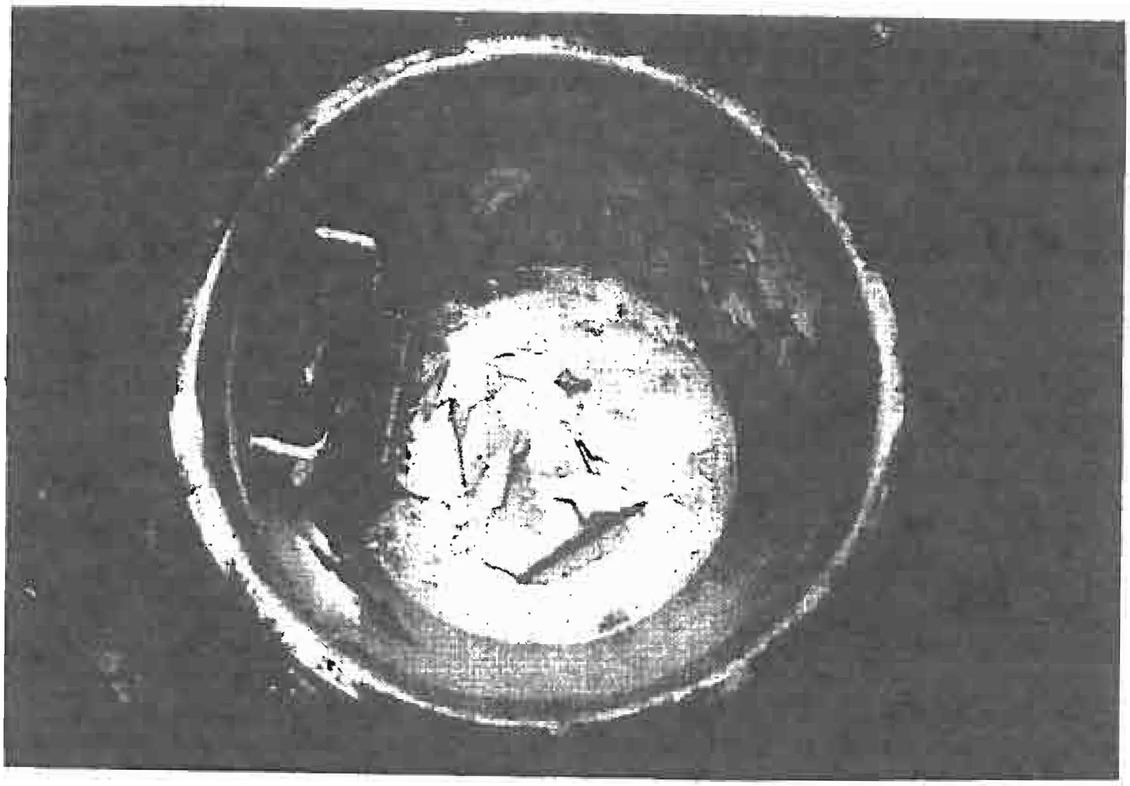

Figure 7. Epoxy coating failure.

Epoxy Mortar

For the epoxy mortars only 9 of the 16 systems (C-25, C-45, C-49, C-50, C-53, C-67, C-69, C-74, and C-95) survived the test. Most of these successful systems involve the application of a thick, inert material filled version of the coating as an intermediate step prior to application of finish coat with the neat epoxy. Minimum thickness of the intermediate coat is 2.2-3.2 mm (90-125 mils). However, C-95 was installed with two thick coats of the epoxy mortar without the filler due to weather concerns. Other epoxy mortar systems (C-15, C-22, C-41, C-42, C-51, C-56, and C-61) failed mostly due to pinholes and application problems. C-67 was applied by a manufacturer's representative after the same system (C-61) failed after being applied by an inexperienced applicator. C-74 is a later version of C-25. Both C-25 and C-74 made extensive use of a gel or filler version of its coating for surface repair and for plugging bug/pinholes in between applications. C-25 was brush applied while C-74 was spray applied. C-25 had almost no problems while C-74 had poor adhesion to the bottom of the tank with no acid penetration.

