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CONSTRUCTION OF NON-CIRCULAR SEWER REHABILITATION PROJECTS IN LOS ANGELES

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ABSTRACT: The City of Los Angeles operates and maintains more than 6,500 miles of sewers ranging in size from 6-inch to 150-inch in diameter. Many of the larger diameter sewers constructed in the early 1900's were constructed of un-reinforced concrete with clay tile liners or of brick. Approximately 64 miles of sewers were constructed using non-circular pipes. Some of these sewers do not follow public right-of-way and cross under homes, businesses and other urban development. These sewers are approaching the end of their service life and need to be rehabilitated while minimizing the impact to the community. An emergency construction project is repairing 1,000 feet of an 85-year-old semi-elliptical sewer and two rehabilitation projects have recently been awarded for construction that will repair 4.5 miles of non-circular sewers. This construction begins a new era in rehabilitation of medium sized non-circular sewers in Los Angeles.

The rehabilitation of 3 miles of the 60-inch by 73-inch oval brick Central Outfall Sewer (COS), 1.5 miles of the 60-inch semi-elliptical tile-lined concrete North Outfall Sewer (NOS), and 1,000 feet of 66-inch semi-elliptical concrete NOS brick sewer will use man-entry installation of a new pipe, non man-entry sliplining and man-entry cast-in-place-lining construction techniques. Sliplining will utilize recently approved materials that will maintain the non-circular shape of the sewer and minimize the reduction of capacity of the existing sewers. The cast-in-place option will construct a new PVC lined concrete pipe inside the existing sewer. These methods will provide a long-term structural repair of these 80 – 100 year old sewers.

This paper will discuss the methods selected for the rehabilitation of the COS and the NOS as well as the lessons learned during the initial phases of the construction projects. This paper will also discuss future projects that will rehabilitate additional non-circular sewers utilizing both sliplining and man-entry methods.

INTRODUCTION

The City of Los Angeles owns and operates one of the largest wastewater collection and treatment systems in the world. The City operates and maintains over 6,500 miles of sewers and 4 wastewater treatment facilities with a combined treatment capacity of 550 million gallons per day (mgd). Sewer construction in Los Angeles began in the 1870's and had major construction periods in the 1920's and 1950's. Many of these older sewers are approaching the end of their useful service life and will need to be replaced or repaired to continue serving the citizens of Los Angeles. Previously, non-circular sewers required the sewers to be bypassed and repaired by man-entry installation of a new pipe or liner. A pilot project in 2002 experimented with a non man-entry lining of a pipe using a Fiberglass Reinforced Pipe (FRP). The City has recently begun to implement a rehabilitation program for non-circular sewers which includes rehabilitation of sections of the Central Outfall Sewer (COS) and the North Outfall Sewer (NOS).

These rehabilitation projects are utilizing newly approved materials and various construction methods to repair these sewers.

BACKGROUND

In the early years of Los Angeles, like other municipalities, the goal of a sewer was to convey the sewage to the outskirts of the City for disposal. The City eventually extended the sewer system to the ocean by construction of the Central Outfall Sewer (COS) in 1904. The oval shaped COS was constructed using 2 or 3 layers of bricks and conveyed the flow from downtown Los Angeles and discharged the sewage into Santa Monica Bay. This sewer remained in operation for approximately 20 years before the effects of corrosion and capacity limitations required the replacement of this sewer by the North Outfall Sewer (NOS) which was constructed in the mid to late 1920's. The semi-elliptical NOS was constructed of un-reinforced concrete and incorporated clay tile liners above the springline to protect the concrete from the attack of sulfuric acid. As the City continued to grow and required additional sewer capacity, the COS was subsequently repaired in the 1940's and returned to service. Of the 6,500 miles of sewers in the City, approximately 68 miles are non-circular pipes which were primarily constructed in the 1920's and 1930's. Figure 1 shows the major sewers in the City.

