

Many areas of California have reinforced concrete sanitary sewer systems that are lined for protection from accelerated corrosion due to elevated concentrations of hydrogen sulfide. This is unique, due in large part to the environment and topography of the heavily urbanized areas of the Golden State. Hydrogen sulfide generation in sewers is often triggered by a combination of insufficient grade to keep solids suspended in the sewage and elevated temperatures that are conducive to increase sulfide levels. Factors that lead to the production of hydrogen sulfide, that under the right conditions converts to sulfuric acid in sewers, are dissolved sulfide, pH, biochemical oxygen

demand (BOD), velocity, junctions, force mains and siphons, and ventilation. Hydrogen sulfide produced from sewage within the pipe is converted to sulfuric acid by bacterial action. In many Californian urban areas, this acidic condensate chemically reacts with the cementitious binder in concrete pipes, causing chemical and physical deterioration (corrosion) of the pipe – if it is not protected.

California public works engineers have recognized the threat to its sanitary sewers for almost a century, and were quick to implement a technology that combines liners with reinforced concrete pipe (RCP) thereby extending the service life of their buried infrastructure. In the early 1900s concrete pipe was lined with clay tile. In the 50s, with the advent of commercially available thermoplastic products, liners were developed to replace the clay tile. Today, California's specifications for sanitary sewer

pipe invariably call for thermoplastic-lined RCP for maximum performance. Ameron Protective Linings, a long-time member of the American Concrete Pipe Association, is a major supplier of liner products to the California market.

In 2001, the City of Los Angeles had an opportunity to test the performance of RCP with liners and removed a section of 1830-mm (72-inch) diameter reinforced concrete pipe from the La Cienega/San Fernando Valley Relief Sewer after 48 years of continuous service. Researchers tested the pipe sections to determine its current condition. The pipe was protected by Ameron's T-

Lock® brand thermoplastic liner. Testing included compressive strength of the concrete, tensile strength and pull out resistance of the reinforcing steel, and petrographic analysis of the concrete of the pipe at invert and springline. The T-Lock liner was tested for hardness, tensile strength, elongation at failure, and pull off resistance. Both the pipe and the T-Lock liner were found to be in excellent condition after 48 years.

Testing was also conducted on sections of pipe removed from the North Outfall Sewer (NOS). This sewer was protected by a clay tile liner. Compressive strength testing and petrographic analysis were performed on this sewer. Significant corrosion was observed due to sulfate attack. The NOS was constructed in 1924 as a predominantly semi-elliptical reinforced concrete sewer. In 2002, the Maze 3 project rehabilitated a 1,738-meter (5,700-foot) portion

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## No End to Useful Life Could Be Predicted for Section of Los Angeles Concrete Relief Sewer

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of the NOS that had been constructed of precast circular segments. Half pipe sections were removed at pushing and cleaning pits to allow access to the sewer. The 1,900-mm (75-inch) diameter pipe had been continuously in service for 78 years.

One of the first City of Los Angeles projects that used T-Lock liners to protect the concrete pipe was the La Cienega/San Fernando Valley Relief Sewer (LCSFVRS), constructed in 1953. As part of the Rosewood/Willoughby Interceptor Sewer project, the City of Los Angeles removed a 3.7-meter (12-foot) long section of the LCSFVRS for testing.

Tests on the LCSFVRS pipe were performed by the City of Los Angeles Standards Division Laboratory, Ameron Engineering Development Center Laboratory, the Ameron Protective Linings Division Laboratory, Concrete Experts International in Copenhagen Denmark,

City of Los Angeles Industrial Waste Management Division, and the Montgomery Watson Laboratories. The testing included concrete compressive strength tests, pipe external load crushing strength (D-Load) tests, reinforcing steel strength property tests, rebar pull out tests, and T-Lock liner properties (hardness, elongation at failure, pull out resistance) tests. A joint of the pipe was disassembled and the gasket was recovered and tested to measure its properties. A petrographic analysis was performed on core samples taken from the invert and

springline to determine if the quality of the concrete had changed radically along the core.

