Trenchless Technology Considerations for Sewer Relocation & Construction

Greater reliance on the use of trenchless technologies and different application of their current uses provide solutions to the re-engineering of urban sewer systems.

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The use of trenchless technologies in the installation of new, or in the rehabilitation of existing, sewer or infrastructure piping systems is becoming more common today throughout the United States and the world. Trenchless technologies consist of the use of underground construction methods that involve little or no surface excavation to complete the work. In many instances, different sizes and types of construction equipment can be used since excavation is eliminated or minimized. Furthermore, considerable cost savings can be realized due to faster production, the avoidance of utility conflicts, eliminating the need for groundwater dewatering and trench shoring, and the avoidance of surface disruptions such as traffic detours, and excessive noise and dust conditions. Trenchless technologies for new sewer construction include:

- Microtunneling;
- Horizontal directional drilling;
- Pipe bursting; and,
- Pipe jacking.

For sewer rehabilitation, trenchless technologies include such systems as cured-in-place pipelining, sliplining, fold and formed, and spiral wound methods. These types of technologies can be used in conjunction with underground utility trenchless location methods.

The relocation of utilities in an urban area can be a difficult and expensive undertaking. When embarking on such a project a number of factors must be considered:

- Traffic diversions;
- Adverse impacts to businesses;
- Construction noise and vibration;
- Groundwater drawdown; and,

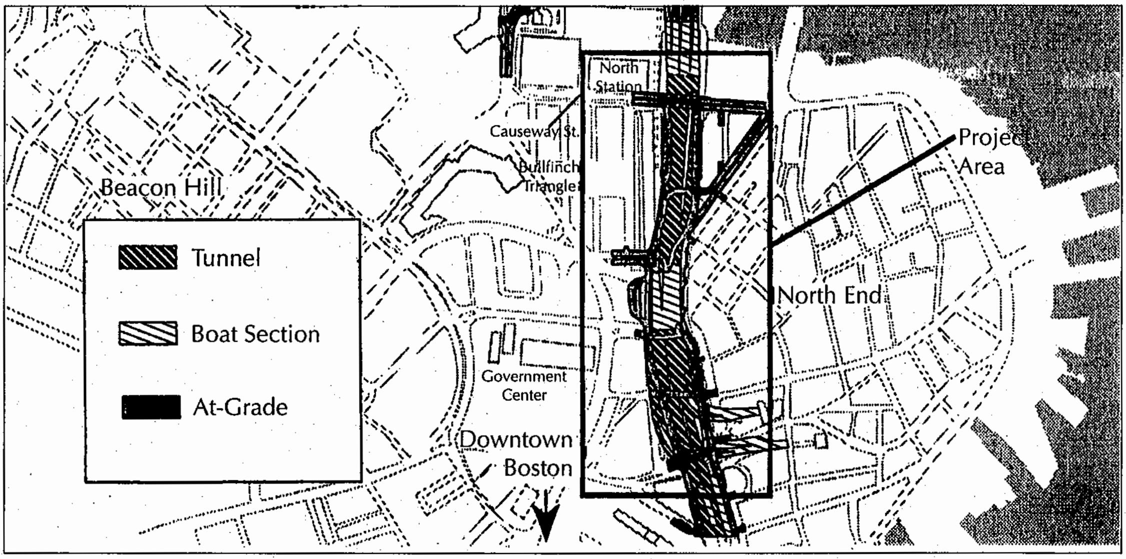

FIGURE 1. Location of the utility relocation area within the CA/T Project.

- Providing an adequate corridor for the construction of the new utilities.

On the Central Artery/Tunnel (CA/T) Project in Boston, these considerations were a significant part of the process to relocate the existing utilities and to provide a corridor for the construction of the mainline tunnel to accommodate the new eight- to ten-lane wide expressway. Utility companies that have to move their conduits and pipes to accommodate the construction process are taking this opportunity to upgrade Boston's infrastructure.