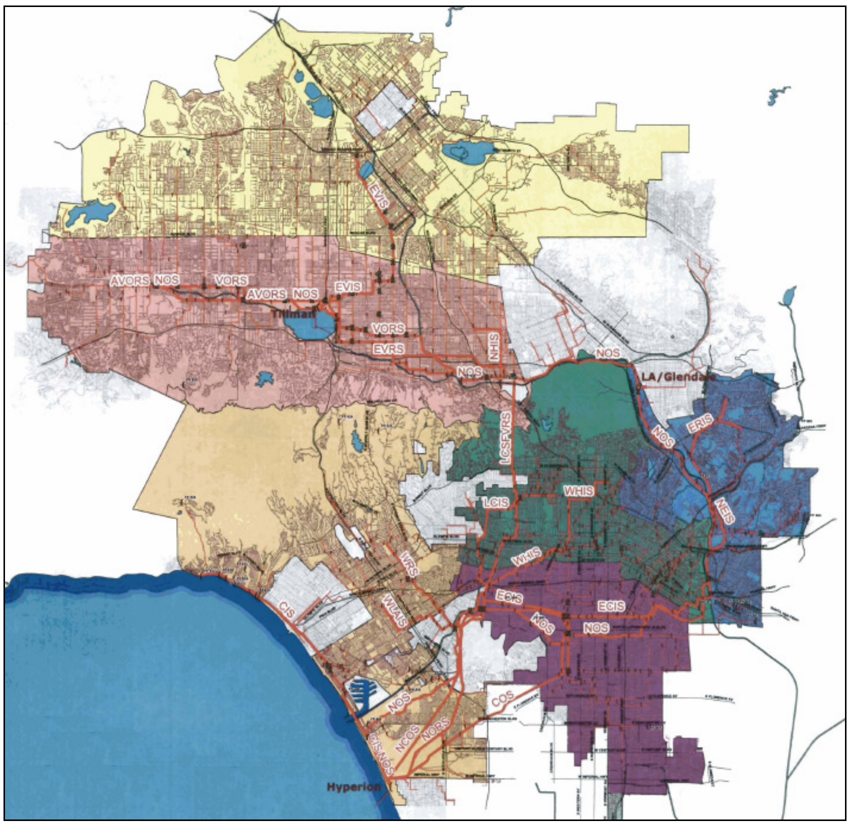

Figure 1. Collection System – City of Los Angeles

As the sewers in Los Angeles continue to age and the pipe conditions deteriorate, the City has moved forward on rehabilitating the collection system and has recently began rehabilitating a number of non-circular sewers using methods and materials that are new to the City.

REHABILITATION METHODS

As part of the design of the recently awarded rehabilitation projects, the City has specified three methods that the contractor can select for construction. These methods are sliplining with a Reinforced Polymer Mortar Pipe (RPMP), cast-in-place PVC liner and a coiled profiled strip liner. In general the City does not specify the actual liner or installation methods to be used by the contractor unless other project considerations dictate one method over another such as limited access or other surface constraints.

Sliplining

Sliplining has been successfully used by the City for numerous rehabilitation projects involving circular pipes. This method allows the sewer to be rehabilitated while remaining in service and does not require a bypass. For circular projects the City has specified a 3-inch annular gap between the new pipe and the existing sewer, typically resulting in a 9-inch reduction in diameter and utilizes a size of pipe that is commercially available. For the non-circular projects the pipes are manufactured using a mandrel that is custom made for the project so specifying a common size or dimension is not necessary. As such a 3-inch gap is being specified on the sides and top, resulting in a slightly modified shape for the final sewer. Figure 2 shows the typical cross sections for the oval and semi-elliptical (SE) pipes.

