**North American Society for Trenchless Technology**
**2007 No-Dig Conference & Exhibition**

**San Diego, California**
**April 15-20, 2007**

# CHALLENGES IN LINING A 100 YR OLD BRICK SEWER

Brad Jenson[1], Keith Hanks[2], Yasmin Hafeez[3], Hassan Masoud[4], Charlene Dennis[5] and Michael Lin[6]

[1, 2, 3, 4] City of Los Angeles, Bureau of Engineering
[5, 6] Parsons Corporation, Pasadena, CA

**ABSTRACT:** The City of Los Angeles is currently constructing nearly $4.5 Billion in sewer system improvements under its 10 year Wastewater Capital Improvements Program. One of the planned projects is the rehabilitation of the Central Outfall Sewer (COS), one of four major land outfalls conveying wastewater to the City's Hyperion Treatment Plant. Since replacement would be very costly and result in significant community disruption and environmental impacts, a decision was made to rehabilitate in place using a trenchless construction method.

Because of its unique architecture (the sewer is a 100 year old brick sewer, oval in shape, 60 inches wide by 73 inches high), there were multiple challenges in evaluating applicable liner methods and designing a liner that could be installed within the existing noncircular sewer. During the planning phase of the project, multiple liner alternatives were evaluated, including: circular slipliners, noncircular slipliners, spiral wound liners, and cured in place liners. Other challenges included:

- How to set up the bid documents to provide an equitable bidding situation for multiple liner methods.
- How to establish design criteria that would maximize benefits to the City at the lowest possible cost.
- Constructability issues such as worker entry and safety issues during construction, bypass requirements, maintaining services during construction, access site requirements, coordinating with multiple agencies, and minimizing community impacts.

Design included a condition assessment, rehabilitation of sections under existing residential and commercial buildings, and evaluating state-of-the-art liner processes for both structural and nonstructural rehabilitation. Value engineering workshops were conducted at two stages in the project development.

This paper focuses on the decision processes in selecting an applicable rehabilitation method, and describes the design challenges and approach ultimately utilized for this unique project.

## 1. INTRODUCTION AND BACKGROUND

With approximately 6,500 miles of sewer lines serving more that 4 million residents, the City of Los Angeles operates one of the largest collection and treatment systems in the world.

With a staff of over 1,000 employees, the Bureau of Engineering in the Department of Public Works accomplishes ongoing planning, design and construction management of its wastewater collection system projects. Emphasis is on state of the art technologies and sustainable development and improvement of the City’s infrastructure for its customers. The City accomplishes much of its planning and design using in-house resources, supplemented by consultant forces as needed.

An extensive record keeping system accessible through the Internet (Navigate LA), used in conjunction with GIS, provides ready access to design engineers of the most current as built documents.

The City is also actively engaged in continual update of its design and construction standards. Standard specifications are based upon the Standard Specifications for Public Works Construction (SSPWC), supplemented by the City of LA’s amendments, often referred to as the ‘Brown Book’.

For sewer liner design projects, such as the Central Outfall Sewer (COS), only liner materials which are either listed in the Brown Book or which are City-approved can be included in the project specifications. The City thereby engages in an active program of product certification, maintains contact with liner manufacturers and keeps abreast of current design practices. Product approval and certification is based upon demonstration of ASTM test results, performed in City-approved testing laboratories. Structural design criteria which determine liner thicknesses are established by the Structural Engineering Division, to ensure consistency among design projects.

Sewer system planning is performed by the City’s Bureau of Sanitation using an in-house hydraulic model which incorporates all the major trunk lines and interceptors. In recent years, the City has been engaged in an integrated planning effort and in November 2006 the City Council approved the Final EIR for the City’s Integrated Resources Plan.

Within this framework, Parsons Corporation was selected in the summer of 2005 to prepare bid documents for the Central Outfall Sewer Rehabilitation, Units 1 and 2 project.