This utility relocation effort is one of the CA/T Project's 60 design contracts and is located in the North End of Boston (see Figure 1). The relocation project encompasses the present overhead Central Artery from the Sumner/Callahan tunnels to the Charles River and is approximately 180 by 1,070 meters (600 by 3,500 feet) in area. This area is one of the more congested and sensitive areas in the city and contains buildings over 150 years old. North End traffic is especially congested on Fridays and Saturdays when the area is used for a fruit and vegetable market. The relocation also crosses the historic Boston Freedom Trail (where over one million visitors walk throughout the year), the Massachusetts Bay Transportation Authority Bus Terminal at Haymarket Square, vehicular surface entrances and exits to the Sumner and Callahan Tunnels, and is adjacent to the new Fleet Center/Boston Garden at North Station. Any construction undertaken in this area of the city must address significant hurdles in satisfying the concerns of each of these entities as well as the daily business and commuter traffic.

Proposed utility realignments posed a significant undertaking within the scope of the CA/T Project. A relocation scheme was developed to minimize disruptions to existing facilities and to provide a clear path (unencumbered by the need for utility relocation) for the construction of the depressed Central Artery and its slurry wall system. Added to these concerns was the need to maintain both pedestrian and vehicular traffic flow while relocating a wide range of utilities with different owners — which required extensive coordination among their varied interests.

This part of the CA/T Project consisted of relocating three utility corridors transverse to the proposed depressed Central Artery as well as other utility corridors parallel to the proposed depression. The utilities to be relocated consisted of:

- 1,040 meters (3,400 feet) of 900- to 1,700-millimeter (36- to 66-inch) combined sewer;

- 3,000 meters (9,800 feet) of 300- to 760-millimeter (12- to 30-inch) water main;
- 800 meters (2,600 feet) of 200- to 500-millimeter (8- to 20-inch) gas lines;
- 1,100 meters (3,600 feet) of electrical conduit; and,
- 975 meters (3,200 feet) of communications conduit (telephone, cable TV, traffic and fire).

There were also two crossings at the mouth of the Sumner/Callahan tunnels:

- A 1,700-millimeter (66-inch) diameter combined sewer; and,
- A separate utility corridor for three 400-millimeter (16-inch) water mains.

It was imperative that the relocation of utilities in this area be accomplished in a timely manner in order to maintain the schedule for the entire CA/T Project. These utility relocations were complicated by technical constraints, agency and private interests along the route, and coordination needs. All of these concerns needed to be addressed in a manner that not only provided an acceptable design and construction sequencing plan, but one that went beyond the concept of "acceptable" and recognized the sensitive nature of the project.

Project Considerations & Constraints

Early in the design of the utility relocations, the design consultant for the relocation recognized that trenchless construction techniques might be employed to mitigate adverse effects on businesses, pedestrians and vehicular traffic. Since the construction work extended to 8-meter (25-foot) depths, relocation required extensive dewatering during excavations and full street reconstruction after completing the work. An added complexity was the need for all existing utilities to remain active during the installation of the earth support systems and the construction of the new utilities. Using conventional sheet pile support systems could not sufficiently address the problems posed by the maze of existing utilities found in Boston. To address these problems, an H-pile and timber lagging support system was proposed for the construction of all utilities. Seepage control in the granular and miscellaneous fills of the deeper excavations was handled by dewatering, provided it did not impact the adjacent structures.

Many of the new utilities were built at a depth of 6 to 8 meters (20 to 25 feet). A major advantage of installing the new utilities at this depth was that they would be below the existing utility corridor. These conditions presented an opportunity to adopt trenchless techniques to install deeper sewer utilities. This approach would reduce the adverse effects, and the time needed, to install extensive excavation supports and seepage control systems along the adjacent businesses in the North End. The total cost of trenchless construction depended on the quantity and size of the pipes installed using the method, with its cost effectiveness increasing with the size of the project. Therefore, it was decided to use trenchless techniques in as many locations as possible.