Liner

Twenty liner systems (C-29, C-35, C-40, C-62, C-63, C-64, C-70, C-72, C-73, C-78, C-79, C-80, C-81, C-82, C-83, C-85, C-86, C-87, C-91, and C-98) have been tested. Two systems (C-29 and C-62), applicable to new construction only, involve the use of PVC liner sections formed with the concrete section. As expected, the PVC liner demonstrated no reaction with the acid. The gasket jointing system used to interlock the lining sections on C-29 was penetrated by the acid. Acid seeped behind the liner and corroded the concrete. The jointing system for C-62, which performed without any problems, was chemically welded at the manufacturing site.

Three PVC lining systems use rigid PVC strips with preformed anchoring extensions (C-63, C-72, and C-78). The lining is anchored by grouting behind the liner with a cementitious grout mixture. The joints are "tongue and groove". The "original" system (C-63) used an epoxy sealant to seal the joint. This system performed without problems. C-72 is a later version of C-63 that uses a joint gasket. It also performed without any problems. A third PVC lining system (C-78), which also used a joint gasket to seal the joints, allowed acid to penetrate behind the liner. This test terminated after 127 days.

C-80 is a PVC liner using preformed arrow shaped ribs. The liner sheets are bonded to the existing concrete structure with a two-part epoxy mastic. This liner performed very well, showing excellent acid resistance and concrete bond.

C-81, C-82, and C-87 are HDPE liners with anchoring studs to mechanically bond to a base cement grout. The HDPE liners were welded into "tanks" before being inserted into the test tank. C-81 performed without problem. The liner remained bonded to the grout, though the grout did not bond to the tank surface. C-82 and C-87 are the same liner, with factory welds at the walls and field welds at the bottom. C-82 failed due to a poor bottom weld, but C-87 passed after using an experienced welder.

C-35 and C-40 are combinations of both a coating (mastic) and a liner. An acid resistant, 100% solids, polyurethane mastic provided bonding of first a polyethylene liner(C-35) and later a PVC liner (C-40) to the concrete substrate. After 598 days of testing it was decided that performance of the polyethylene liner was unacceptable, due to the gradual loss of bond between the mastic and the liner. The PVC liner (C-40) was unaffected after 646 days of acid exposure.

A modification of C-40 created by replacing the mastic with a urethane foam undercoat (C-64 and C-70) was also evaluated. The advantage of foam mastic is to circumvent the need for surface repair on badly corroded surfaces. Acid penetrated through the seams in C-64 and caused deterioration of the concrete under the liner. C-70 is a later version of C-64, and no problems were observed after one year of acid service.

C-83 is a glass fiber reinforced plastic. This liner was manufactured in the factory into a tank shape. The grout used to bond the liner to the test tank contained a corrosion-inhibiting admixture. This liner had no performance problems, but there were no field joints.

C-79 is a polyethylene coated corrugated galvanized steel pipe. The pipe was acid resistant. However, because no method for bonding it to existing concrete structures has been demonstrated, a suitable use for it has not yet been determined.

Three cured-in-place fiberglass and PVC lining systems were evaluated in five different tests (C-73, C-85, C-86, C-91, and C-98). These systems are used for rehabilitation of corroded manholes and consist of a nonpermeable PVC liner and one or two layers of woven fiberglass fabric in the form of a bag. C-85, C-86, and C-91 have polyester fleece embedded in the PVC. The fiberglass and fleece were saturated onsite with an epoxy resin with modified polyamide curing agents. The liner was then inflated in the manhole and steam cured under pressure, using an inflation bladder. C-73, C-85, C-98, and the bottom of C-86 had a sandwich construction with fiberglass on both sides of the PVC liner. C-91 and the walls of C-86 were configured with a thicker PVC layer exposed to the acid, and fiberglass between the PVC and the concrete substrate. The acid attacked all exposed resin on C-73, C-85 and C-86, but did not penetrate the PVC barrier. On C-85 and C-86, the wall and bottom liners were overlapped with resin between the PVC liners; both installations failed as acid attacked the concrete substrate behind the seam. On C-91 and C-98, the epoxy did not deteriorate and these systems passed. On C-73 and C-91, the wall and bottom liners were sewn together, and these installations passed.