Figure 1 depicts the major trunk sewer system including the COS. [Note that Figure 1 only shows the lower portion of the City’s major outfall system and does not include the San Fernando Valley]. As one of four major land outfalls conveying wastewater to the City’s Hyperion Treatment Plant, the COS is a critical link in the collection network.

While the sewer has served the City well for 100 years, it is reaching the end of its service life and is in need of upgrade and rehabilitation (condition assessments have resulted in a large portion of the sewer being ranked as Condition “D”/Very Poor). In the year 2000, the City rehabilitated the Lower COS which upgraded 2.5 miles of sewer under Los Angeles Airport.

The portion currently scheduled for rehabilitation is the 3 mile section just upstream of LAX (referred to as COS Rehabilitation Project, Units 1 and 2). Rehabilitation of the upper 4.5 mile section (Units 3 and 4) will be accomplished in a future capital project. Total construction value of Units 1 through 4 is over $70 million.

As the original construction of the sewer occurred between 1904 and 1908, the sewer pre-dated much of the current development within the City. Because of this, the alignment for the most part does not follow the existing street right-of-way and instead the sewer easement traverses a number of private properties, runs underneath existing 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 angled section located under the building.


**Figure 1. City of Los Angeles Wastewater Collection System**

Major characteristics of the existing sewer are summarized in Table 1. Eighty-five percent (85%) of the alignment of COS Units 1 & 2 traverses commercial development (i.e. 15% residential). Along Units 3 & 4 there is a higher percentage of residential development. Surface conditions include a wide range of external loading conditions on the existing sewer: open areas with negligible development such as within Los Angeles Airport and community parks; busy traffic roads subject to heavier vehicular loading conditions; closely paralleling active railroad tracks along about a mile of the alignment; and underneath private properties with light commercial or residential land uses as mentioned above.

**Table 1. Central Outfall Sewer Units 1 through 4 – Key Parameters**

| | |
|---|---|
| Size | 60 in wide x 73 in height, oval shaped |
| Length | 38,185 LF |
| Existing capacity (full pipe) | 90 cfs (n = 0.014) |
| Design Capacity (2090 design Q) | 60 cfs (flowing full at n = 0.014) |
| Depth to cover | Above grade to >60 ft to invert (in tunnel) |
| Configuration(s) | 2-ring brick<br>3-ring brick<br>3-ring arch with concrete cap and cradle |
| Rehabilitation cost | > $70 Million |
| Major crossings and features | Highway 405 crossing (concrete sewer bridge)<br>Parallel to railroad tracks for approximately 1 mile<br>Alignment under several existing structures |
| Prior repairs | 1937, 1948, 1999 (various sections) |

With a part of the sewer located in the City of Inglewood, community and interagency coordination has been extensive. Other agencies involved in the project include Los Angeles World Airports, Metropolitan Transit Authority, Burlington Northern Railway, and the Los Angeles Department of Water and Power.

## 2. PREDESIGN, CONDITION ASSESSMENT AND VALUE ENGINEERING

The focus of this paper is on the decision processes involved in evaluating project alternatives and on the design and construction challenges of the project. The remainder of the paper addresses the COS Units 1 & 2 project, as these sections are currently in design. Design of Units 3 and 4 is scheduled to begin in summer 2007.

Initial investigations conducted in the early phases of the design provided the basis for the detailed design effort (see References).

### Pre-Design

The pre-design report was prepared by the City in September of 2004. It characterized project challenges and provided a comprehensive summary of the project features, hydraulic conditions, repair history, and other known information. It also included a ranking of rehabilitation alternatives and a preliminary cost estimate. The alternatives included : folded/deformed and reformed systems, cured-in-place systems, coiled/profiled (spiral wound) strip systems, slipline systems and cast-in-place liners.

### Condition Assessment

Following the preliminary design and as a first task in the detailed design, the existing sewer was televised and a condition assessment report developed based upon the CCTV results. Condition assessment rankings were established using WRc procedures as presented in the Sewerage Rehabilitation Manual 4th Edition (see References).

