REHABILITATION OF A LARGE SEMI-ELLIPTICAL SEWER

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ABSTRACT

The Sanitation Districts of Los Angeles County (Districts) own, operate, and maintain a wastewater treatment and collection system that includes approximately 1300 miles of sanitary sewers ranging from 6 to 144 inches in diameter. A portion of the Districts’ Joint Outfall “A” Trunk Sewer was constructed of cast-in-place reinforced concrete having a semi-elliptical cross section and included an interior lining of vitrified clay tiles for corrosion protection. This paper describes the rehabilitation of approximately 15,200 feet of 114- and 126-inch semi-elliptical sewer using a flexible and spiral wound polyvinyl chloride (PVC) liner embedded in a structural grout.

The 114- and 126-inch semi-elliptical Joint Outfall “A” Trunk Sewer was constructed in the late 1920s. The sewer is located immediately upstream of the Districts’ Joint Water Pollution Control Plant in the City of Carson, California and conveys a peak flow of 100 cfs. Over the years, the majority of the vitrified clay tiles above the low flow level became dislodged and allowed debris to accumulate in the sewer to depths of approximately two to four feet, significantly reducing the capacity of the sewer. Moreover, physical inspections of the sewer and manholes indicated that the exposed concrete had corroded up to four inches at some locations.

An $8.5 million contract to rehabilitate 6500 feet of 114-inch and 700 feet of 126-inch semi-elliptical sewer was awarded in May of 2001. Construction of this contract was successfully completed in October 2003. A second contract for $12.6 million to rehabilitate 8000 feet of 114-inch semi-elliptical sewer was awarded in March 2005. One-half of the lining on the second contract has been completed and it is anticipated that the remaining work will be completed by October 2006. Both contracts specified the rehabilitation system to be installed by person-entry methods and the selection of the contractor was based not only on the overall bid price, but also on the contractor’s proposal and approach to the project.

KEYWORDS

Sewer rehabilitation, corrosion, semi-elliptical, protective linings
INTRODUCTION

The County Sanitation Districts of Los Angeles County (Districts) are a confederation of 24 independent sanitation districts that serve the wastewater treatment and solid waste management needs of approximately 5.1 million people in Los Angeles County. The Districts’ service area covers approximately 800 square miles and encompasses 78 cities and unincorporated areas within the county. The Districts own, operate, and maintain more than 1300 miles of main trunk sewers ranging from 6 to 144 inches in diameter that convey approximately 510 mgd of wastewater to 11 wastewater treatment plants.

Seventeen of the sanitation districts are signatory to a Joint Outfall Agreement, which provides for a regional system of interconnected facilities known as the Joint Outfall System (JOS). The JOS service area encompasses 670 square miles of unincorporated territory and 73 cities, including some portions of the City of Los Angeles. The JOS includes six upstream water reclamation plants and the Joint Water Pollution Control Plant (JWPCP), located in the City of Carson. These plants together treat approximately 475 mgd of wastewater.

The backbone of the JOS consists of nine joint outfall sewers, which are shown in red on Figure 1. The 17 sanitation districts party to the Joint Outfall Agreement proportionately share the ownership, operation, and maintenance of the 450-mile network of joint outfall sewers. These sewers typically carry wastewater generated from more than one sanitation district. Individual sanitation district sewers, which are shown in blue on Figure 1, only carry flow from one particular district. Connector sewers, which are not shown on the figure, are owned and operated by local jurisdictions.

FIGURE 1
JOINT OUTFALL “A” TRUNK SEWER

The Joint Outfall “A” Trunk Sewer (JO “A”) was the first joint outfall sewer constructed by the Districts. The majority of JO “A” was constructed in the late 1920s. The nominal pipe sizes of this 22-mile long sewer range from 33 to 126 inches. The farthest downstream section of the JO “A” sewer system includes Joint Outfall “A” Units 2, 3A, and 3B Trunk Sewer (JO “A”-2, 3A and 3B), located entirely within the City of Carson. These units are composed of approximately 14,500 ft. of 114 in. and 700 ft. of 126 in. semi-elliptical sewers. The height and width of each of these semi-elliptical sewers are equal. Figure 2 illustrates the configuration of the 114 in. sewer. JO “A”-2, 3A and 3B has a capacity ranging between 170 and 260 cfs and conveys a dry-weather peak flow of approximately 100 cfs to the JWPCP.