Phenolic

No full scale evaluation was conducted with a phenolic coating system; however, a preliminary test with ingots of one system (C-24) showed poor acid resistance. It is no longer being marketed.

Polyester

A stand-alone polyester resin system (C-57) was evaluated for 56 days. This system was the same coating as C-17, but without the sand aggregate (see polyester mortar). The application of various thicknesses of this resin to the test tank, up to 1 mm (40 mils), without the sand aggregate, allowed penetration of acid through thin spots and pinholes.

Polyester Mortar

One polyester mortar (C-17) was evaluated in a test tank for 1,429 days. The coating was not affected by the sulfuric acid exposure after almost four years of acid service and demonstrated excellent bonding characteristics to concrete. It is believed that the success of this coating hinges upon the application of a 3.2-mm (125 mils) thick intermediate mortar mixture of the polyester resin and a sand aggregate. After the one-year test period a small disbonded area in the tank base was opened. No acid penetration had occurred, but the system had disbonded in a 10-cm diameter area that had moisture underneath it. The area was patched and the test continued to evaluate the repair ability of the system. The results were impressive.

A second polyester resin system (C-44), also a sand extended mortar, was successfully evaluated for 378 days. During application of this coating to the test tank an excessive quantity of solvent was spilled on the coating in the base of the test tank. Upon acid exposure, many areas in the base of the test tank blistered. These damaged areas were subsequently repaired. Test tank areas not exposed to the solvent spill, as well as the repaired areas, performed well.

Polyurea

Three polyurea systems were evaluated in four different tests (C-68, C-75, C-94, and C-96). The systems are two component, 100% solids, spray on systems with a rapid cure time. The first system (C-68) was applied at a thickness of 60 mils and was evaluated for 385 days, without being affected by the sulfuric acid. The second system (C-75) was applied at a thickness of 100 mils and was evaluated for 404 days, without being affected by the sulfuric acid. The third system was tested with and without surface repair (C-94 and C-96), but failed due to poor bonding to the repair material, delamination, and breakage.

Silicone

One silicone rubber coating (C-31), advertised as both abrasion and acid resistant, proved to be a rapid failure.

Specialty Concrete/Mortar

The twelve systems that have been evaluated in thirteen different tests in this category include fast cure systems applicable to damp concrete (C-2, C-6, C-11, C-12, and C-13), more conventional acid resistant concrete systems typically used in the installation of acid brick (C-27 and C-34), a furfuryl alcohol resin based concrete system (C-46, C-58, and C-59), a sulfur polymer concrete used to manufacture pipe (C-65), and two polymer concretes (C-76 and C-77) used to manufacture pipe. All of the fast cure systems showed reaction with acid. One system (C-12) was more acid resistant, but was difficult to apply.

The acid resistant concretes (C-27 and C-34) require anchoring, an underlay membrane or coating, and can be applied by forming or gunning. They were either affected by the sulfuric acid solution (C-27) or allowed the acid to penetrate through the cross-section to the underlying coating (C-34). In the latter case, the polyurethane underlayment protected the concrete substrate. There were areas in the upper reaches of the test tank where the underlayment was exposed directly to the acid solution, because of a failure of the forms during the placement of the acid resistant concrete. In these areas the underlying coating did not prevent deterioration of the concrete substrate.

Problems were encountered with the application of the furfuryl alcohol resin based concrete system (C-46) which allowed acid attack to the concrete and failure of this system. Subsequent testing of this product in both spray (C-58) and formed (C-59) applications proved to be acid resistant; however, the bond to the uncorroded concrete surfaces in both applications was weak. An anchoring system would be recommended.