The ranking methodology involved a two-step process. First an internal condition grade (ICG) was assigned for each reach based on the CCTV results. Both the November 2005 CCTV as well as prior CCTV tapes were included in the assessment. (Internal grade condition descriptions shown in Table 2 are similar to the City of Los Angeles' A through D grading system.) The ICG's were then adjusted for environmental factors such as soil types and depths of cover to provide a structural performance grade (SPG) for each reach.

**Table 2. Internal Condition Grade Descriptions**

| Grade | Implication |
|---|---|
| 5 | Collapsed or collapse imminent |
| 4 | Collapse likely in foreseeable future |
| 3 | Collapse unlikely in near future but further deterioration likely |
| 2 | Minimal collapse likelihood in short term but potential for further deterioration |
| 1 | Acceptable structural condition |

Source : Condition Assessment Report, Central Outfall Sewer Rehabilitation, Units 1&2 project, March 2006.

The condition assessment concluded that the 'upper' reaches of Units 1 & 2 were classified as highly degraded and not suitable for person-entry without extensive safety protections in place. The 'lower' reaches of Units 1 & 2 (i.e. lower one-third of the alignment) were classified in better condition, structural performance grade 3 or better. Classification of the upper reaches as highly degraded was due to observance of missing brickwork, showing heavy degradation along a number of sections of the existing alignment.

**Value Engineering**

Value engineering workshops were held at two stages of the project. The first workshop was a ‘conceptual’ VE (not a traditional value engineering study, but rather a participatory, working level session involving the value planning team, members of the design team and City staff). The first VE workshop was held immediately following completion of the condition assessment; cost analyses were based upon the cost estimate in the pre-design report.

Key issues were identified prior to the workshop in order to focus the evaluations (see Table 3). The Value Planning team focused heavily on Issue 5, Value of Existing Capacity, since it was the factor that appeared to (and ultimately did) have the greatest impact on the total cost and scope of the project. (See Figure 2). The VE team concluded that if a 54-inch circular pipe section could be inserted into the existing brick sewer, it would be the best value on an initial capital investment basis (i.e. a 54-inch circular pipe would be the least costly alternative for meeting the 2090 design flow condition). Upon further evaluations, a 54-inch circular pipe was not considered feasible since it would not allow a sufficient annular space during sliplining. The value team then focused on a 51-inch circular pipe. The “disadvantage” of the 51-inch circular section was that it was much more limited in capacity than a noncircular section and would just meet the 2090 design criteria at a Manning’s “n” value of 0.011. Further, a noncircular cross section was found to provide a lower cost solution on a unit cost ($ per cfs) basis. So if the City would ultimately need the additional capacity which could be provided by a noncircular slipline pipe, it would be less costly to install it with the current construction project.

At the conclusion of the first VE workshop, it was decided by the City and the design team to move forward with preparing the 50% submittal based upon the assumption that a 51-inch circular slipliner would be installed. This allowed continued progression of the design, while still providing flexibility to incorporate noncircular liner methods at a more mature stage of the project. The 50% submittal was subsequently completed three months after the first VE workshop was conducted.

**Table 3. Key Project Issues for Value Planning (Concept VE) Workshop**

| ISSUES | | SIGNIFICANCE |
|---|---|---|
| 1. | Increasing flow in COS through placing Slauson/Van Ness diversion on-line before or during construction. | Risk impacts to City, constructability, cost |
| 2. | Project cost estimates | Cost risk |
| 3. | Identify need for detailed/additional condition assessment work | Cost and schedule impacts vs. benefit of additional information |
| 4. | Evaluate methods to maximize use of available technologies and sewer rehab alternatives | Identify best methods and approach for design to maximize competitive bid options (cost reduction) |
| 5. | Value of maintaining existing capacity in COS | Value of maintaining full or close to full capacity (90 cfs); impacts possible rehab methods |
| 6. | Maintenance holes – rehab vs replacement | Constructability and cost for maintenance holes rehab |
| 7. | Constructability and Right of Way/Easements - Evaluate other constructability issues as they affect rehab methods selection (bypass requirements, access pits and community disruption, right-of-way needs, water and power requirements during construction, ability to negotiate angle points, etc) | Constructability issues |