FIGURE 2

The JO “A”-2, 3A and 3B semi-elliptical sewers were constructed of cast-in-place reinforced concrete in 1927. The interior arch of the semi-elliptical sewers was lined with vitrified clay tiles to protect the concrete from hydrogen sulfide corrosion. The 7/8-inch thick tiles, which were used in over 90 percent of the JO “A” system, were approximately 9-3/8 inches wide and 15 inches long. To embed the tiles in concrete, continuous lugs that projected 5/8 of an inch beyond the back of the tiles were included on the long sides of the tiles. The invert slab and starter walls were poured prior to forming the arch. The tiles were then placed on an internal form and the joints between the tiles were mortared with a mixture of sand, molten sulfur and silica. The reinforcing steel (rebar) for the arch was then placed and the final concrete was poured. Photographs of the joint mortaring process and the interior of the finished sewer are shown on Figure 3 and Figure 4 respectively.
Although the tiles initially protected the JO “A”-2, 3A and 3B sewer, after approximately 10 years of service, the tiles began to dislodge from the concrete. Prior to 1940, Districts’ forces were able to enter the sewer to remove the fallen tiles. However, after World War II, flow in the JOS increased significantly and this option was no longer feasible. Despite the loss of tiles, physical inspections of the sewer adjacent to manholes revealed that corrosion rates of the unprotected concrete were relatively slow. Corrosion rates increased dramatically after the 1970’s when source controls on industrial dischargers were implemented in order to meet more stringent state and federal effluent limits (Martyn and Kremer, 1987). Concurrent with a sharp reduction in metals in the wastewater due to the source controls, a significant increase in hydrogen sulfide levels was detected in the JO “A” sewer. Studies found that these metals inhibit the sulfate reducing bacteria responsible for hydrogen sulfide generation (USEPA 1991).

SEWER INSPECTIONS

Hydrogen sulfide corrosion within the Districts’ sewer system was not limited to JO “A” sewer. Approximately 660 miles of the Districts’ sewers are made of unlined concrete pipes and are susceptible to hydrogen sulfide corrosion. Inspection of unlined concrete sewers through the mid 1970’s revealed that the sewers had only slight corrosion, and based on estimated corrosion rates, it was believed that the sewers had hundreds of years of service life remaining. However, the significant increase in sulfide levels led to accelerated corrosion rates in the unlined concrete sewers. Sewers, which were in good condition in the mid 1970’s, were severely corroded by the mid 1980’s. By the late 1980’s, the Districts had identified approximately 25 miles of sewers constructed of unlined concrete pipe that had exposed reinforcing steel (rebar) visible and another 35 miles of unlined concrete pipes where rebar would become visible. In the 1990’s, through the use of closed circuit television (CCTV), the Districts were able to conduct a more thorough evaluation of the collection system and identified an additional 75 miles of deteriorated sewers.

Starting in the late 1980’s, the Districts began to replace corroded sewers in the JOS system. The majority of these replacement sewers were constructed of reinforced concrete pipe lined with PVC T-lock liner manufactured by Ameron Protective Linings (Ameron). However, since it would not have been feasible or it would not have be cost effective to replace all of the deteriorated sewers, the Districts also began a program of sewer rehabilitation, using sliplining with segmented liner pipes to repair the larger diameter JOS sewers. Since there was no means to divert flow from most of the corroded sewers, sliplining with circular segmented liner pipe
became the preferred sewer repair method for the Districts. To date, the Districts have awarded more than 110 contracts to replace and rehabilitate the deteriorated sewers at a construction cost in excess of $320 million. In addition, the Districts have implemented an extensive crown spray program. In this process a magnesium hydroxide slurry is sprayed onto the crown of unlined concrete pipe to inhibit corrosion and extend the life of the pipe.

INSPECTION OF JO “A”–2, 3A AND 3B

Physical inspections of the JO “A”–2, 3A and 3B in the 1980’s revealed that the majority of the tiles above the low flow level dislodged and debris had accumulated along the bottom of the sewer significantly reducing hydraulic capacity. Physical inspections also revealed exposed rebar in the sewer adjacent to five of 16 manholes, and corrosion had extended beyond the rebar at several locations. Core samples taken of the concrete at the crown of the semi-elliptical sewer indicated that up to 4 inches of corrosion had occurred; however, the core samples also indicated that the “as-built” thickness of the sewer exceeded the design thickness by 1 to 4 inches. Based on the remaining thickness, the sewer was determined to be structurally adequate to support the existing loads. However, it was also clear that repair of the sewer would ultimately be required.

As previously noted, the Districts began replacing sewers within the JOS in the late 1980’s. One of the first sewers replaced was the 144-inches diameter Joint Outfall “B” Unit 1A Trunk Sewer (JO “B”-1A), which was located roughly parallel to JO “A”–2, 3A and 3B. Construction of a 10 foot by 12 foot reinforced concrete box (RCB) sewer to replace JO “B”-1A was completed in 1993. The RCB sewer included a cross connection to the JO “A”, which allows flow to be diverted out of the JO “A” system.