A modified sulfur cement (C-65) remained in acid service for approximately six years. The acid has had no effect on the concrete. The modified sulfur cement (C-65) was also tested in 5% sodium hydroxide for approximately six years. The sodium hydroxide has had no effect on the concrete either.

One polymer concrete (C-76) remained in acid service for 445 days. The polymer concrete consists of up to 90% quartzitic, oven dried fillers, including mineral sands and grit, with polyester resin as a bonding agent. The acid had no effect on the polymer concrete. The polymer concrete (C-76) was also tested in 5% sodium hydroxide for 445 days. The sodium hydroxide has had no effect on the polymer concrete. Coupons of a second polymer concrete (C-77) were tested in both acid and 5% sodium hydroxide for 503 days. This polymer concrete consists of up to 90% dry mineral aggregate, inert reinforcement and approximately 10% vinyl ester resins with catalysts. The coupons showed no chemical attack.

Urethane

A total of 19 evaluations were performed with 18 different urethane coatings (C-1, C-3, C-4, C-5, C-8, C-9, C-10, C-26, C-32, C-33, C-36, C-39, C-47, C-48, C-52, C-60, C-71, C-92, and C-93). All but three coatings (C-10, C-71, and C-92) failed the test. Common problems, shared by most of the urethane systems evaluated, involve poor bonding characteristics to concrete, as illustrated in Figure 8, and an extreme tendency to form pinholes or blow holes following application. A primer to provide a bond to concrete, or an anchoring system is a necessity for urethane coating systems. Almost all of the two component urethane coatings (C-1, C-3, C-4, C-5, C-8, C-9, C-10, C-26, C-32, C-33, C-36, C-39, C-47, C-48, C-52, C-60, C-71, and C-92) were resistant to sulfuric acid, but only two coating systems (C-10 and C-71) provided a tenacious bond to the concrete substrate, and a relatively pinhole free surface.