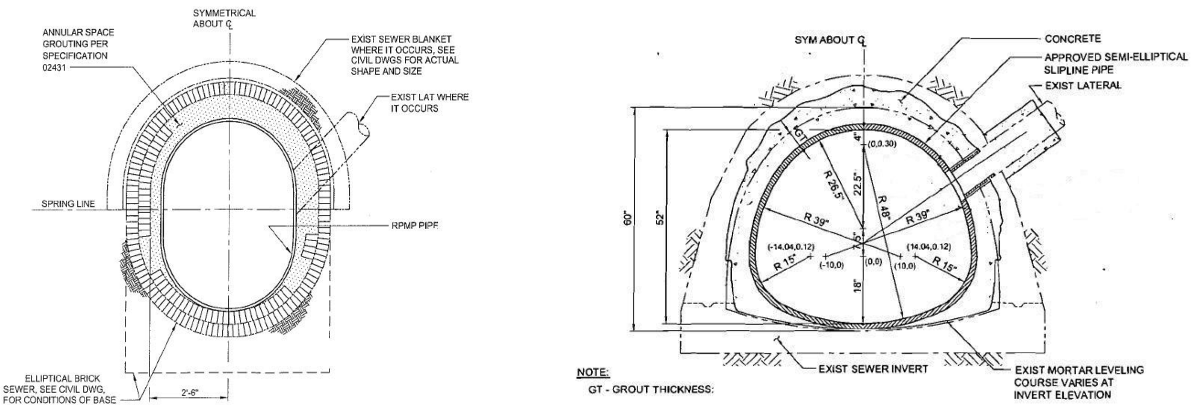

Figure 2. Slipliners for Oval and Semi-Elliptical sewers

The installation method for sliplining may also differ for the non-circular projects. The methods of installing these slipliners can be by non man-entry sliplining or by man-entry and carrying the pipes into the sewer. The man-entry option will typically require the sewer to be bypassed or diverted. Any man-entry installations will require the contractor to comply with tunnel safety orders assuring that a safe work environment is maintained for the contractor and City inspectors. Rehabilitation by non man-entry sliplining of a non-circular pipe into an existing non-circular sewer has been very limited. The City completed a pilot project in 2002 that repaired a section of the Woodvale storm drain by sliplining a semi-elliptical pipe into the storm drain. This project was done in completely dry conditions to see what issues might arise by this type of construction. In 2008 the City installed approximately 40 feet of oval pipe into the COS by non man-entry sliplining. In 2009 the City installed 200 feet of SE pipe into the NOS by man-entry installation as part of an emergency repair project near the Los Angeles River. In the City the majority of the non circular sewers rehabilitated to date have been by man-entry installation.

Cast-in-Place

The City has specified or approved two methods for installing a cast-in-place PVC liner in the existing sewer. One method is to utilize a form and a PVC liner which is combined with high strength concrete to construct a new pipe within the old sewer. The City has typically specified a 4-inch concrete thickness. The PVC lining can be specified to be less than a 360 degree lining. The second method is a coiled profile strip liner. This method winds in a PVC liner using a machine to create the specified cross section. The annular space is then filled with high strength concrete which completes the liner. In this case the PVC is a 360 degree lining. The semi-elliptical cross section has specified reinforcement at the lower corners and additional reinforcement if the contractor installs the concrete using multiple lifts. Both options require man-entry installation and compliance with tunnel safety requirements. Bulk cleaning of the sewer and surface cleaning of the pipe walls is required. Figure 3 shows the typical cross sections of the cast-in-place methods.

