City of Los Angeles Tests 48 Year Old T-Lock Protected Pipe and 72 Year Old Tile Lined Pipe

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ABSTRACT

The City of Los Angeles has removed a section of pipe from the La Cienega / San Ferndando Valley Relief Sewer after 48 years of service and performed testing on it to determine how its current condition. This pipe was protected by T-Lock and has been continually in service. Testing included compressive strength of the concrete, tensile strength and pull out resistance of the reinforcing steel, petrographic analysis of the concrete of the pipe at invert and springline. The T-Lock was tested for hardness, tensile strength, elongation at failure, and pull off resistance. Both the pipe and the T-Lock were found to be in excellent condition after 48 years of service.

Testing was also done on sections of pipe removed from the North Outfall Sewer after 78 years of service. This sewer was protected by clay tile liner. Compressive strength testing and petrographic analysis were performed on this sewer. Significant corrosion due to sulfate attack was found in this sewer.

KEYWORDS

Concrete Pipe, corrosion, corrosion protection, sulfate attack, sewer, testing

INTRODUCTION

La Cienega & San Fernando Valley Relief Sewer - One of the first City of Los Angeles projects that used T-Lock to protect the concrete pipe was the La Cienega & San Fernando Valley Relief Sewer (LCSFVRS), which was constructed in 1953. As part of the Rosewood/Willoughby Interceptor Sewer project, the City of Los Angeles recently removed a 3.7 meter (12 ft) long section of the LCSFVRS (Figure 1). This 1830 mm (72 inch) diameter reinforced concrete pipe had been in service continuously for the past 48 years [J].

North Outfall Sewer - In 1924 the City of Los Angeles constructed the North Outfall Sewer (NOS), a predominantly semi-elliptical, reinforced concrete sewer, that was protected with clay tile liners. In 2002 the Maze 3 project rehabilitated a 1,738 meter (5,700 foot) long section of this pipe that had been constructed of precast circular pipe segments. Half pipe sections were removed at pushing and cleaning pits to allow access to the sewer (Figure 2). The 1,900 mm (75 inch) diameter pipe had been continuously in service for the past 78 years.

This paper presents the results of tests that were performed on these sections of the LCSFVRS and the NOS.

METHODOLOGY

Testing of the pipe was conducted under the direction of the City of Los Angeles Bureau of Engineering, Wastewater Conveyance Engineering Division.

Tests on the NOS pipe were performed at the City of Los Angeles Standards Division Laboratory, and at Concrete Experts International in Copenhagen, Denmark. This testing included compressive strength and petrographic analysis.

Tests on the LCSFVRS pipe were performed at the City of Los Angeles Standards Division Laboratory, the Ameron Engineering Development Center Laboratory, the Ameron Protective Linings Division Laboratory, at 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 and properties tests, re-bar pullout tests and T-Lock 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 changed radially along the core. A liquid was found trapped in small "blisters" between the T-lock and the concrete of the pipe. This liquid was analyzed for content.

LOCATION OF SEWERS

NOS – The sections of this pipe described in this paper were installed as a part of the North Outfall Sewer under plan number PP-17938. The segments were removed from the Sewer at the intersection of Vernon Ave and 11th Ave, and at Vernon Ave and 4th Ave. Flow gaugings show that the sewer reaches a flow depth (d/D) of 0.65[A].

LCSFVRS - The section of pipe that is described in this paper was installed as a part of the City of Los Angeles La Cienega and San Fernando Valley Relief Sewer Unit "A", under plan number D-10016. The pipe was removed from the Southerly side of the intersection of Rosewood Avenue and Martel Avenue in Hollywood. City of Los Angeles records show that the pipe was installed in April 1953. The area tributary to this sewer includes the San Fernando Valley, and a portion of Hollywood. Flow gaugings show that the sewer currently reaches a flow depth (d/D) of 0.70[B].

PHYSICAL DESCRIPTION OF REMOVED PIPE

NOS - The segments of pipe removed from the sewer were half diameter sections. The concrete was corroded and tiles were missing from much of the inside surface of the sewer. In some places the rebar had been exposed and corroded. All of the concrete behind the tile segments had been damaged, visual inspection could not determine that the tiles had been cast into the concrete of the pipe, without the use of mortar, although this was the method of construction. Wall thickness varied from 178 mm (7 inches) to approximately 66 mm (2.6 inches). The exterior wall of the pipe was undamaged. Substantial debris was found on the bottom of the pipe, including clay tile liner that had fallen from the sewer, and other debris.