### LCSFVRS RCP Section Observations

- The reinforcing steel appeared to be elliptical, containing two layers of 11-mm (7/16-inch) diameter wire with longitudinal steel at 45 degrees around the RCP.
- The wall of the pipe was 178-mm (7-inch) thick.
- The pipe had steel joint rings with an O-ring gasket.
- The length of each pipe section was 2.4 metres (8 feet).
- There was minimal abrasion observed at the invert of the sewer.
- Approximately 5 mm (1/4 inch) of the concrete had been scoured and the aggregate of the pipe was exposed.
- The interior concrete appeared to be sound and no raveling was present.
- Approximately 328 degrees of the pipe was lined with black colored T-Lock lining. The liner had been welded from sheets of T-Lock, approximately 1220-mm by 2440-mm (4-foot x 8-foot) in dimension, with joints at the springline and at the soft-fit of the pipe.
- The T-Lock liner appeared sound and by visual inspection the tees were securely embedded in the concrete.
- The T-Lock liner had blistered at the tees. All of the blisters appeared to be intact.
- All of the tees visible at the cut surfaces were cleanly embedded and none of the tees had pulled out of the concrete.
- A thin layer of slime covered the inside of the pipe at removal.
- No debris was found inside the removed pipe.
- The exterior of the pipe appeared to be in good condition.
- A joint was recovered intact and was found to have been wrapped with a bituminous material.
- The joint that had been cut contained a reddish material, apparently part of the joint seal.

**Testing**

*Pipe D-Load Test Results*

D-Load is a three-point bearing load that is sufficient to cause a 305 mm (12 inch) long crack, 0.25 mm (0.01 inch) wide in a concrete

1830 D. The following table compares the results of D-Load testing to the D-Load required for the project, as well as that of a Class V reinforced concrete pipe.

A section of the removed pipe, 1.39 meter (4.56 foot) was selected for D-Load testing. This length of test section was chosen to avoid holes that the contractor had drilled into the pipe for placing concrete anchors prior to removal. This was the longest section without external penetration of the pipe wall. A crack was observed in the soffit of the pipe prior to testing. It is not known whether the pipe had this crack at the time that it was removed from the ground, or if handling

**TABLE 1     D-Load Testing results of removed 4.56 feet of LCSFVRS**

DESCRIPTION	GAUGE READINGS (kPa)	TOTAL LOAD (kg)	D-LOAD	COMMENTS
Project 0.01-inch D-load	5425 kg (787psi)	23,657 kg 52,155 lbs.	1830 D	Required by Plans
Load required for ASTM C76 Class V 0.01-in. crack	8895 kPa (1290 psi)	37,230 kg (82,080 lb)	3000 D	
0.01"<12" 0.000254m<0.3048m	10620 kPa (1540 psi)	45,140 kg (99,510 lb)	3630 D	21% greater than 3000 D-Load
Ultimate Load	12760 kPa (1850 psi)	54070 kg (119,200 lb)	4350 D	45% greater than 3000 D-Load, 16% greater than 3750 D-Load to produce ultimate load

sewer pipe. The design engineer typically specifies a required D-Load and the pipe producer will then produce a pipe with that strength. The plans for the LCSFVRS at Martel and Rosewood Avenues call for a D-Load of

caused the crack. The D-Load test was conducted using two 150-ton capacity rams. The partial pipe section was 1.82 meter (72 inch) in diameter and had a pipe wall thickness of 178 mm (7 inches). The partial, plain end, pipe section lined with 328 degrees of T-Lock material was loaded at the Ameron Engineering Development Test Facility in the presence of City of Los Angeles Bureau of Engineering and Bureau Contract Administration personnel. The D-Load required to produce a crack of 0.25 mm (0.01 inch) in width and 305 mm (12 inch) in length, was measured at 3630D. The 3630 D recorded is 21% greater than the 3000 D requirement for the highest rated pipe listed in ASTM C 76 (Class V). This is 198% of the 1830 D-Load speci-

**Table 2     Physical Properties - Compressive Strength, Absorption, Bulk Specific Gravity, and Void Content of Removed Concrete Section LCSFVRS**