While the construction of the JO “B”-1A replacement sewer made it possible to divert flow out of the JO “A” system, it was determined that the JO “A” sewer would surcharge upstream of the cross connection due to the elevation difference between JO “A” and JO “B”. The double barrel JO “A” Unit 3C Trunk Sewer, located approximately 800 feet. Upstream of the cross connection, was also deteriorated and in need of repair. The Districts were concerned that portions of this double barrel sewer would be damaged and could possibly collapse if surcharged; therefore, prior to the rehabilitation of JO “A”-2, 3A and 3B downstream, the double barrel portion of the JO “A” upstream of the cross connection had to be rehabilitated. This rehabilitation project was completed in 2000.

PROJECT OBJECTIVES

The primary objectives of the JO “A”-2, 3A and 3B rehabilitation project were to restore the structural integrity and the hydraulic capacity of the semi-elliptical sewer, and to provide a protective barrier to prevent future corrosion. To restore the hydraulic capacity of the sewer, the contract documents required the removal of all debris from the sewer. In addition, the contract documents required the removal of all clay tiles that remained attached to the sewer to maximize the final internal dimensions of the sewer. To restore the structural strength, the contract documents required the contractor to thoroughly prepare the concrete surfaces, replace rebar corroded in excess of 25 percent of the cross-sectional area, and rebuild the interior of the sewer with high strength cementitious grout. To provide protection from hydrogen sulfide corrosion, a plastic lining material was to be embedded in the structural grout.
CONTRACT NEGOTIATION AND AWARD

Due to the acceleration in corrosion rates and the need to expedite the repair of the deteriorated sewers, the Districts were granted the authority by the Districts’ Board of Directors in 1996 to use an alternative contract approach to accelerate repair of joint outfall sewers. The Districts used the competitive proposal approach for the rehabilitation of JO “A”-2, 3A and 3B. Instead of competitive bidding, contractors were pre-qualified based on past experience and performance and required to submit competitive proposals. This approach allowed the Districts to not only evaluate the construction cost, but also the contractor’s understanding of the project requirements, construction methods, ability to perform the work, and innovative alternatives and suggestions prior to entering into a contract. Subsequent negotiations between the Districts and the contractor would establish the basis for handling some of the uncertainties and unknown conditions. The Districts could also modify the specifications based on the contractor’s input and proposed construction methods. The pre-qualified contractors had significant experience rehabilitating large diameter sewers for the Districts. These contractors were familiar with the Districts’ rigorous inspection of concrete surface preparation and welding of plastic liners. This would ensure the quality of the work and minimize conflicts during construction.

Due to the length of sewer involved and the flow diversion required to dewater the sewer, a decision was made to divide the rehabilitation of the JO “A”-2, 3A and 3B sewer into two phases. The Districts had never implemented the flow diversion from the JO “A” system into the JO “B” system. The cross connection was a 54-inch diameter inverted siphon that crossed under the existing 144-inch diameter JO “B”-1A sewer and had a 3 feet higher invert elevation. The JO “A” system would surcharge upstream of the cross connection due to the elevation difference. To minimize the risk associated with surcharging the JO “A” system, the contractor was not allowed to divert flow during the rainy season, which runs from October 15th to April 15th in Southern California. With work only occurring during dry months, it was estimated that four years would be required to complete the rehabilitation of the sewer. To avoid awarding a single contact of such a long duration, the project was split into two phases.

A Request for Proposal (RFP) for the Phase I project was released to the pre-qualified contractors in March 2001. Proposals from six contractors were received with construction costs ranging from $8.5 million to $14.7. In May of 2001, negotiations for Phase I were completed and an $8.5 million contract for the project was awarded to the highest rated contractor, J.R. Pipeline, Inc. Phase I included the rehabilitation of 750 feet of 126-inch and 6500 feet of 114-inch semi-elliptical sewer. These reaches located at the downstream end of the sewer were the most severely corroded in the JO “A” system. The contractor completed the work for Phase I in October 2003 and the Districts’ Board of Directors accepted the contract in April 2004. A RFP for the Phase II project was issued to the pre-qualified contractors in February 2005. Proposals from 4 contractors were received with construction cost ranging from $12.6 million to $16.8 million. A $12.6 million contract for Phase II was awarded to the highest rated contractor, Mladen Buntich Construction Company, for the rehabilitation of the remaining 8000 feet of 114-inch semi-elliptical sewer located at the upstream end of the JO “A” system. To date, approximately 4100 feet of the 114-inch has been rehabilitated and it is anticipated that the remaining portion will be completed by October 2006.
PROTECTIVE LINING SYSTEMS