LCSFVRS - The secton of pipe removed was 3.6 meters (12 feet) of reinforced concrete pipe (RCP) having an inside diameter of 1820 mm (72 inches). 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 section of pipe was 2.4 meters (8 ft). 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 by 8 foot) in dimension, with joints at the spring line and at the soffit of the pipe. The T-Lock appeared sound and by visual inspection the tees were securely embedded in the Concrete. The T-Lock had blistered between the tees. All of the tees visible at the cut surface were cleanly embedded and none of the tees had pulled out of the concrete. All of the blisters appeared to be intact. 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 likewise 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.

The dimensions of the LCSFVRS pipe are summarized in Table (1).

TABLE 1 – LCSFVRS PIPE DIMENSIONS

Dimensions	**Complete pipe**	**Partial pipe**
Inside Diameter	1.82 m (72”)	1.82 m (72”)
Length	2.438 m (8 ft)	1.402 m (4.6 ft)
Wall Thickness	0.1778 m (7”)	0.1778 m (7”)
Steel Rod Diameter	0111 m (7/16”)	0111 m (7/16”)
Approx. Circumferential Rebar spacing	.0762m - 0.0857m (3" to 3-3/8")	0762m - 0.0857m (3" to 3-3/8")
Longitudinal Rebar	0.3048m- .6096m (12" to 28")	0.3048m- .6096m (12" to 28")
Approx. Longitudinal Rebar spacing	10 to 14	10 to 12
Minimum Rebar Cover	0.034925m (1-3/8")	0.034925m (1-3/8")
Maximum Rebar Cover	1.4859m (4-7/8')	1.4859m (4-7/8')

TEST RESULTS - LCSFVRS CONCRETE PIPE

Specified D-Load at Time of Construction[c]

D-Load is a three point bearing load that is sufficient to cause a 0.31 mm (12 inch) long crack, 0.25 mm (0.01 inch) wide in a concrete sewer pipe. The engineer typically specifies a required D-Load and the manufacturer will then produce a pipe with that strength. The plans for the LCSFVRS at Martel and Rosewood call for a D-Load of 1830 D.

Pipe D-Load test results after 48 years of service

A section of the removed pipe, 1.39 meter (4.56 foot) of RCP 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 segment without external penetrations 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 the crack was caused by handling. 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 was loaded at the Ameron Engineering Development Test Facility in the presence of City of Los Angeles Bureau of Engineering and Bureau of 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 3630 D. The 3630D recorded is 21% greater than the 3000D requirement for the highest rated pipe listed in ASTM C76-00. This is 198% of the load specified in the construction plans. The results are shown below in Table (2-A).

Table 2-A D-LOAD TESTING RESULTS OF REMOVED 4.56 FT OF LCSFVRS

Description	Gauge readings (kPa)	Total Load (Kg)	D-Load	Comments
Load required for ASTM C76-00	8895 kPa (1290 psi)	37,230 kg (82,080lb)	3000D	
First Hairline Crack	4482 kPa (650 psi)	18,780 kg (41,400lb)	1510D	50% of 3000 D Load
0.01" < 12" 0.000254m < 0.3048m	10620 kPa (1540psi)	45,140 kg (99,510lb)	3630D	21% greater than 3000 D Load
Ultimate Load	12760 kPa (1850 psi)	54070 kg (119,200 lb)	4350D	45% greater than 3000 D- Load, 16% greater than 3750 D-load to produce ultimate load

PHYSICAL PROPERTIES OF CONCRETE - LCSFVRS

Physical properties of the concrete in the pipe such as compressive strength, absorption, bulk specific gravity, and void content of the concrete were determined from core samples that were taken from the pipe at the invert, springline, and soffit. The results of the testing are summarized in Table (2-B).

CONCRETE STRENGTH - LCSFVRS

Eight 81 mm (3.2 inch) diameter by approximately 178 mm (7 inch) long concrete core samples were taken from the pipe at the 12, 3, and 6 o'clock positions. Three of the cores (2, 4, 6) were broken for compressive strength at the Ameron Engineering Research facility, three (3, 5, 7) were broken at the City of Los Angeles Standards Laboratory [c]. Two cores (1, 8) were reserved for petrographic analysis and were not broken for compressive strength. The results of the compressive concrete strength tests are presented in Table 3.