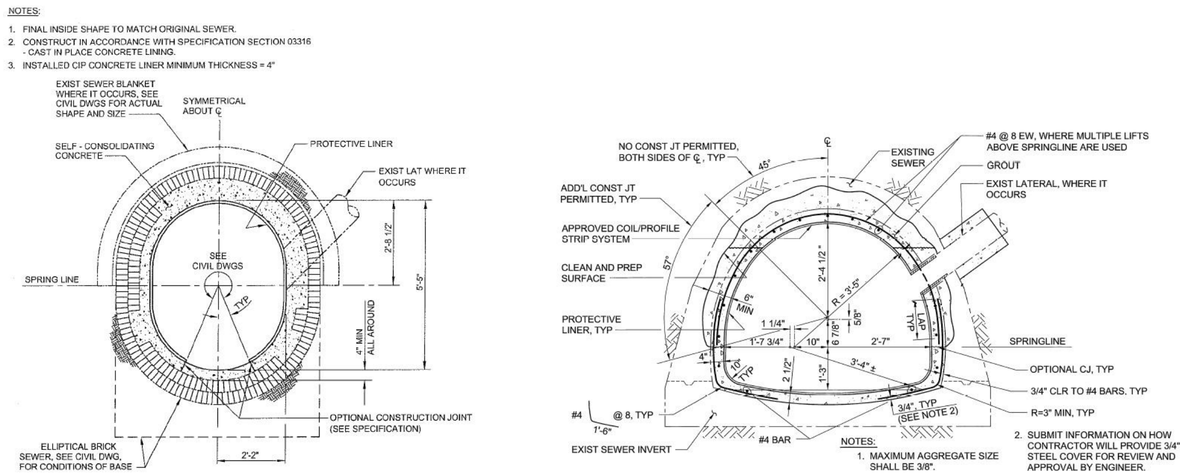

Figure 3. Cast-in-place options for Oval and Semi-Elliptical Sewers

NON-CIRCULAR SLIPLINING PROJECTS

The City has recently begun three rehabilitation projects, one as an emergency sewer repair and two as part of the Capital Improvement Program. The NOS experienced a failure in November 2008 requiring an emergency contract to make repairs to the damaged sewer. In June 2009 the City awarded two contracts, one to repair 1.5 miles of the NOS and one to repair 3 miles of the COS. Each of these projects is utilizing different materials and installation methods than previously utilized.

NOS EMERGENCY REHABILITATION 23rd AT TRINITY

In November 2008 the City was notified by local residents of unusually high sewer odors in and around their homes. Upon further investigation as to the source of these odors, it was discovered that a large void had developed in the crown of the existing 66-inch brick and concrete semi-elliptical NOS. This void had resulted in the collapse of the local 8-inch sewer and was allowing the sewer gases to migrate from the NOS into the local residential properties through the house connections. A contractor was immediately mobilized to stabilize the intersection and to prepare to repair the sewers.

This section of the NOS had been constructed in the mid 1920's and was constructed with an un-reinforced concrete base with a two ring brick arch. Immediately downstream of the void, the sewer joins a 57-inch SE brick and concrete sewer and becomes a 72-inch SE concrete pipe with clay tile liners. In 2005 the 72-inch sewer had been intercepted and the flows diverted to a drop structure which drops the flow 90 feet into a 132-inch pipe. Gases from this drop structure and from the junction of the 57-inch and 66-inch sewers likely added to the corrosion and eventual pipe failure. The immediate construction focused on stabilizing the street and local utilities and preventing a street collapse and subsequent sewer blockage and sewer spill. This work entailed excavation of the curved portions of the 57-inch and 66-inch sewers as well as the existing junction structure. The sewers upstream of the void were inspected by CCTV and found to have several sections with one layer of bricks missing from the crown of the sewer and the scope of this emergency project was increased to address the extent of the problem.

The scope of this emergency project was eventually increased to include repair to sections of the 72-inch, 57-inch and 66-inch semi-elliptical sewers as well as the existing junction structure. A total of 112 feet of 72-inch sewer, 45 feet of 57-inch and 1,044 feet of 66-inch were included in the project to be lined. The straight sections of the sewers were to be lined by non man-entry sliplining using a non-circular reinforced polymer mortar pipe (RPMP). The curved sections of the sewer could be rehabilitated by RPMP or by removing the top of the existing sewer and replacing this with a PVC lined concrete section. Due in part of the lead time in getting the RPMP pipe, the contractor rehabilitated the curved sections with PVC lined concrete while the pipe was being manufactured for the remaining sections of the project. Cast-in-place PVC liners were not included as an option for the 66-inch sewer because flows could not be diverted and the structural condition of the sewer raised concerns over the worker safety of a man-entry liner installation. Cured-in-place (CIPP) liners were not included because of the existing flows and the need for a major bypass and the number of missing bricks. The sections of missing bricks would be required to be filled in prior to lining by CIPP.