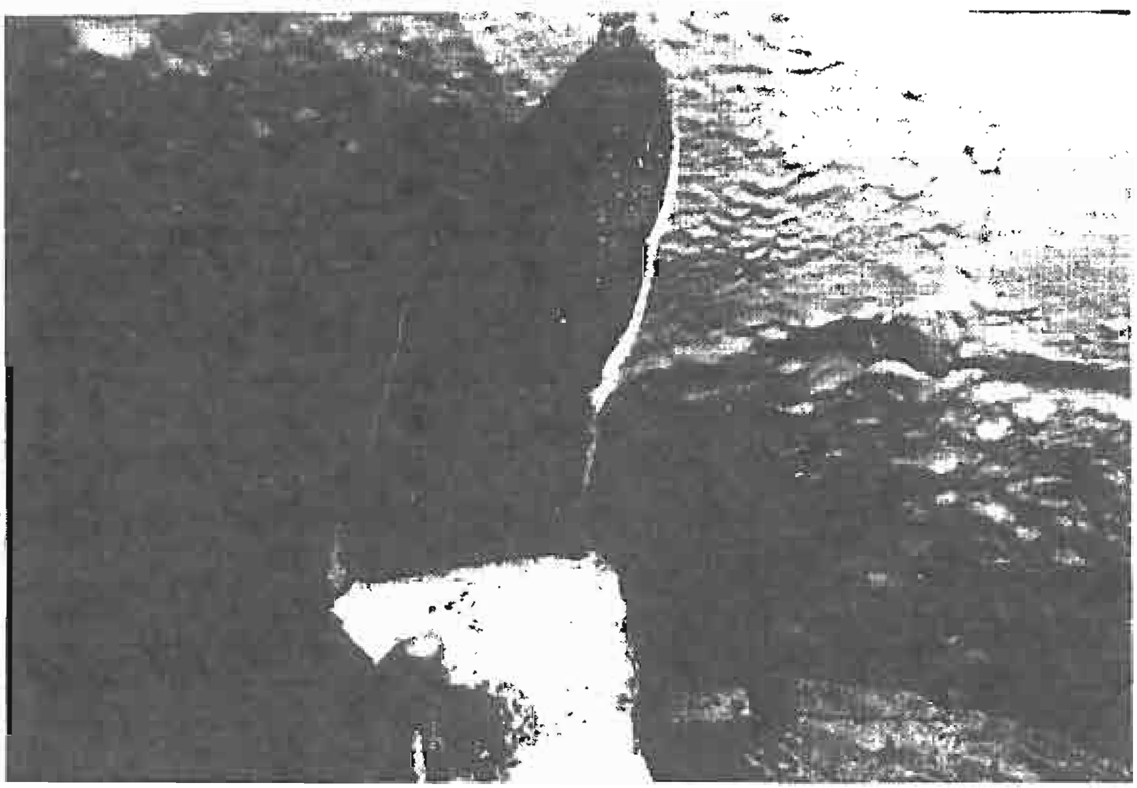

Figure 8. Section of urethane coating pulled from a test tank wall.

Vinyl Ester

A neat vinyl ester coating (C-54) developed pinholes and allowed acid to penetrate to the concrete.

Vinyl Ester Mortar

One vinyl ester mortar system (C-38) was exposed to acid for 548 days with no adverse effects. The long cure time required for application of this coating system would eliminate this coating for consideration in most rehabilitation projects, unless "down" times of more than one week are possible.

CONCLUSIONS

Most coating manufacturers will point, and in many cases with justification, to application problems as being the cause of coating failure. It is certainly true that surface preparation and conditions under which the coating is applied are extremely critical. It is difficult to determine the reasons why so many coating systems, advertised to provide protection in wastewater industry, have failed in the test facility, but it really is of little consequence. The purpose of the evaluation facility was to provide a non-laboratory environment to evaluate the coatings. To survive the test, a coating system not only had to be acid proof and able to bond to the concrete substrate, but it also had to be applicator friendly. Ideal conditions for applying a protective coating probably never exist in wastewater collection and treatment facilities. Therefore, a successful coating system has to be one that can be applied under less than ideal conditions.

The predominant reason for failure of so many coating systems was the formation of pinholes or blowholes. In general, the mortar or filler extended coating systems had dramatic improvements in their survival rates versus their parent neat systems. The predominant reason for failure of the lining systems were poor bonding of the liner at the seams. The predominant reason for failure of the specialty concretes was insufficient acid resistance.

The purpose of this evaluation program was to develop a list of suitable coatings and specifications for application of the coatings. The program has fulfilled that purpose to some extent. Table 4 is a list of 39 coating systems that have successfully completed this test. Only successful coating systems that were assigned a score equal to or less than 5 are listed in Table 4. The successful coating systems include: one coal tar mortar (C-37); five epoxies (C-28, C-66, C-88, C-89, and C-97); nine epoxy mortars (C-25, C-45, C-49, C-50, C-53, C-67, C-69, C-74, and C-95); thirteen liners (C-40, C-62, C-63, C-70, C-72, C-73, C-79, C-80, C-81, C-83, C-87, C-91, and C-98); two polyester mortars (C-17 and C-44); two polyureas (C-68 and C-75); three specialty concretes (C-65, C-76 and C-77); three urethanes (C-10, C-71, and C-92); and one vinyl ester mortar (C-38).

The information developed should be of some assistance, but as previously indicated, does not address gas permeability and subsurface microbial acid generation[3]. When attempting to select a coating, don't be satisfied to deal with the manufacturer's sales representative alone. Contact the manufacturer directly and be sure to explain fully the conditions under which the coating will be applied and the environment it has to withstand. Don't hesitate to ask for a list of applications and consult with the owners, as well as the applicators. If application projects are inspected, try to categorize the applications by the exposure level to hydrogen sulfide. Never assume that a coating system that has performed well has been exposed to corrosive conditions unless you can substantiate it. It is recommended that only coatings with total scores of 5 or less be considered for corrosive environments (see Table 3 and 4).