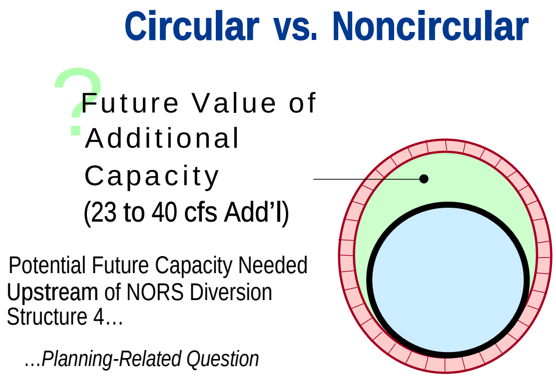


**Figure 2. Value of Additional Sewer Capacity**

A second VE workshop was held after the 50% plans and specifications were submitted and reviewed by the City. The Design Value Engineering workshop utilized a traditional VE format. Liner issues and constructability were the primary project factors focused on by the Design VE team.

## 3. DESIGN ISSUES AND CHALLENGES

At the time of writing of this paper, design is proceeding and the 90% submittal is being prepared based upon the assumption that a 51-inch circular slipliner will be installed. Some project issues have been resolved; others remain to be finalized. The key design issues and current status are presented in Table 4.

**Table 4. Design Issues and Status (COS Units 1 & 2)**

| DESIGN ISSUE | STATUS SUMMARY |
|---|---|
| Design Capacity and N-Value | City standard for Manning's n = 0.014. Variance to design standard to n = 0.011 was evaluated. Factor is critical to design since at n = 0.011, 2090 design Q can be met using 51-inch circular sliplined pipe. Approval of variance is anticipated. |
| Pipe Configuration and Size | Required size (and configuration) will be based upon approved Manning's n-value and hydraulic modeling and capacity analyses. Design assumption to use 51-inch circular slipliner allowing project to proceed while providing flexibility to incorporate future liner methods upon City certification and approval. |
| Circular vs Noncircular | Benefits of each method summarized in Figures 5 and 6. Value of noncircular capacity is primary decision factor. |
| Hydraulic Analysis | City's in-house hydraulic model (MOUSE program) being used to evaluate capacity needs for current condition as well as ultimate 2090 flowrates. |
| Sewer Liner Alternatives and Materials | One circular product currently applicable and approved (Hobas slipline pipe). Noncircular methods under review for City approval prior to bid. Advantages and disadvantages of various noncircular methods are summarized in Table 5. |
| Structural Investigations | Alignment review was performed. Two large commercial buildings identified for special attention and structural evaluation. One structure spanning 400 feet of the existing sewer was found to be constructed on concrete piles. Proposed rehabilitation methods determined acceptable |

| | |
|---|---|
| | for use in rehabilitation of sewer. |
| Access Pit Locations | Pit locations are critical for determining multiple aspects of the design including utility relocation requirements, community coordination, traffic control. Twelve (12) access pit locations selected for 90% drawings. |
| Flows in the Sewer During Construction and Bypasses | Slauson/Van Ness diversion structure capable of diverting entire flow out of COS during construction. Anticipated that diversion structure will be operated in this mode for construction duration. |
| Seismic Approach | Fault crossing located near upstream end of alignment. Design approach will involve : (1) use of shorter pipe sections along 100 feet of upper end of alignment; (2) enlargement of maintenance structure near projected fault crossing and (3) use of low strength cellular grout in vicinity of crossing. |
| Bid Approach – Multiple Liner Methods | Alternative bid strategies being evaluated. |
| Worker Safety and OSHA | Worker safety is primary driver in design. OSHA safety requirements to be met. |
| Sewer Cleaning | Demonstration project to use ‘Sewer Hog’ cleaning method scheduled to be performed on another City project. Cleaning specifications may include method as option for the COS. |
| Additional Condition Assessments | Laser profiling method(s) being performed as ‘product demo’ for usage along entire COS alignment. |
| Agency Coordination and Community Impacts | Extensive coordination is ongoing as part of project design and development. |

The issue having the greatest impact on the final configuration and project is the hydraulic analysis and liner type. Factors related to the issue of circular vs noncircular are summarized in Figure 3.