The 72-inch was the first section to be rehabilitated. A pit was constructed near the downstream end of the 72-inch sewer that was to be lined and the excavation at the junction structure was used for a second access pit. The contractor cleaned and removed all debris prior to the sliplining operation. The installation of the liner was completed by installing 17 foot segments of pipe in the downstream pit and pulling these segments into the sewer toward the upstream junction structure using a cable. A pulling ring was fabricated that was attached to the cable and distributed the pulling forces evenly over the pipe joint. The short distance for this installation allowed the contractor to use a crane to pull the cable and the pipe into the sewer. Cables attached to the lead pipe were utilized to restrain the pipe while the next segment was pulled forward in order to close the joint. One section of pipe was pulled into place from the pit toward the downstream diversion structure. The final closure piece was then placed into the access pit. Once all segments had been installed, the upstream segment was restrained and the cable was used to pull the final joint together. This installation was completed in one day excluding the grouting of the annular space. Figure 4 shows the pipe and the installation into the existing sewer.

Figure 4. Installation of the 72-inch slipliner

The 66-inch sewer used a slightly different installation procedure. As with the 72-inch sewer, the contractor pulled a cleaning sled through the sewer to remove the bulk debris. Just prior to sliplining this reach, the contractor used a hydroflusher to remove any remaining debris in the invert. A modified pushing rig was used that utilized a crane to pull a cable through pulleys and was attached to a beam and pushing ring which in turn pushed the slipliner into the existing sewer. As this was the first non-circular slipliner installation into a non-circular sewer, a CCTV camera was attached to the lead pipe in order to monitor the progress of the liner and to observe if there was any damage to the existing sewer caused by the installation of the slipliner. The City and the contractor were concerned over loose bricks falling into the annular space and preventing the pipe from advancing or potentially creating a local collapse. The 1,000 feet of slipliner was installed in 3 days with minimal difficulties.

A number of challenges were encountered during this installation. One issue encountered was orienting the pipe and pushing the joint together. The non-circular liner requires the pipe to be precisely oriented with respect to each other in order for the joints to go together. The contractor needed to make sure the pipe was vertical when attached to the lifting device and picked up and lowered into the sewer. This ensured that the joint would go together in the minimal amount of time. After installing approximately 700 feet of liner, the contractor began to have problems in pushing the pipe. During the installation the CCTV camera observed numerous occasions of the slipliner hitting the side of the existing sewer causing bricks to fall into the sewer. Because the CCTV camera was installed in the lead pipe, the contractor was able to observe debris accumulating in front of the lead pipe. A hydroflusher was used to pull this debris out of the sewer and the installation of the pipe was able to proceed. The contractor also reported that there may have been slight variations in the horizontal alignment and invert of the sewer. The slipliner may have also pushed over some of the debris in the invert causing the pipe to rise. There was evidence on the lead pipe that the pipe had scraped the top of the existing sewer during the installation process. The contractor utilized 8 foot pipe lengths for this section which were able to provide enough flexibility to negotiate these changes in alignment. Figure 5 shows the installation of the liner. The pipe was successfully installed.

Figure 5. Installation of the 66-inch slipliner

The City specifications for non-circular slipliners currently require anti-rotation devices for installation on each non-circular shape pipe. The intent of these devices is to prevent rotation along the pipe center of mass. These devices need to be designed as to not add significant weight to the pipe or prevent grout from flowing around the outer surface of the pipe. The device also needs to have a small surface area as to minimize the possibility of impact with unknown obstructions while meeting its intended purpose. These devices were not used on this project and no observable rotation of the slipliner was seen.