TABLE 2-B - COMPRESSIVE STRENGTH, ABSORPTION, BULK SPECIFIC GRAVITY AND VOID CONTENT OF REMOVED CONCRETE SECTION - LCSFVRS

Description		Core No.		
		2	4	6
Location		Springline	Bottom	Top
Compressive Strength specimen	Presence of Steel	NO*	NO*	YES
	Core Length, meters	103 mm (4-1/16in)	121 mm (4-3/4in)	154 mm (6-1/16in)
	Core diameter, meters	82 mm (3.24in)	82 mm (3.22in)	82 mm (3.22in)
	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	10.8	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 -COMPRESSIVE CONCRETE STRENGTH TEST RESULTS - LCSFVRS

Agency	Core #	Location	Strength	Length
Ameron	2	Springline	71,020 kPa (10,300 psi)	103 mm (4-1/16in)
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)

PETROGRAPHIC ANALYSIS OF CONCRETE - LCSFVRS

Two cored cylinders were reserved for petrographic analysis, which was performed by Concrete Experts International, Copenhagen, Denmark. Cylinder #1 was taken at the springline of the pipe, and had T-lock cover. Cylinder #8 was taken from the invert of the pipe and was exposed to the sewer flow.

Three thin sections, each measuring 30 x 45 mm, were taken from each cylinder at the inner surface, the middle of the cylinder, and the outer surface. The thin sections were made by impregnating slices of the cylinder with epoxy resin containing a fluorescent dye. The slices were ground and polished to a thickness of 0.20 mm and examined in a polarizing optical microscope using transmitted light, crossed polarized light, and blue transmitted light with a yellow blocking filter. A scanning electron microscope was also used in the analysis.

CONCRETE COMPOSITION - LCSFVRS

The concrete of both cores was composed of course aggregate with rounded particles with a maximum diameter of 29 mm (1 1/8 inch). The rock types in the coarse aggregate are primarily schists and gneisses, and volcanic rock. Fine aggregate consists of rounded to angular particles of the same kinds of rock. The cement paste matrix is dense and gray and consists of a rather coarse grained well-hydrated Portland cement with no mineral admixtures. The air content of the concrete is estimated at 0.5%

> "The concrete composition is estimated to be 387 kg/m^3 (652 pcy) cement, 193 kg/m^3 (326 pcy) water, 1,233 kg/^3 (2,078 pcy) coarse aggregate, and 573 kg/m^3 (965 pcy) fine aggregate, assuming densities of 3,150 kg/m^3 for cement and 2,640 kg/m^3 for coarse and fine aggregates.
>
> *Surface Alterations*
>
> All surfaces except the inner surface of core # 8 exhibit very little alteration. Approximately 5mm of concrete is missing from the inner surface of core #8, and the aggregate is exposed. The inner surface of core #8 is, or has been under attack from the environment, and the cement paste has decomposed. Right at the inner surface (1-1.5 mm) of core #8 is a rust zone where un-reacted ferrite has reacted to form rust colored iron oxides and hydroxides. Behind the rust zone the paste consists of a heavily cracked zone (4-6 mm thickness). The composition of the paste in the cracked zone cannot be determined under the optical microscope, but EDXA analysis in the scanning electron microscope reveals that the paste in many areas in this zone is rich in magnesium and silicon, while being low in calcium. This is strong evidence of a magnesium-salt attack during which magnesium is substituting for calcium according to the followiing reaction equations:
>
> 1) $MgX + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaX$ (X could be e.g. sulfate or chloride)
> 2) $MgX + CaSi.H_2O \rightarrow Mg(OH)_2 + CaX + SiO_2$ (X could be e.g. sulfate or chloride)
>
> The reaction results in a softening of the paste, and the calcium-salts formed are soluble, and therefore easily leached from the concrete. Consequently, the concrete may erode away, in particular if exposed to running sewage. Behind the cracked zone is a 2-4mm thick "popcorn"

carbonated zone, and behind this zone is an isotropic zone of 5-7mm in which the paste appears totally black without any calcium hydroxide.

The deterioration will continue as long as a steady supply of magnesium-salt is provided. The front of attack will move towards the outside pipe surface, and the concrete thickness will slowly decrease as the softened paste is eroded and leached away.

Evidence of water movement

The Ca $(OH)_2$ content of the cement paste is generally low particularly considering how well hydrated the cement is. No calcium hydroxide is found in the carbonated and partly carbonated areas, as well as in isotropic areas. Generally the paste in both cores has an opaline appearance when viewed in cross-polarized light.

Ettringite is found in varying amounts in voids throughout the cores. In core #1 the ettringite content is increasing from none observed at the inner to a massive filling of most voids at the outer surface. The voids of the center part of the core are only partially filled with ettringite are observed in most voids at the outer surface, while only few needles are found in voids in the center of the core. The presence of opaline paste, low calcium hydroxide content and massive formation of ettringite in voids is indicative of considerable water movements, dissolution and reorganization of phases in the concrete.