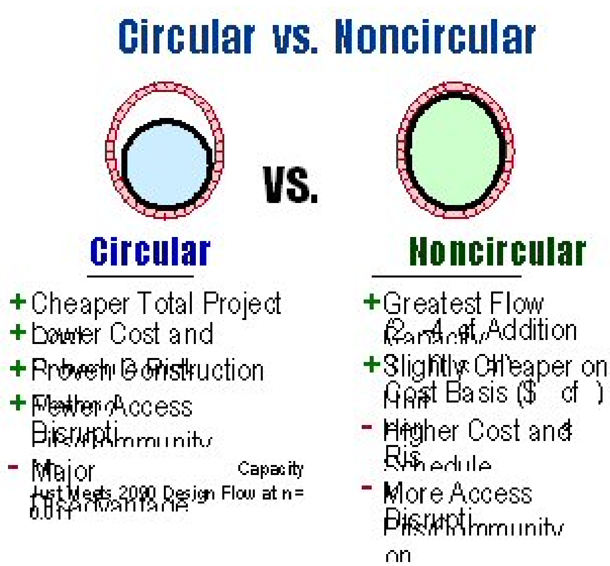


**Figure 3. Comparison of Liner Methods**

While a 51-inch circular slipliner is the ‘baseline’ design configuration, other liner methods and materials continue to be evaluated. For the noncircular products, advantages and disadvantages of the most applicable methods are summarized in Table 5. While two of the methods (cured-in-place-pipe (CIPP) and Meyer Polycrete) are Brown Book approved, both of these materials are limited in applicability for fairly significant portions of the alignment. Ameron Bondstrand RPMP and Sekisui SPR will be City approved in the near future. The approval of the Channeline slipline product is further in the future.

Cured-in-place-pipe is not only Brown Book approved but also has an established history of extensive use, recently on large diameter applications. The limitations in applicability of CIPP for major portions of the COS alignment are related to : (1) bypasses will be difficult to implement for sections of the alignment traversing multiple private properties, (2) large access site requirements may not be possible in some of the residential neighborhoods, (3) structural liner design criteria will increase thickness of the liner along sections which require a ‘structural’ rehabilitation.

Critical to assessing and deciding upon a liner method is the determination of the VALUE of the potential additional capacity provided by a noncircular liner. Should the City need the additional capacity at a future date, it would require construction of a new sewer at a much higher cost. (Total future project cost for a new parallel sewer is estimated to well exceed $45 Million in current year dollars, which is much greater than the ‘cost difference’ of putting in a noncircular liner with the current COS rehabilitation projects).

Determination of future capacity needs is a highly complex issue related to system operations and other integrated planning factors. A risk assessment was considered for facilitating the evaluation of the pros and cons of the circular vs noncircular liner issue, but the cost and time investment of performing such an assessment was deemed not to be worth the potential benefits given many of the key decision parameters such as system hydraulics, operational issues and community disruption are not readily quantifiable.