The grouting of the annular space between the new slipliner and the existing sewer was completed in multiple lifts using a 300 psi grout. For the 72-inch sewer, the contractor constructed grout bulkheads at both ends of the sliplined reach. Three grout lifts were used to reduce the potential for floating the pipe during the grouting operation. For the 66-inch sewer the contractor provided intermediate grout ports every 250 feet in order to install the grout in the annular space. The flow in the pipe was also restricted to flood the pipe to provide additional weight during the grouting procedure. No floating of the pipe was observed.

NOS MAZE REHABILITATION PHASE 5

The NOS Maze Phase 5 is the final project to rehabilitate a section of the NOS known as the “Maze”. This project has a combination of circular and non-circular pipes to be rehabilitated. The project also includes 517 feet of an existing 42-inch semi-elliptical pipe that will be removed and replaced as it was determined to be too small for sliplining. The majority of the project is to rehabilitate 6,719 feet of 60-inch semi-elliptical concrete sewer. The project will also rehabilitate 120 feet of 75-inch and 840 feet of 63-inch circular pipes. A contract for this project was awarded in June 2009 for $12,481,511. The construction is scheduled to be completed in August 2011.

The contractor has selected to install a semi-elliptical RPMP pipe into the sewer by man-entry installation. The basic process of this rehabilitation will be to construct access pits, clean the sewer and remove the bulk debris, install the liner in the sewer and grout the annular space. The design provided work sites at the beginning and end of the project and at both ends of each curve. The contractor will not use all of the proposed pits. Pipe cleaning will be done by hydroflushing and will utilize existing maintenance holes. The contractor will install 4 foot pipe lengths of the slipliner pipe from the pit into the sewer, including the straight and curved sections. These pipes will be blocked in place as the installation proceeds which will allow the grouting of the annular space without movement of the slipliner pipe.

The alignment of this project contains numerous curves and angle points that will require special installation methods. The project has a total of eight curves that have a 50 foot radius. The design allowed most of these curves to be rehabilitated by either lining the curves by man-entry or to open cut the curve, remove the top of the sewer and then install the new liner inside the existing pipe invert. A curve on the existing 75-inch pipe will likely require the contractor to install the liner by sliplining as existing utilities limit the surface access and bypassing the 90 cfs of flow may not be practical to allow a man-entry installation of the liner. The contractor is proposing to line the curves on the 60-inch semi-elliptical pipe by man-entry and using 4 foot pipe lengths. These pipes are being manufactured with a curvature that has a 4 ½ degree curve per pipe. This will allow the pipe to negotiate the curve and incorporates a joint with a gasket. The project also includes two 15 degree angles that have no surface access at the angle points. Access pits are located near the angle points that may be used by the contractor. Surface access at the angle points was restricted by traffic restrictions and by existing utilities above the sewer. The contractor is again proposing to use shorter pipe lengths and man-entry installation to install the pipes past these angle points. This process will minimize the surface impacts and disruption as seen on previous rehabilitation projects.

The current flow level in the NOS within the limits of this project varies substantially and will affect how the contractor rehabilitates the sewer. The southern portion of the 60-inch sewer is currently conveying flows from local sewers only and has a minimal amount of flow, with the exception of water backing up from the connection of this sewer to the 75-inch pipe. The northern portion of the project has flows that range from 50% to 75% full. The contractor may have the option of diverting flows from the north to the south only during the dry season of April through October. Flows in the 75-inch and 63-inch circular sewers can not be diverted. The man-entry installation will require the flows in the sewer to be reduced to a depth of less than 10 inches.

Ventilation of the sewer pipe to allow workers to safely work inside the pipeline will be necessary. The contractor will be required to comply with confined space entry regulations. Along with the ventilation, odor control will be required to prevent any odors from affecting the local community. The contractor will provide an odor control scrubber(s) that will typically draw air into the sewer from the access pit, through the sewer and the work zone and out through the odor control unit. A chemical injection unit will also be used to inject a 27.5% solution of hydrogen peroxide into the sewer to reduce existing hydrogen sulfide (H_2S) levels. Between the use of hydrogen peroxide and odor control scrubbers, the contractor is required to reduce the existing H_2S concentration in the sewer from 24 parts per million (ppm) to less than 10 parts per billion (ppb) as measured at the surface of the access site.