Carbonation

Carbonation is observed at all surfaces, but to a varying extent. At the outer surface of both cores carbonation extends to a depth of 3mm, and an outer thinner layer ordinary carbonation is observed. Behind the ordinary carbonation , a thicker layer of “Popcorn” carbonation(in-complete carbonation where calcium hydroxide is reacted but calcium silicate hydrate may still be present) is observed. At the inner surface of core #1 protected by the T-lock liner the carbonation behind the cracked zone. The presence of a narrow approx. 1mm thick ordinary carbonation zone at all surfaces could indicate that this carbonation is a result of the similar exposure conditions at all surface, i.e. it could result from storage of the pipe section after it was taken out of service.

Water to Cement Ratio

Under the optical microscope, the cement paste of both cores is very inhomogeneous with green tone intensities corresponding to apparent w/c-ratios between 0.35 and 0.60 in the interior paste, and as high as 0.70 in the partly carbonate zones at the surfaces. It is important to notice, however, that the w/c ratio determined is given as an apparent w/c ratio because water movements, which may have changed the capillary porosity, may have influenced the paste throughout the core. The inhomgeneity is observed as dense zones around aggregate particles. It is suggested that the dense zones are a result of mixing of the cement with aggregate of considerable excess moisture leading to adhesion of dense cement paste to the aggregate particles. Subsequent mixing after addition of the remaining mixing water appears to have been insufficient to break up the dense zones on all aggregate particles.

Cracks

At the outer surface of both cores a number of short (1-15 mm) micro, and fine cracks are observed. These cracks are all early cracks. The soft edge cracks are formed in the plastic or semi-plastic state, while the jagged edge cracks are likely formed within the first few weeks after casting. On the plane section of core #8 a fine brittle crack is observed extending from the outer surface, and 150 mm into the concrete. This is a typical crack resulting from non-compensated shrinkage. At the inner surface of core #8 a fine brittle crack extending across the thin section is observed. This crack is partially lined with calcite in the 10-12 mm nearest the inner, and complete to partially filled with massive ettringite at larger depths. The concrete contains a vast amount of short plastic micro cracks in the paste. The cracks are not considered to influence durability, and are probably a result of the production technique used in the manufacture of the pipe.

Other observations were that no signs of alkali silica reaction are observed in the concrete. Reinforcement is found in both cores at distances greater than 40 mm from the inner surfaces. No rust was seen on the reinforcement, and the carbonation does not exceed 10 mm on either core. Not expecting chloride to have been present in more than trace amounts in the environment, reinforcement corrosion is not likely to occur. The PVC-liner at the inner surface of core #1 appears to be in fair condition."[6]

PHYSICAL PROPERTIES OF T-Lock - LCSFVRS

The physical properties of T-lock are specified in the Standard Specifications for public Works Construction (SSPWC), Greenbook 2000, Section 210-2.4 Flexible PVC Liner, table 210-2.4.1(A). Material thickness is specified in section 210-2.2.2, Thickness of Material, table 210-2.2.2(A). The tensile strengths, elongation and durometer "D" hardness at 1 and 10 seconds of the black T-Lock removed from the 48 year old LCSFVRS RCP section and of a white T-Lock control sample recently produced are shown in Table 4. The hardness values met the requirements that are specified in the SSPWC Table 210-2.4.1(A) (Greenbook 2000). The tensile strength observed was slightly lower than the minimum requirement of 15170 kPa (2200 psi) for new unexposed material. The average value meets the minimum tensile strength requirement for liner after 112 days of chemical exposure per SSPWC 210-2.3.3. The elongation was lower than the 200% requirement. Although the T-Lock sample did not meet requirements for never in service material, visually the T-lock and the underlying concrete were in excellent condition, thus indicating that the T-Lock performed its function as intended. The results are represented in Table 4. The T-lock was able to withstand substantial deformation experienced at ultimate pipe load during D-load testing.

Table 4 shows the results of tests taken on 6 samples of T-lock. The tensile tests were performed parallel to extrusion and tees. The black samples, 1 through 3 were removed from the actual LCSFVRS that dates back to 1953. These samples were taken from near the pipe springline and were cut lengthwise from in between the embedded tees. The remaining white samples, samples 4 through 6, were newly made T-Lock that had not been exposed to the pickle jar, and were used as a control in the testing. The Shore Hardness Test results shown in Table 4, were obtained and performed in accordance with the ASTM D2240, Shore Durometer, Type D standards.