**Table 5. Advantages and Disadvantages of Proprietary Systems (Noncircular)**

| Proprietary Rehabilitation System | Advantages | Disadvantages |
|---|---|---|
| CIPP<br>(CIPP structural liner or CIPP Type II) | 1. Brown Book approved – vinyl ester resin only<br>2. Little loss of hydraulic capacity<br>3. Minimal excavation required<br>4. Limited man-entry work<br>5. Type II lining may give low cost solution<br>6. Established and very extensively used<br>7. Forms to any regular profile<br>8. Leaktight | 1. Tight controls on quality of site work required<br>2. Type I structural design not possible<br>3. Vinyl ester resin (as required to meet City’s Brown Book requirements) is expensive<br>4. Bypass required |
| Sekisui SPR<br>(coiled/profiled strip system) | 1. Little loss of hydraulic capacity<br>2. Minimal excavation required<br>3. May be Type II design<br>4. Forms to any regular profile | 1. Tight controls on quality of site work required<br>2. Relatively new product<br>3. Type I structural – feasibility still under evaluation |
| Ameron Bondstrand RPMP<br>(slipline system) | 1. Good product quality control<br>2. Limited man-entry working<br>3. Design as new sewer<br>4. Custom made profiles available<br>5. Pipe joints | 1. Significant loss of hydraulic capacity<br>2. Limited installation history |
| Meyer Polycrete<br>(slipline system) | 1. Brown Book approved<br>2. Good product quality control<br>3. Limited man-entry working<br>4. Design as new sewer<br>5. Pipe joints | 1. Significant loss of hydraulic capacity<br>2. Not used extensively for rehabilitation<br>3. Only circular or egg shapes available<br>4. May not be practical or |

| | | |
|---|---|---|
| | | economical due to thick wall of siplined pipe and more extensive jacking equipment for construction. |
| Channeline<br>(slipline & cast-in-place liners) | 1. Forms to any regular profile<br>2. Moderate loss of hydraulic capacity<br>3. Minimal excavation required (cast-in-place only)<br>4. Could be low cost solution<br>5. Established and extensively used (cast-in-place only)<br>6. Can be designed as a Type I or Type II system | 1. Very limited experience with non-circular slipline option<br>2. Larger number of launch pits required (slipline only)<br>3. Extensive man-entry working with associated risks (cast-in-place only)<br>4. Tight controls on quality of site work required<br>5. Extensive jointing increases leak risk (cast-in-place only) |

In addition to liner material and sewer capacity, there are a number of other issues on the project related to constructability which will need to be addressed. Cleaning of deposited debris, fallen bricks and sludge from the existing sewer will be the initial challenge during construction. The City and design team are evaluating new cleaning methods for potential inclusion in project specifications. Odor control measures will require the contractor to utilize scrubbers and provide peroxide for liquid phase odor control. Access pit locations have been analyzed in detail for siting in areas which will minimize disruption of traffic flow, noise, and community impacts. Worker safety is a project priority and there will be proactive OSHA coordination throughout the project. Agency coordination and community impacts also remain a key focus in evolution of the project, and a 3D model (Figure 4) was developed for presentation to the public.


**Figure 4. 3D-Model for Central Outfall Sewer Alignment**

## 4. REFERENCES

Condition Assessment Report, Central Outfall Sewer Rehabilitation Units 1 and 2 Project, prepared by WRc for Parsons Water & Infrastructure and the City of Los Angeles, March, 2006.

Design Value Engineering Workshop, Final Report, prepared by Parsons Corporation for the City of Los Angeles, November 2006.

Final Value Planning Study Report for the Central Outfall Sewer Rehabilitation project, prepared by RSR Solutions, Inc for Parsons Corporation and the City of Los Angeles, April 2006.

Geotechnical Investigation Report, COS Rehabilitation from NORS to Market Street, WO SZC11387, GED File #05-156, prepared by City of Los Angeles, Department of Public Works, Bureau of Engineering, Geotechnical Engineering Division, May 2006.

Pre-Design Report, COS Rehabilitation from NORS Diversion 4 to Rodeo Road, SZC11387, WCED File : RHRP-71-3-2, prepared by City of Los Angeles, Department of Public Works, Bureau of Engineering, Wastewater Conveyance Engineering Division, September 2004.

Sewerage Rehabilitation Manual 4th Edition, WRc plc, 2001.