The lining materials specified for the Phase I project included Danby PVC liner, Ameron PVC T-lock liner, and Agru high-density polyethylene (HDPE) liner, all of which provide some form of mechanical lock with the structural grout. While all of these liner materials have gone through various chemical resistance testing and have been used successfully in sanitary sewer environments, only the Danby PVC lining system had been used extensively to rehabilitate sewers in the United States. There was a limited history on the use of these lining systems to rehabilitate large non-circular sewers. The Danby system had been used successfully in Districts’ sewers since 1990, including a 78-inch semi-elliptical sewer. Ameron PVC T-lock was introduced in 1947 and has been used extensively by the Districts in precast concrete pipe and cast-in-place structures, but had not been used in sewer rehabilitation. Agru HDPE liner began production in 1988. While it had been used extensively in Europe and Canada, including non-circular applications, installation of this product in the United States was limited.

Due to its successful use on Phase I project, Ameron PVC T-lock was specified as the only lining system for the Phase II project. During the proposal process for the Phase II project, the highest rated contractor proposed to install an alternate lining system in approximately 1800 feet of the 4000 feet of sewer scheduled to be rehabilitated in 2005. The alternate proposed by the contractor was a spiral wound PVC system with an integral steel reinforcement band. This lining system was manufactured by the Sekisui Chemical Company, Limited of Japan and was referred to as the SPR system. The contractor planned to install the SPR system in parallel with the Ameron PVC T-lock system for the work scheduled in 2005. The contractor proposed to use the SPR system in order to comply with the tight schedule imposed by the Districts. The Districts ultimately allowed the contractor to install the SPR system in the least corroded section of semi-elliptical sewer at the upstream end of the Phase II project.

PRELIMINARY WORK

The following subsections discuss the tasks that were required to be complete for both Phase I and II prior to the installation of the protective lining system. These tasks included implementation of flow diversion, installation of bypass pumping equipment to handle residual flow in the sewer, installation of odor control systems, construction of access pits, and the removal, treatment and disposal of debris.

FLOW DIVERSION

To implement the flow diversion, the contractor was required to remove and install stoplogs in accordance with a diversion schedule that was included in the contract documents. The contractor was allowed to implement the flow diversions only between April 15th and October 15th of each year. A schematic showing the stoplog locations and flow pattern during the rehabilitation is shown in Figure 5. The contractor was required to remove two stoplogs to open the 54-inch diameter cross connection between JO “A” and JO “B”. A stoplog was then installed in the upstream end of JO “A” to divert flow from JO “A” to the RCB JO “B”-1A Replacement Sewer. A temporary bulkhead was constructed at the downstream end of JO “A”-2, 3A, and 3B to prevent flow from backing up into the work area. At the end of each work period, the contractor was required to restore the sewer system to normal operating conditions.
FIGURE 5

FLOW BYPASS PUMPING

Downstream of the diversion between JO “A” and JO “B”, the only trunk sewer connected to JO “A”-2, 3A, and 3B was the Districts’ Rocha Street Trunk Sewer. To adequately dewater the work area, the contractor was required to bypass pump a peak flow of 7 cfs from this trunk sewer. The primary discharger to the Rocha Street Trunk was a refinery, which had a permit that allowed the discharge of wastewater to a temperature up to 140 °F. For the Phase I project, flow from the Rocha Street Trunk was allowed to remain within JO “A”-2, 3A and 3B to a point immediately upstream of the work area. Temporary bulkheads and bypass pumps were installed within JO “A”-2, 3A and 3B to allow flow to be pumped to the JO “B” system. For the Phase II project, the Rocha Street Trunk Sewer connected to JO “A”-2, 3A and 3B within the work area. Thus, it was not possible to install temporary bulkhead and pumps within JO “A”-2, 3A and 3B. For the Phase II project downstream of the Rocha Street Trunk, the contractor was required to construct a 8 foot by 16 foot temporary well wet on the 30-inch sewer upstream of its connection with the JO “A”, install submersible pumps, construct 600 feet of temporary 20-inch diameter welded steel force main and connect to the adjacent JO “B-1A sewer.

The remaining flow from local sewers, which carried relatively low volumes, were allowed to remain in the JO “A” sewer for most of the work but were bypassed internally or aboveground as required by the contractor’s operation. Temporary bulkheads and small diameter pumps were installed to handle this internal flow from these connections. The height of the temporary
bulkheads were kept approximately 2 feet below the top of the semi-elliptical sewer, which would allow upstream flow to spill over the bulkhead in the event of prolonged bypass system failure.