TABLE 4 - QUALITY CONTROL RESULTS FOR T-LOCK - LCSFVRS

Mfg'ng Date	T-Lock Product	Extruder No.	Sample No.	Pounds Break	Thickness meters. (Min)	Width (meters)	Tensile (kpa)	Elongation %	Hardness "D" 1-Sec	Hardness "D" 10-Sec
1953	Black	Molded	1	18.8kg (41.45lb)	0.001956 m (0.077 in)	0.00635 m (0.25 in)	14,840 (2,153 psi)	125	55	48
1953	Black	Molded	2	18.14kg (40lb)	0.002032 m (0.08 in)	.00635 m (0.25 in)	13,790 (2,000 psi)	150	55	46
1953	Black	Molded	3	20.64kg (45.51lb)	0.002134 m (0.084 in)	.00635 m (0.25 in)	14,940 (2,167 psi)	150	57	50
	CONTROL									
9/18/01	White	2	4	25.72kg (56.71lb)	0.001727 m (0.068 in)	.00635 m (0.25 in)	23,000 (3,336 psi)	275	55	46
9/18/01	White	2	5	25.88kg (57.06 lb)	(0.001753 m (0.069 in)	.00635 m (0.25 in)	22,810 (3,308 psi)	300	55	46
9/18/01	White	2	6	26.28kg (57.93 lb)	0.001778 m (0.07 in)	.00635 m (0.25 in)	22,820 (3,310 psi)	300	55	46
	Reference				*Minimum*	*N/A*	*Minimum*	*Minimum*	*Range*	*Range*
	SSPWC STANDARDS				0.065		2200	200	50 - 60	35 - 50

PRESENCE OF "BLISTERS" IN T-LOCK - LCSFVRS

When the pipe was removed from the sewer, it was immediately apparent that substantial blistering had occurred in the T-Lock. Throughout the bottom half of the pipe, in excess of 50 percent of the T-Lock exhibited blistering. In the top half of the pipe blistering had also occurred, but to a lesser extent. All of the blisters occurred between adjacent tees, and no blister crossed any tee. The T-Lock was initially cut from one blister for testing. In the process of making the cut, a yellowish, foul smelling, liquid squirted from the cut. This liquid was tested with pH indicating paper and was determined to have a pH between 10 and 11. A small sample of the liquid present in the bubbles was tested by the City of Los Angeles Industrial Waste Management Division Laboratory at the D C Tillman water reclamation plant. The liquid was found to be inorganic. Two larger composite samples of one liter each were obtained later, by cutting individual blisters open and removing the liquid. These were submitted for analysis to the Industrial Waste Management Division and the second, after a period of time, to Montgomery Watson Laboratories. The results from these tests are shown in Table (5) and Table (6).

TABLE 5 - DC TILLMAN TESTS OF LIQUID FROM T-LOCK BLISTERS - LCSFVRS

Test Definition	Units	Results	Analysis date
Hardness	mg/L	30	8/29/01
Total Dissolved Solids	mg/L	54,600	8/29/01
Conductivity	umhos/cm	50	8/16/01
Sulfide	mg/L	904	8/16/01
Calcium	mg/L	24	9/10/01
Magnesium	mg/L	0.66	9/10/01
Potassium	mg/L	5,000	9/10/01

TABLE 6 -MONTGOMERY WATSON TESTS OF LIQUID FROM T-LOCK BLISTERS - LCSFVRS

Sample ID	Unit	Result	Analysis Date
Alkalinity	mg/L	54,500	11/27/01
Anion Sum-Calculated	meq/L	1.103+03	11/7/01
Calcium, Total, ICAP	mg/L	170	11/2/01
Cation Sum, Calculated	meq/L	904	11/7/01
Chloride	mg/L	300	11/26/01
Lab pH	Units	9.7	10/31/01
Magnesium, Total, ICAP	mg/L	5	11/2/01
Potassium, Total, ICAP	mg/L	4,400	11/2/01
Sodium, Total, ICAP	mg/L	18,000	11/2/01
Specific Conductance	umho/cm	55,160	10/31/01
Sulfate	mg/L	196	11/26/01

BOND OF REINFORCING STEEL TO CONCRETE - LCSFVRS

Three samples were cut from the pipe segment to test the pullout resistance of the reinforcing steel. After the test specimens had been trimmed, and the rebar straightened they were inserted into a jig that had been built to hold the specimen in place and the load was applied. The results may have been affected by curvature of the steel within the concrete, however, the pull out resistance of the reinforcing steel embedded in six inches of concrete approached the yield stress of the steel.