It is suggested that coating manufacturers, recognized testing agencies, or technical organizations consider the development and use of an accelerated evaluation technique to screen coatings for application in the wastewater field. With such a technique, the advances in coating technology can be evaluated by the end user. A testing chamber and procedure was developed by Tnemec Company, Inc. that includes evaluation of permeability properties[3].

TABLE 4
Successful Protective Coating Systems

CODE NUMBER	COATING DESIGNATION	TOTAL SCORE	MANUFACTURER
Generic Type – Coal Tar Mortar			
C-37	Mainstay DS-4	3	Madewell Products Corporation 7561 Industrial Court Alpharetta, GA 30004 (770) 475-8199
Generic Type – Epoxy Coating			
C-28	Concresive 1305	4	Degussa Building Systems 889 Valley Park Drive Shakopee, MN 55379 (952) 496-6000
C-66	Hydro-Pox 204 (formerly Hydro-Pox 193)	4	Con-Tech of California 2211 Navy Drive Stockton CA 95206 (209) 941-8324
C-88	Warren Epoxy - spray	5	Warren Environmental, Inc. P.O. Box 1206 Carver, MA 02330 (508) 947-8539
C-89	Warren Epoxy - laminate	4	Warren Environmental, Inc. P.O. Box 1206 Carver, MA 02330 (508) 947-8539
C-97	NeoPoxy NPR-5305	3	NeoPoxy Corporation 27057 Industrial Boulevard., Suite 208 Hayward, CA 94545 (510) 782-1290
Generic Type – Epoxy Mortar Coating			
C-25	AquataPoxy	4	Raven Lining Systems 1024 N. Lansing Avenue Tulsa, OK 74106 (800) 324-2810
C-45	Chesterton 798 Polymer Quartz Compound, reformulated as ARC 791	4	A.W. Chesterton Company 225 Fallon Road Stoneham, MA 02180 (781) 438-7000
C-49	Semstone 140S	3	Carboline Company 350 Hanley Industrial Court St. Louis, MO 63144 (800) 848-4645
C-50	Magma Quartz or Belzona 4111	4	Belzona, Inc. 2000 NW 88th Court Miami, FL 33172 (305) 594-4994
C-53	I.P.I. Crystal Quartz	3	Integrated Polymer Industries, Inc 3029 S. Harbor Boulevard Santa Ana, CA 92704-6448 (714) 434-0800

TABLE 4
Successful Protective Coating Systems

CODE NUMBER	COATING DESIGNATION	TOTAL SCORE	MANUFACTURER
C-67	Sauereisen-210	4	Sauereisen 160 Gamma Drive Pittsburgh, PA 15238 (412) 963-0303
C-69	Raven 405	4	Raven Lining Systems 1024 N. Lansing Avenue Tulsa, OK 74106 (800) 324-2810
C-74	A-6 AquataPoxy	5	Raven Lining Systems 1024 N. Lansing Avenue Tulsa, OK 74106 (800) 324-2810
C-95	Tnemec Series 434 Chembloc	4	Tnemec Company inc. 6800 Corporate Drive Kansas City, MO 64120-1372 (800) TNEMEC1
Generic Type – Liner Systems			
C-40	Linabond Mastic System (PVC)	4	Linabond, Inc 12960 Bradley Avenue Sylmar, CA 91342 (818) 362-7373
C-62	Con-plast Plastic Liner System	1[2]	Southwest Concrete Products 519 S. Benson Avenue Ontario, CA 91762-4002 (909) 983-9789
C-63	Danby PVC Liner	3[1]	Danby of North America, Inc. P.O. Box 5127 Cary, NC 27512-5127 (919) 467-7799
C-70	Linabond Structural Polymer System (PVC and polymer)	4	Linabond, Inc 12960 Bradley Avenue Sylmar, CA 91342 (818) 362-7373
C-72	Danby PVC Liner	2[1]	Danby of North America, Inc. P.O. Box 5127 Cary, NC 27512-5127 (919) 467-7799
C-73	Poly-Triplex Liner (PVC and fiberglass)	5	Poly-Triplex Technologies, Inc. 1701 Wynkoop, Suite 250 Denver, CO 80202 (303) 893-3100
C-79	SRP (Polyethylene-coated CMP)	1[2]	Pacific Corrugated Pipe Co. P.O. Box 2450 Newport Beach, CA 92658-8972 (949) 650-4555