**ODOR CONTROL SYSTEMS**

To minimize the emission of odors during the work, the contractor was required to operate odor control equipment at all times when the sewer was open to the atmosphere. For the Phase I project, the Districts furnished two activated carbon odor control systems, each having a capacity of 16,000 cfm. For the Phase II project, the contractor was required to furnish activated carbon odor control systems. The contract documents required the activated carbon units to be operated at a flux between 50 and 60 feet per second through a bed with a minimum depth of 3 feet. For both the Phase I and Phase II projects, the contractor was required to furnish the activated carbon units, 460-volt electrical service for each unit, and air ducts to connect the sewer to the blowers. One odor scrubber system was placed upstream and one downstream of the open access pit. Blowers pulled air out of the sewer and through the activated carbon units, creating a negative pressure at the access pit.

**ACCESS PITS**

For both Phase I and Phase II projects, potential access pits were shown on the plans. The locations of these access pits were chosen by the Districts to minimize the potential impacts to the surrounding community from noise, traffic, odors and the other inconveniences of construction. The contractor was allowed to propose alternate access pit locations subject to approval by the Districts. The access pit provides access into the sewer and is the location from which all cleaning and rehabilitation activities are performed. To construct the access pits, the contractor excavated the area around the sewer, installed shoring and after sealing the inside of the pit to provide a watertight enclosure, the top portion of the semi-elliptical sewer was saw-cut and removed. The access pits were approximately 18 feet wide and 30 feet long. Photographs of one of the access pits and the top sections of sewer after removal are shown in Figures 6 and 7 respectively.
DEBRIS REMOVAL AND DISPOSAL

The debris in the sewer consisted of broken concrete, grit, fine sediments, sludge and broken pieces of the clay tiles. The estimated depth of the debris ranged from 6 to 36 inches. During the Phase I project, debris levels were fairly consistent with the estimated depth, however, the Phase II project found the debris level exceeding 48 inches throughout the upstream end of the sewer. The contract documents included a unit price bid item for the removal of the debris. The contractor was instructed to include all costs for the removal, transportation and handling, dewatering, disinfection, and final disposal of the debris. All debris removed from the sewer on a given day was to be removed from the site on that day. If storage areas or facilities were needed, they were to be arranged by the contractor. A photograph of the front-end loader transferring debris to the excavator is shown in Figure 8. A photograph of the debris being loaded into a container is shown in Figure 9.

Analytical testing of the debris prior to the Phase I and Phase II projects determined that the debris was contaminated with up to 15,000 mg/kg of total petroleum hydrocarbons (TPH). Although not hazardous due to the TPH contamination, the debris could not be disposed of at a standard Class III landfill. Disposal facilities that could accept the debris required additional testing prior to disposal. These tests, which were conducted after the award of the contract, found some TPH contamination as high as 80,000 mg/kg. The contractor for both Phases of the project used a compact front-end loader within the sewer to collect the debris and transport it to the access pit. At the access pit, the debris was transferred to a secondary container/bucket and removed from the sewer. The debris was then loaded into sealable containers, which included screens to dewater the debris. Liquid that drained from the debris was removed from the container and returned to the sewer. The containers were removed from the job site on a daily basis and transported to an off-site facility prior to final disposal.

FIGURE 8
FIGURE 9

INSTALLATION OF THE PVC T-LOCK LINING SYSTEM

The following subsections discuss the tasks involved in the installation of the PVC T-lock lining system. These tasks included the preparation of concrete surfaces, replacement of corroded rebar, placement of welded wire fabric, installation of a PVC T-lock lined starter wall, placement and positioning of PVC liner and the semi-elliptical forms, annular space grouting, and welding of the PVC liner.
**SURFACE PREPARATION**

To ensure an adequate bond between the structural grout and the existing concrete substrate, thorough surface preparation of the existing concrete was required. The contract documents required the removal of all white calcium sulfate corrosion product so that only hard grey concrete remained. The required surface pH after preparation was 7.0 or greater. The contractor was allowed to utilize sandblasting, gritblasting, high pressure water blasting (hydroblasting), or combination thereof to achieve the above requirements. For both the Phase I and Phase II project, all of the contractor’s proposals indicated that hydroblasting alone would be used for the surface preparation.

In addition to surface preparation, the contractor was required to demolish the clay tiles that remained attached to the existing surface. For the Phase I project, five of the contractors stated in their proposal that they intended to use mechanical methods to dislodge the tiles prior to hydroblasting. The highest rated contractor stated that they intended to use hydroblasting not only for surface preparation, but also to demolish the tiles. To accomplish this, highest rated contractor requested during contract negotiations that the maximum allowable hydroblasting pressure be increased. The Districts agreed, provided that the contractor could demonstrate the increased operating pressure would not remove an excessive amount of sound concrete. For the Phase II project, all of the contractors proposed to use hydroblasting to remove the remaining attached tiles.