DESCRIPTION		CORE NUMBER		
		2	4	6
LOCATION		Springline	Bottom	Top
COMPRESSIVE STRENGTH SPECIMEN	Presence of Steel	ND*	ND*	YES
	Core Length, meters	103 mm (4-1/16 in)	121 mm (4-3/4 in)	154 mm (6-1/16 in)
	Core Diameter, meters	82 mm (3.22 in)	82 mm (3.22 in)	82 mm (3.22 in)
	Compressive Strength (kPa)	71020 kPa (10,300 psi)	75150 kPa (10,900 psi)	67570 kPa (9,800 psi)
ABSORPTION, SPECIFIC GRAVITY AND VOID CONTENT SPECIMEN	Absorption, %	4.65	4.51	ND
	Bulk Specific Gravity	2.45	2.49	ND
	Void Content, %	10.9	10.	ND

\* A portion of the core containing the steel rebar was removed for absorption determination. ND indicates that the property was not determined since the entire length of the core including steel was used to determine the compressive strength.

**Table 3   Concrete Strength - Compressive Concrete Strength Test Results - LCSFVRS**

AGENCY	CORE#	LOCATION	STRENGTH	LENGTH
Ameron	2	Springline	71,020 kPa (10,300 psi)	103 mm (4-1/16 in)
Ameron	4	Bottom	75,150 kPa (10,900 psi)	121 mm (4-3/4 in)
Ameron	6	Top	67,570 kPa (9,800 psi)	154 mm (6-1/16 in)
City	3	Bottom	41,360 kPa (6,000 psi)	150 mm (5.91 in)
City	5	Top	65,220 kPa (9,460 psi)	164 mm (6.44 in)
City	7	Top	68,880 kPa (9,990 psi)	152 mm (5.97 in)

fied in the construction plans (Table 1).

The compressive strength test is used for design of pipe and control of the manufacturing process. The compressive strength test typically ranges in value from 4000 psi and greater in concrete pipe. A value of approximately 10,000 psi indicates the concrete strength has remained high and concrete is in good condition.

Absorption of concrete is a measure of the pore space in the material. It is determined by drying a specimen to constant weight, immersing in water and noting the increase in weight. For comparable types of concrete with similar aggregates the quality tends to decrease as the absorption increases. ASTM C 76 for concrete pipe requires values less than 9%, therefore, values of approximately 4.5% shows dense concrete in excellent condition.

The values of specific gravity and percent voids also show the concrete is still in excellent condition, demonstrating the long-term durability of precast concrete pipe.

### Test Results

#### *T-Lock Protected RCP (LCSFVRS)*

The RCP of the La Cienega/San Fernando Valley Relief Sewer is in remarkable condition. After 48 years, the D-Load of the pipe is approximately 3800, compared to a specified D-Load of 1830. Compressive strength averages approximately 10,000 psi. No corrosion was

found in the area of the concrete protected by the T-Lock liner, and only mild erosion was experienced at the invert of the pipe. The erosion was facilitated by a magnesium-salt attack that softened the concrete, making it more susceptible to erosion. The reinforcing steel is in excellent condition with no corrosion evident, and good pullout resistance. The T-Lock liner exhibited “blistering” between the tees, but no pull out of any tee was evident, and no blister crossed any tee. Heat seamed welds remained intact in the sample pipe.

By test, the tees retain a pullout (tear off) resistance in excess of 100

lb/in. T-Lock liner hardness meets current specification. Elongation at break falls below current specifications for new T-Lock liners of 200% (three samples tested broke at 125%, 150%, 150% elongation respectively). The T-Lock exhibited an ability to withstand significant deformation without tearing when the sample pipe was loaded to failure.

The researchers also concluded that the joints are intact and that the gasket material remains viable after 48 years, meeting or exceeding the requirements of all tests except the compression set test for new gaskets.

### Summary

Even though the 78-year-old pipe had failed, the system did demonstrate the long-term durability of RCP. The sewer was constructed with the technology and mix designs available to the industry in 1924, and placed in an environment known to be aggressive toward concrete. The clay liner probably delayed the sulfate attack to some extent, but the structure itself did not fail prematurely, and withstood the corrosive environment until it was replaced in 2002. Today’s RCP can be produced with admixtures that resist sulfate attack without the use of liners. There is no doubt that properly manufactured RCP with T-Lock liners for sanitary sewers, characterized with high hydrogen sulfide environments, will perform for the design life of the sewer. ☺