TABLE 7-A -PULL-OUT STRENGTH OF PLAIN REINFORCING STEEL BAR IN CONCRETE - LCSFVRS

Specimen No.	1	2	3
Maximum Load, Kg	2971 kg (6,550 lb)	3475 kg (7,660 lb)	3039 kg (6,700 lb)
Steel Diameter, meters	11 mm (7/16 in)	11 mm (7/16 in)	11 mm (7/16 in)
Length of steel in Concrete, meters	143 mm (6.00 in)	159 mm (6.25 in)	143 mm (5.63 in)
Pull-Out Strength, kPa	5447 kPa (790 psi)	6136 kPa (890 psi)	5929 kPa (860 psi)

TABLE 7-B - PULL-OFF STRENGTH OF T-LOCK FROM CONCRETE - LCSFVRS

Specimen No.	Test Length	Breakage Length	Maximum Load	Pull-out Strength (lb/linear in)	Failure type
1	76 mm (3 in)	76 mm (3 in)	176.9 kg (390 lb)	130	Through Leg Of "T" adjacent to flat panel
2	76 mm (3 in)	76 mm (3 in)	157.4 kg (347 lb)	115	Through Leg Of "T" adjacent to flat panel
3	76 mm (3 in)	58 mm (2.3 in)	101.6 kg (224 lb)	75	Through Leg Of "T" adjacent to flat panel
4	76 mm (3 in)	58 mm (2.3 in)	178.3 kg (393 lb)	131	Through Leg Of "T" adjacent to flat panel
5	79 mm (3.1 in)	66 mm (2.6 in)	201.4 kg (444 lb)	143	Through Leg Of "T" adjacent to flat panel

PHYSICAL PROPERTIES OF REINFORCING STEEL - LCSFVRS

The reinforcing steel present in the removed section of the LSFVRS was tested for various parameters. Tests were conducted on the Tensile strength, the yield (0.2% offset) strengths, the reduction of area, elongation within a 2-inch gage length and the modulus of elasticity. The results obtained are shown in Table 8. The corresponding requirements given in ASTM A615-96a “Standard Specification for Deformed and Plain Billet – Steel Bars for Concrete Reinforcement” which is the specification referred to in ASTM C76-00 “Standard Specification for reinforced Concrete Culvert, Storm Drain, and Sewer pipe” are also shown as a comparison. The properties of the steel reinforcing bars are very similar to those of ASTM A615 steel bars.

TABLE 8 - REINFORCING STEEL TESTING - LCSFVRS

Physical Property	Specimen No.			ASTM C76/A615 Specifications
	1	2	3	
Diameter, meters	11.1mm (.4376 in)	11.2mm (0.4418 in)	11.1mm (0.4376 in)	Between Bar No. 3&4
Tensile Load to Failure, (kg)	5076 kg (11,190 lb)	5230 kg (11,530 lb)	5076 kg (11,190 lb)	
Tensile Strength, kPa	513000 kPa (74,400 psi)	518500 kPa (75,200 psi)	524000 kPa (76,000 psi)	>70,000.
Yield Strength (0.2% Offset), kPa	284100 kPa (41,200 psi)	306100 kPa (44,400 psi)	306800 kPa (44,500 psi)	>40,000.
Reduction of Area, %	50.8	53.6	53	
Elongation in 2" Gage Length,%	15.7*	22.1*	28.3	>11% to 12% in 8" Gage Length
Modulus of Elasticity, 10^6 psi	25	20	34	

TEST OF RUBBER GASKET FOR CONCRETE PIPE - LCSFVRS

Samples of the neoprene rubber gasket used to join sections of the concrete pipe were tested at the City of Los Angeles, Department Of General Services Standards Division [F]. The samples were taken from the removed (RCP) section that had previously in operation for the past 48 years. The sample was tested in accordance with the SSPWC, section 208-3, and gasket for concrete pipe. The sample did not meet the requirements for the compression set. The test results that were obtained are shown in Table (9). The physical properties of the gasket removed are shown in Table (9). These results show that the gasket met all specification requirements set by “The Standard Specification For Public Works Construction-Greenbook 2000”.