The hydroblasting equipment operated at a typical pressure near the 20,000-psi limit with a flow rate of 100 gpm. An average of 85 feet per day were prepared while achieving the specified requirements. A photograph of the prepared surface is shown in Figure 10. The lugs from the clay tiles, which did not require removal if embedded in sound concrete, are visible in the photograph. A photograph of the dark grey prepared concrete surface next to the unprepared concrete is shown in Figure 11. The prepared concrete is on the left side of the photograph.

**FIGURE 10**

**FIGURE 11**

**REINFORCING STEEL**

Rebar was exposed at number of locations throughout the length of the sewer, particularly in the area of the crown of the sewer. The contractor was required to thoroughly clean the exposed rebar of all deteriorated concrete and rust. At locations where the existing 5/8-inch square rebar had lost more than 25 percent of its original cross-sectional area, it was replaced with No. 6 rebar spaced at 12 inches on center. A corrosion-inhibiting admixture was included in the grout mix to protect the rebar.

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Welded wire fabric was added to help control shrinkage cracks that could form in the grout. The welded wire fabric was attached to anchor bolts embedded in epoxy grout. The anchor bolts were spaced 36 inches each way.

**INSTALLATION AND GROUTING OF PVC T-LOCK LINER**

The lining limits shown on the contract drawings covered the entire arch of the existing 114-inch and 126-inch semi-elliptical sewers. The existing starter wall, which was not protected with the clay tiles, was always below the low flow level and was not subject to hydrogen sulfide corrosion. However, it appeared more practical to include the existing starter wall within the lining limits since this would facilitate the sealing of the forms along the bottom of the arch. The curved invert slab of the sewer was determined to be in good condition and lining was not required.

One of the biggest challenges the contractor faced was to develop a method to seal the bottom of the forms during grouting. After the Districts reviewed a few initial proposals, the contractor proposed to construct a PVC T-lock lined starter wall prior to lining the arch of the sewer. The contractor intended to jack the bottom of their adjustable forms outward, thus “pinching” the bottom of the form against the starter wall to create the required seal. This proposal required a longitudinal field weld of the PVC liner to be placed approximately one foot higher than shown on the plans. Since this weld was still below the low flow level, the Districts accepted the contractor’s proposal to use the starter wall. The PVC T-lock lined starter wall, which was constructed using simple wooden forms, was used successfully for the entire project.

The contract documents required the contractor to utilize adjustable forms in order to deal with potential dimensional variations in the existing sewer. The contract documents required the contractor to utilize adjustable forms in order to accommodate potential dimensional variations in the existing sewer. The forms used for the Phase I project were constructed from liner plates that were supported by sets of ring beams spaced at 4-foot intervals. The radius of curvature of the forms was 10 feet along the sides and 3 feet at the crown. Hinged connections were used to join the top and side ring beams so that the width of the forms to be adjusted. Each set of forms used by the contractor consisted of six of the 4-foot long units and had a total length of 24 feet. The side ring beams were adjusted inward and outward around the hinged pivot point by a set of hydraulic jacks. An additional set of jacks was used to adjust the overall height of the forms. Sets of wheels were included on the bottom of the forms to allow the forms to be moved along the sewer.

After the forms were moved to the location to be lined, the PVC T-lock liner was transported to the forms. The liner was draped over an arched-shaped frame that was transported using the same front-end loader used for the debris removal process. Initially, the forms were set in a lowered position to allow the PVC liner to be moved from the transport frame to the forms. The liner was placed on the forms, properly positioned, and then pulled from the bottom to hold it firmly against the forms. Pull straps were looped through holes in excess material at the bottom of the liner. The excess PVC liner was trimmed after installation. Once the PVC liner was held firmly in place, the sets of jacks were used to adjust the height and width of the forms to the required dimensions to seal the bottom edge against the starter wall and the end of the forms to the section previously lined. Photographs of the forms in the lowered and final positions are shown in Figures 12 and 13 respectively.
After the forms were in the final position, the annular space at the open end was sealed with a bulkhead. The annular space was then filled with a grout having a specified compressive strength of 5000 psi. The contractor’s grout mix, which did not include any aggregate, contained equal amounts of cement and fly ash and had a water/cement ratio of 0.4. The grout mix was designed by Pacific International Grout and included admixtures to improve the flow characteristics and to control shrinkage. Grout was introduced into the annular space through a single port at the crown of the sewer using a 2-inch diameter grout lance. Venting was accomplished with 1-inch diameter PVC pipe installed through the bulkhead. Leaks at the bottom of the forms were experienced during initial grout pours. To correct the problem, the dose of the flow control admixture was decreased in order to increase the viscosity of the grout mix. The contractor typically grouted two sets of the 24-foot long forms at one time using a single lift. The grout was allowed to cure approximately 16 hours before the forms were pulled and moved to the next location.