The rehabilitation portion of this project is expected to begin in March 2010. The contractor is currently mobilizing and completing the open-cut elements of the project. The project is scheduled to be completed in 2011.

COS REHABILITATION NORS DIVERSION 4 TO MARKET

The COS is the oldest outfall in the City that is still in use. After the sewer was rehabilitated in the 1940's minimal repair work has been done on this sewer during the past six decades. The sewer is now experiencing major brick loss and in one location a hole in the pipe has been discovered immediately upstream of this project. A contract to repair three miles of this sewer was awarded in June 2009 for $15,050,237. The construction is scheduled to be completed in 2011.

The construction of the COS in 1904 predated much of the current development in this part of Los Angeles. Because of this, the alignment does not follow the public right-of-way and instead the sewer easement traverses a number of private properties, runs underneath residential and commercial buildings, and over a major interstate highway. Due to variations in fill elevations, the profile is not at a uniform elevation below grade level, and rises above grade along some sections. At one location, the sewer runs 400 feet under an active two story commercial building, and there is an angle point under this building. The alignment presented a challenge in identifying available work sites to be used during the construction phase.

The design of the project identified 10 primary access sites that could be used by the contractor during the construction phase. Some of these work areas are in the parking lot of Los Angeles World Airport, an electrical substation, adjacent to active railroad tracks as well as in residential and commercial neighborhoods. Typically access sites were located every 600 to 1,800 feet apart to allow the contractor adequate access areas depending on the repair method used. The contractor for the project is planning on using only 4 primary work areas which will reduce the community impacts. The contractor will be installing new maintenance holes (MH's) per the design plans and will use these structures as temporary access points to get material into the sewer along the alignment of the project.

The contractor has selected to use a man-entry cast-in-place liner to rehabilitate this sewer. This method will require the sewer to be completely dry during the construction phase. The contractor will be required to bypass local sewers as necessary. Because of the size of the sewer and the equipment to be used, an external bypass of local flows will be required as to not interfere with the lining operations. One of the factors that influenced the contractor to choose man-entry cast-in-place over sliplining was the risk during the sliplining operation to encounter bricks that were protruding and that would prevent the slipliner from being successfully installed and the risk of the pipe being slightly smaller that expected due to variations in the original construction. With the cast-in-place option, the form will have a small amount of flexibility to modify the cross section should the existing cross section be different. The schematic of the proposed form is shown in figure 6.