TABLE 9 - RUBBER GASKET TESTING - LCSFVRS

TEST METHOD	TEST RESULTS	SPECIFICATION REQUIREMENTS
Initial Tensile Properties		
Tensile Strength, psi ASTM D412	4244	>1500
Elongation @ break , % ASTM D412	439	>359
Compression set, %ASTM D395, 22hrs @ 158° F	35*	16 <
Hardness, Shore A Durometer ASTM D2240	59	40-65
After Oven Aged, 96hrs, 158° F		
Tensile strength,% original ASTM D412	94	>80
Change in Shore A Durometer ASTM D2240	1	10 <
Ozone resistance, 70 hrs, 104° F, 20% Strain		
Exposure to 150 ppm Ozone ASTM D1149	Pass	No Cracks
Spliced Joint		
No of splices in gasket	N/A	1 per gasket
100% Elongation Test	N/A	no split
Bend Test	N/A	no split
Porosity	Pass	free of Porosity

TEST RESULTS - NOS PIPE

Ten core samples were taken from the top half of pipes removed from the NOS. These samples were selected to represent various stages of obvious deterioration of the pipe and included samples through tile that had remained in place, through moderately damaged concrete, and through the thinnest pipe sections found in the available sample.

Seven of the cores were broken for compressive strength by the City of Los Angeles Standards Division Laboratory E. Samples marked with an * were calculated with a correction factor for compressive strength that was extrapolated, due to insufficient sample length, from the correction factor chart of ASTM C42.

Table 10 -COMPRESSIVE CONCRETE STRENGTH TEST RESULTS - NOS

Agency	Core #	Dia.	L/D Ratio	Compressive Strength	Location
City	1	71mm (2.8 in)	.93	43,850 kPa (6,360 psi)*	Vernon and 11th, Shaved rebar both sides
City	2	71mm (2.8 in)	.96	37,230 kPa (5,400 psi)*	Vernon and 11th, adjacent to core #1
City	4	71mm (2.8 in)	1.11	34,340 kPa (4,980 psi)	Vernon and 4th, Same Segment as Core #3, 6” off Center Line
City	5	71mm (2.8 in)	1.18	48,400 kPa (7,020 psi)	Pipe section #12, Center of crown
City	6	71mm (2.8 in)	1.18	48,400 kPa (7,020 psi)	Pipe Section #12, 4” off Center
City	7	71mm (2.8 in)	1.04	47,780 kPa (6,930 psi)	Vernon and 11th, Pipe #6
City	10	71mm (2.8 in)	1.21	39,780 kPa (5,710 psi)	Pipe #7, Top of Crown

PETROGRAPHIC ANALYSIS OF CONCRETE – NOS

Three cored cylinders, #3, #8, #9, were reserved for petrographic analysis, which was performed by Concrete Experts International, Copenhagen, Denmark. The concrete of all three cores was very similar on both macroscopic, and microscopic scales, with the exception of the length of sample recovered. All three cores demonstrated a zoning which consisted of a layer of fully converted gypsum ranging from 2-3 to 11 mm in depth at the inner surface, a zone of gypsum filled cracks, an interior zone with opaline paste and etringite in air voids, with a zone of carbonation at the outer surface varying from 0 to 20 mm in thickness.

“The concrete has all the characteristics of a sever sulfate attack progressively decomposing the concrete. The concrete is zoned with a relatively deep zone of iron stained gypsum, and many surface parallel cracks at the inside pipe surface. The gypsum zone is evidence of a total dissolution and transformation of all cement phases. The iron staining of the gypsum zone is typical for acidic sulfate attack and is due to the transformation of the cement’s ferrite phases into iron oxides and hyrdroxides. The distict very rusty-red iron layer of cores #8 and #9 is however due to corrosion products from the exposed steel. The interior of the concrete had a high amount of ettringite in voids as well as an opaline (hazy) shine throughout.”

SIGNIFICANCE

T-LOCK PROTECTED LCSFVRS - The pipe in question is in remarkable condition. After 48 years of service 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, 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 hardness meets current specification. Elongation at break falls below current specification for new T-lock 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.

Based on the petrographic analysis of the two concrete cores, the following can be summarized, and concluded: G

- The overall condition of the concrete in cores #1 and #8 is good considering it's 48 years of service.

- Comparing cores #1, and #8 it is clear that core #8 taken from near the bottom of the pipe has experienced a more hostile environment than core #1. This is not what is commonly experienced in sewer pipes, where concrete positioned around the average sewage line (core #1) normally is expected to deteriorate more rapidly than concrete near the bottom of the sewer. It is reasonable to attribute the better condition of core #1 as compared to core #8 to the protection provided by the T-lock PVC liner.

- The un-protected core #8 shows evidence of a mild magnesium-salt attack, and approximately 5 mm of concrete has decomposed, and eroded away on the inside. In the altered zone, the calcium-phases of the paste are substituted by magnesium. This substitution makes the concrete soft, and susceptible to erosion by the flowing sewage.