To minimize the number of transverse field welds, standard widths of the PVC T-lock liner were factory welded to produce liner of sufficient lengths to cover one set of the forms. The T-shaped locking extensions were oriented in the transverse direction, except for the bottom two extensions on the starter wall, which were oriented in the longitudinal direction. The transverse field joints between adjacent lined sections and the transverse joints with the starter wall included a 4-inch overlap and were welded with a 1-inch wide weld strip. Welders certified by Ameron performed all welding of the PVC T-lock liner. Photographs of the lined sewer are shown in Figures 14 and 15.
TESTING AND INSPECTION

After installation, the liner was cleaned and visually inspected. The contractor was required to spark test the liner in the presence of a representative from an independent laboratory. In addition, individual welds were tested by vigorously probing the welds with the corner of a stiff putty knife. Repairs of defective welds and other defects were extended a minimum of 3 inches beyond the defect.

The interior of the sewer was sounded in an effort to detect voids and areas of poor adhesion between the grout and substrate. Core samples were collected from locations suspected of having voids, but no voids were discovered.

A minimum of three grout samples were collected from each batch delivered to the job and tested for bleeding, density, and consistency. In addition, one sample from each batch was collected and tested to demonstrate conformance with the compressive strength specification.

INSTALLATION OF THE SPR SYSTEM

The Districts allowed the contractor to install the SPR system in upstream 1800-foot long reach of the Phase II project. This reach of the 114-inch sewer has less severe corrosion compared to the other portions of the sewer. In addition, the soil loads in the upstream reach were significantly less than other portions of the sewer. Thus, this reach of the sewer had an adequate factor of safety for the loads currently imposed on it. Although calculations performed by the manufacturer indicated the SPR system had the capacity to support all dead and live loads, the Districts only relied on the SPR system as a non-structural protective lining system.

The SPR process uses a rigid PVC ribbed profile strip with integral steel reinforcement band. This PVC profile is spirally wound into the shape of the host sewer using an internal winding machine. The winding machine rotates along a restraining frame, which can be configured into a variety of shapes including semi-elliptical. The PVC profile strip is delivered to the job site on reels with the steel reinforcing strip already attached to the profile. The profile strip, which is approximately 3 inches wide, is fed into the sewer from aboveground as the winding machine advances inside the sewer. The final spiral-wound pipe stays stationary relative to the host pipe as the winding machine advances, as opposed to other spiral wound systems where the winding machine is stationary and the wound pipe advances (see Figures 16 and 17). The profile strip includes interlocking edges on opposite sides that are mechanically joined and locked to the adjacent strip by the winding machine. The interlocking edges include a secondary lock fits and a rubber gasket sealing material, which produces a water tight seal and prevents slippage of the joints. The profile strip is designed with 7/8-inch high “T” shaped ribs that are embedded in structural grout injected into the resulting annular space.

Prior to installation of the SPR system, the contractor was required to pressure wash the existing concrete surfaces. Since the SPR system was not looked upon as a structural liner, there was no need to create composite action between the grout and the existing conduit. Therefore, the contractor was not required to remove all calcium sulfate and achieve a surface pH of 7.
After the winding of the profile was complete, the annular space was filled with the same grout that was used for the Ameron PVC T-lock system. The resulting annular space between the profile strip and the existing conduit was approximately 3 to 4 inches. Prior to grouting, bracing was installed to support the spiral wound liner. Each bracing unit was approximately 6 foot long and consisted of multiple evenly spaced wood beams approximately 5 in. by 5 in. running longitudinally along the bracing system and mounted on an internal form shaped in the same contour of the lined sewer (see Figure 18). The bracing units were equipped with hydraulic jacks that extend to hold the bracing against the liner and support the liner in place during the grouting operation. During the installation of the SPR liner, intermediate bulkheads were placed every 225 feet to limit the length of each grouting run. A total of 30 bracing units (approximately 180 feet) were required for each grout operation. After grouting a 225-foot long section, the bracing units were moved to the next section of sewer and the process was repeated.
STATUS OF THE PHASE II PROJECT AND COMPARISON OF LINING SYSTEMS

The contractor mobilized to job site in April 2005 and began to install traffic control, odor scrubbers and construct an access pit. The contract documents required the contractor to schedule and complete the rehabilitation of the upstream 4000 feet of 114-inch semi-elliptical sewer by October 15, 2005. This portion of the sewer is upstream of the Rocha Street Trunk, which eliminated the need to bypass flow during 2005. Although the contract documents showed two potential access pits that could be used for the upstream work, the contractor elected to use only one access pit. The contractor utilized the Ameron PVC T-lock system downstream of the pit and the SPR system upstream of the pit.