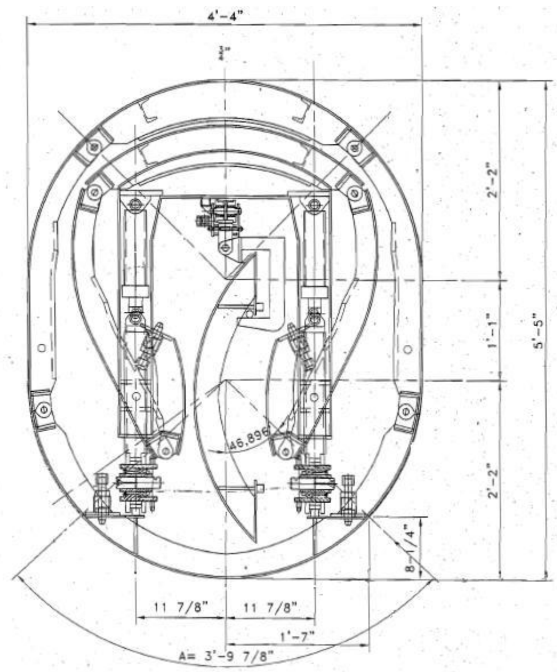

Figure 6. Strip and Travelling Form

The cast-in-place liner will require additional cleaning that is not required for the sliplining option. In addition to removing the bulk debris from the invert of the sewer the contractor will be required to clean the walls of the sewer to remove all debris such as sewage wastes, grease, loose bricks and other solid or semi solid foreign material. This cleaning will involve the use of low water pressure washing equipment using a water pressure ranging from 1,000 to 3,000 psi. Following the cleaning, a neutralizing agent of magnesium hydroxide will be applied to the surface. The City is requiring the contractor to complete a test section to demonstrate the equipment, personnel, procedure, and production rates. Adequate control is required to ensure the stability of the sewer and that it is not adversely affected by the cleaning method, that removal of loose bricks is controlled and that damage to the sewer does not occur. The contractor will also be responsible for providing a moveable overhead protection system to provide a safe work environment to the contractor and City employees, both during the cleaning and the rehabilitation work.

The basic work approach for the rehabilitation will involve providing ventilation and odor control of the sewer for man-entry work, construction of access pits, debris removal and cleaning of the sewer, installation of the form, and installation of the concrete. The contractor will install an odor control scrubber near the downstream end of the project. Air will be drawn into the sewer from an opening at the upstream and downstream terminus of the project. A major access pit will be located 2,200 feet from the upstream end of the project at a major angle point in the alignment. This location will be used to insert the form into the COS. This form will be moved to the upstream end of the project where the lining will begin. A crew will install the form, including the PVC liner and set the form to grade. A crew will then install the 4,000 psi concrete into the 100 foot long form. The following day, a crew will move the form downstream, install the PVC liner over the form and again set the form to grade. This operation will then be repeated. The contractor will have a cleaning crew working ahead of the rehabilitation crew to prepare the sewer for lining.

This project is currently in the initial stages of construction. Ventilation and odor control equipment have been installed and the contractor has constructed the main access pit. Cleaning of the sewer is progressing including bulk debris removal and surface cleaning. The traveling slipform is being manufactured and once delivered to the project site, the installation of the liner will commence.

FUTURE PROJECTS

The City has many miles of non-circular sewers that are between 80 and 100 years old that will need to be rehabilitated in the coming years. Figure 7 shows the non-circular sewers in Los Angeles.

Figure 7. Non-Circular Sewers in Los Angeles

The City is preparing design packages to address these non-circular sewers that will be constructed in the future.

La Cienega Interceptor Sewer

The LCIS project will rehabilitate 2,000 feet of 63-inch SE pipe. This project is currently in the final design phase. The existing sewer does not follow public right-of-way and is under numerous commercial and industrial buildings. Construction access will be limited and will influence the final rehabilitation processes to be used. This project is currently scheduled to go to construction in 2011 however budget constraints may require the construction of this project to be delayed. Rehabilitation of additional sections of the LCIS are in the pre-design stages.

North Outfall Sewer

The North Outfall Sewer, which was constructed in the 1920's, extends from the Hyperion Treatment Plant near Los Angeles World Airport to the San Fernando Valley and is nearly 44 miles in length. This sewer varies in size from 10'6" semi-elliptical to 24-inch circular. With the portions previously repaired about 30 miles of this system remains to be rehabilitated in the future. This sewer is currently scheduled for rehabilitation beginning in 2013. Due to the large estimated construction cost for the rehabilitation of the North Outfall Sewer, the City currently plans to rehabilitate approximately 1 mile per year with an estimated construction cost of 10 million per year. A condition assessment of this sewer is currently being completed which will be used to prioritize sections of the sewer for rehabilitation.

Central Outfall Sewer

The COS will continue to be rehabilitated upstream of the current construction project. The rehabilitation of the next 4 ½ miles is currently being designed and the plans are scheduled to be completed mid 2010. The current cost estimate for this project exceeds 50 million dollars. The construction of this project is currently scheduled to begin in 2014.

CONCLUSION

The rehabilitation projects that are currently being constructed will provide valuable experience as future projects are designed. These projects have and will demonstrate the capabilities of sliplining non-circular pipes into non-circular sewers by both man-entry and non man-entry methods. The man-entry projects will also help identify key issues such as safety that will be addressed in future designs.