Pipe joints are intact and the gasket material remains viable after 48 years of service, meeting or exceeding the requirements of all tests except the compression set test for new gasket material.

CLAY TILE PROTECTED NOS – This pipe is severely damaged after 72 years of service. Zoned concrete transformation to gypsum is complete in all areas of the upper half of the pipe, including behind clay tiles. The concrete has corroded in places beyond the rebar, allowing the rebar to have been corroded away.

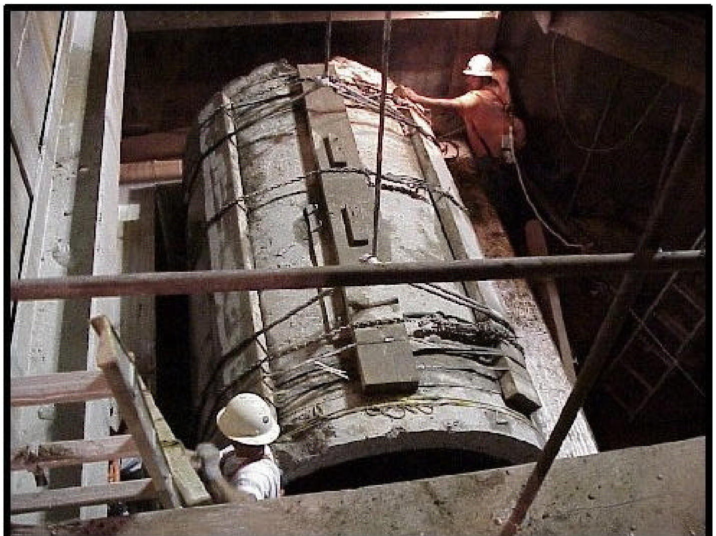
The petrographic analysis summarizes the condition of the concrete as follows:

“The similar zoning of all three cores indicates that the present sulfate attack is a progressive process that gradually decomposes the concrete from the inside surface of the pipe towards the outside surface…. The process will continue as long as a source of sulfate is present in the sewer. The attack is however at this stage so severe/progressed that it may be impossible to prevent further damage to the concrete even if the source of sulfate is eliminated [K].”

CONCLUSION:

Based on the results of testing conducted by the City of Los Angeles the T-Lock lined La Cienega and San Fernando Valley Relief Sewer pipe is in good condition and at this point no end to its useful life could be predicted. The use of plastic liner has protected the pipe much more effectively than the earlier clay liner tile protection used by the City in the North Outfall Sewer.

Figures



City of Los Angeles
La Cienega and San Fernando Valley Relief Sewer

Figure 1. LCSFVRS Pipe Segment Being Removed From Sewer

City of Los Angeles
North Outfall Sewer, Maze 3 Pipe Halves

Figure 2. NOS Maze 3 Pipe Half Sections

Source Information

A Gauging for February 13, 1999. MH#563-09-063.

B Gauging for Sunday March 12, 2000. MH# 492-08-174, 12:30 p.m. Martel Av. S/o Rosewood Ave, Gauging Hole #LC-2.

C City of Los Angeles Plan D-10016, Sheet #32 of 70 (Originally sheet 28 of 64).

D City of Los Angeles, Department of General Services, Standards Division, Report of Compression Test of Concrete Core. Date November 7, 2001, Reference Number 02-615, samples 197-199.

E City of Los Angeles, Department of General Services, Standards Division, Report of Compression Test of Concrete Core. Date November 7, 2001, Reference Number 02-615, samples 188-194.

F City of Los Angeles, Department of General Services, Standards Division, Report of TEST OF RUBBER GASKET FOR CONCRETE PIPE. Date November 7, 2001, Reference Number 2002-503-13

G Petrographic Analysis of Concrete Pipe, City of Los Angeles, Bureau of Engineering, November 12, 2001; Concrete Experts International, Ref Number: 011024r.001

H Report 001-7050-1602-2, T-LOCK LINED RCP AFTER 48 YEARS OF SERVICE; Sylvia C. Hall, December 2001;Ameron International Corporation, Engineering Development Center, South Gate, Ca

I Original Notes, Still Photos, Video Recording of testing; Keith Hanks, City of Los Angeles, Bureau of Engineering

J HOW TO CONNECT A NEW SEWER LINE TO AN EXISTING 72-INCH SEWER WHILE FLOWING AT 2/3 FULL AND OVER 13 FPS, WEFTEC 2002, Samara Ali-Ahmad, Keith Hanks,

K Petrographic Analysis of Concrete Pipe, City of Los Angeles, Bureau of Engineering, April 2002; Concrete Experts International, Ref Number: 020211r.001