As the October 15, 2005 deadline for flow diversions approached, it was clear that the contractor would not complete all of the lining scheduled for 2005. Based on favorable long-term weather forecasts, the Districts allowed the contractor to continue the flow diversion and work within the sewer until December 2005. As the contractor gained experience with both lining systems, production rates increased and the contractor completed the planned work by the end of 2005. Shortly after completing the upstream lining, the contractor began constructing the temporary wet well to bypass flow from the Rocha Street Trunk. In April 2006 the contractor placed the bypass system in service and began removal of debris from the sewer shortly thereafter. As of May 2006, the contractor had removed all debris from the remaining 3900 feet of 114-inch semi-elliptical sewer and is on schedule to complete the project on schedule.

Although the SPR system has been installed extensively in active combined sewers in Japan, all upstream flow was directed out of JO “A”-2, 3A and 3B during installation on the Phase II project. Currently, there are virtually no other options to line active non-circular sewers. The Districts own and operate other semi-elliptical sewers where it is not possible to divert all flow out of the sewer. One of the factors that motivated the use of the SPR system was to evaluate the installation process in a dry sewer prior to attempting its use in a live sewer.

Since the SPR system did not require extensive surface preparation for the existing concrete surfaces, installation initially advanced faster than the Ameron PVC T-lock system. In addition, due to the integral steel reinforcing, the replacement of rebar and addition of welded wire fabric and associated anchors were not required for the SPR system. For efficiency, the contractor proposed to use the same grout specified for the Ameron PVC T-lock system for the SPR system. The contractor planned to use an on-site batch plant for the structural grout to be used for both lining systems. However, the contractor was not able to produce grout that complied with the specifications using the batch plant, which delayed the start of grouting for the SPR system. The contractor eventually obtained the grout from a local ready-mix company. Due to the grouting delay, the installation of the Ameron PVC T-lock system essentially caught up with the SPR system. If not for the grouting issues, it appears that the contractor would have achieved higher production rates with SPR system.

Another advantage of the SPR system relative to the Ameron PVC T-lock system is that the SPR system provides a full circumferential liner. Ameron PVC T-lock only provides lining of the arch for a semi-elliptical sewer. In addition, the SPR system does not require any welding of the PVC liner, as is required for Ameron PVC T-lock.
The Ameron PVC T-lock system does offer some advantages compared to the SPR system. The Ameron system can be designed to maintain the maximum existing flow area, providing a hydraulic capacity advantage relative to the SPR system. Although the capacity reduction due to the SPR system was only about 10 percent, based on the Districts’ analysis, there may instance where that magnitude of reduction is unacceptable. Also, the Ameron system can be install by most sewer contractors with a reasonable amount of rehabilitation experience. Conversely, a licensed installer must be used for the SPR process. Due to this factor and higher material costs, it appears likely that that the Ameron PVC T-lock system would be less costly if bid directly against the SPR system. The Districts use of the competitive proposal approach to award the contract allowed the District to have the SPR system installed at the essentially the same bid cost as for the Ameron PVC T-lock system.

CONCLUSION
Prior to the District undertaking the rehabilitation of the Joint Outfall “A” Units 2, 3A and 3B Trunk Sewer, there was limited history and experience on the rehabilitation of large non-circular sewers. Despite the uncertainties, risks, and time constraints associated with the work, the first phase of the project was successfully completed on time and within budget.

The Districts were able to apply the lessons learned from the first phase of the project were implemented into the contract documents for the second phase of the project. To avoid potential delays due to operational problems with furnished odor control equipment, the contractor was required to furnish all odor control equipment on the second phase of the project. To avoid potential disputes over debris disposal, the contractor was required to perform additional analytical tests of the debris composition prior to final disposal. The contract documents were revised to include a separate bid item for the disposal of hazardous material in the event the composition of the debris deviated from the first phase, and the quantities of various bid items were adjusted to reflect the actual amounts used during the first phase.

The second phase of the project is more than half complete and to date, the contractor has not encountered major difficulties. The completion of the second phase is anticipated to be on time and within budget as well and to be as successful as the first phase of the project. The success of this project can be attributed to careful planning and staging of the project, by thorough inspection and monitoring of the project, by contractors’ ingenuity and resourcefulness, by allowing the use of the alternative lining system, and by the use of the alternative contracting approach, which fostered a cooperative relationship between the District and the contractors.

REFERENCES