TABLE 4
Successful Protective Coating Systems

CODE NUMBER	COATING DESIGNATION	TOTAL SCORE	MANUFACTURER
C-80	Arrow-Lock (PVC and epoxy mastic)	3	Ameron Protective Lining Products 201 N. Berry Street Brea, CA 92621 (714) 256-7755
C-81	Agru Sure Grip (HDPE)	2[1]	Agru (www.agru.at)
C-83	Channeline GRP liner	3	Channeline Sewer Systems (N.A.) Inc. 125 Half Mile Road, Suite 200 Red Bank, NJ 07701 (800) 231-7198
C-87	Studliner (HDPE)	4	GSE Lining Technology Inc. 19103 Gundle Road Houston, TX 77073 (800) 435-2008
C-91	Multiplexx PVCP (PVC and fiberglass)	5	Terre Hill Composites 485 Weaverland Valley Road Terre Hill, PA 17581 (717) 445-3100
C-98	Poly-Triplex Liner PTLS-5600 (PVC and fiberglass)	4	Poly-Triplex Technologies, Inc. 1701 Wynkoop, Suite 250 Denver, CO 80202 (303) 893-3100
Generic Type – Polyester Mortar			
C-17	PPC Coating (formerly Quantum)	3	Polymorphic Polymers Corporation 1775 Broadway, Suite 527 New York, NY 10019-1903 (212) 262-9220
C-44	I.E.T. System 3	4	Integrated Environmental Technologies P.O. Box 40759 Santa Barbara, CA 93140 (805) 969-2292
Generic Type – Polyurea			
C-68	Structural Seal Polyurea (formerly Sprayseal)	4	Structural Seal Polyurea Manholes 2652-D N. Southport Avenue Chicago, IL 60614 (773) 528-4723
C-75	ThoRoc IC-2480 and Sonneborn TF30 (formerly Polyquick P300)	3	Degussa Building Systems 889 Valley Park Drive Shakopee, MN 55379 (952) 496-6078
Generic Type – Specialty Concretes			
C-65	Chempruf (Sulfur Concrete)	1[2]	F. E. Ward Constructors 2710 NE 78th Street Vancouver, WA 98665 (360) 573-8929
C-76	Meyer Pipe (Polymer Concrete)	1[2]	Meyer Rohr + Schacht GmbH (http://www.meyer-polycrete.com/en

TABLE 4
Successful Protective Coating Systems

CODE NUMBER	COATING DESIGNATION	TOTAL SCORE	MANUFACTURER
C-77	iNTERpipe (Polymer Concrete)	1[2]	Polymer Pipe Technology, LLC 500 E. Locust, 5th Floor Des Moines, IA 50309 (515) 267-8884
Generic Type – Urethane			
C-10	PR 475 [3]	5	Products Research and Chemical Corp. 5430 San Fernando Road Glendale, CA 91203 (818) 240-2060
C-71	Endura-flex EF1988	4	Global Eco Technologies P.O. Box 767 Pittsburgh, CA 94565 (925) 473-9250
C-92	SprayWall	5	Sprayroq, Inc. 4707 Alton Court Birmingham, AL 35210 (205) 957-0020
Generic Type – Vinyl Ester Mortar			
C-38	120 Vinester	3	Tnemec Company Inc. 6800 Corporate Drive Kansas City, MO 64120-1372 www.tnemec.com

Notes:

1. Total score includes evaluation in only two categories. The remaining one category was not applicable to the product being tested.
2. Total score includes evaluation in only one category. The remaining two categories were not applicable to the product being tested.
3. Reported to be discontinued.

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