In 1991, the design consultant responsible for the relocation compared the cost of trenchless construction versus open cut methods. It was determined that the costs for trenchless construction ranged from equal to twice the costs for open cut construction. Since the CA/T Project's Management Consultant was concerned with the overall project cost and schedule, and since only a limited amount of the deep sewer construction could use this approach, it was determined not to incorporate trenchless design approaches in the contract documents. Also, from experience gained in constructing other utility relocations for the CA/T Project, it was common to uncover unknown existing utilities. Therefore, it was believed that additional costs would be incurred if these unknown utilities were encountered during microtunneling operations. The project was under a nine-month design schedule for the utility relocation, and the design consultant was directed to proceed with design using conventional open trench construction and to provide staging, traffic management plans and construction sequencing that would minimize adverse effects on North End businesses and residents.

Several project criteria changes occurred during the design process that affected the use of open trench construction. The most significant criteria change was the implementation of guidelines for construction impact mitigation. The initial principal objective of these guidelines was to limit building settlement, vibration and groundwater drawdown. For vibration, buildings were assigned a structural category from I through IV that was based on an evaluation of the type of structure. Limiting values of vibration were then established based on the assessment of each structure's ability to withstand the loads and displacements due to construction vibration. Unfortunately, the majority of the North End's older masonry buildings fell into the most restrictive category (IV). In some cases, this rating limited the vibration peak particle velocity to 3 millimeters/second (0.12 inches/second). The contract specifications included a strong mandate to monitor construction vibration and building conditions closely and to stop work when architectural damage to historic structures occurred or when damage to non-historical buildings started to occur.

Structure settlement criteria were based on the tolerable amount of angular distortion that each particular building or structure could withstand. Slight damage to historic buildings was avoided based on the building's age, condition, construction and foundation type. Since many of these buildings were set on granite rubble foundations, excavation support wall deflection criteria and allowable differential settlements were set to be very restrictive.

Last, preventing detrimental effects on adjacent facilities was the basis for setting limits for groundwater drawdown. The design accounted for site-specific subsurface conditions, anticipated construction procedures and detailed information regarding structures within the zone of influence of construction. In many cases, the groundwater drawdown limits were restricted to no more than 0.6 meter (2 feet) of lowering outside the excavation support system.

These three construction mitigation criteria significantly affected the design and construction of the excavation support systems for the deep sewers. Larger soldier piles with closer spacing and additional horizontal supports were necessary to meet these criteria. In addition, seepage control would need to be addressed by using more costly cement grouting or jet grouting to create a seepage barrier behind the timber lagging. Thus, the excavation support system costs increased nearly 100 percent.

Another consideration related to any open excavation work pertained to complying with Occupational Health and Safety Administration (OSHA) regulations. The contractor would need to comply with OSHA regulations for trench support, access and egress, exposure to vehicular traffic, exposure to falling loads, emergency rescue equipment, stability of adjacent structures, fall protection and competent person provisions. Each of these issues could become a significant undertaking with work associated with the utility installations in the congested urban setting of downtown Boston.

Design documents were completed and put out to bid using conventional open cut construction techniques. As the construction progressed, underground utility conflicts were occurring in virtually every excavation undertaken by the contractor. After evaluation of the above issues, the contractor proposed to use trenchless technologies and was supported by the project team.

Construction Considerations

The relocation of utilities for the new Central Artery tunnel in the North End was bid in four separate construction contracts. Two early contracts were awarded to move the utilities that were in conflict with the mainline construction work or that needed to be relocated in advance of construction. On other utility relocation contracts under construction, the project was incurring significant claims from contractors due to existing utility conflicts and unknown utility locations that were prevalent in the downtown Boston area. To mitigate the potential for claims, the project team required the contractor to perform a *subsurface utility engineering* investigation to find the exact location of utilities prior to construction.

Subsurface utility engineering is a new technology that offers designers and engineers a methodology to determine the exact location of underground utility lines prior to design or construction. It provides substantial insight into the utility unknowns prior to construction since it combines geotechnical prospecting technologies, vacuum excavation, conven-

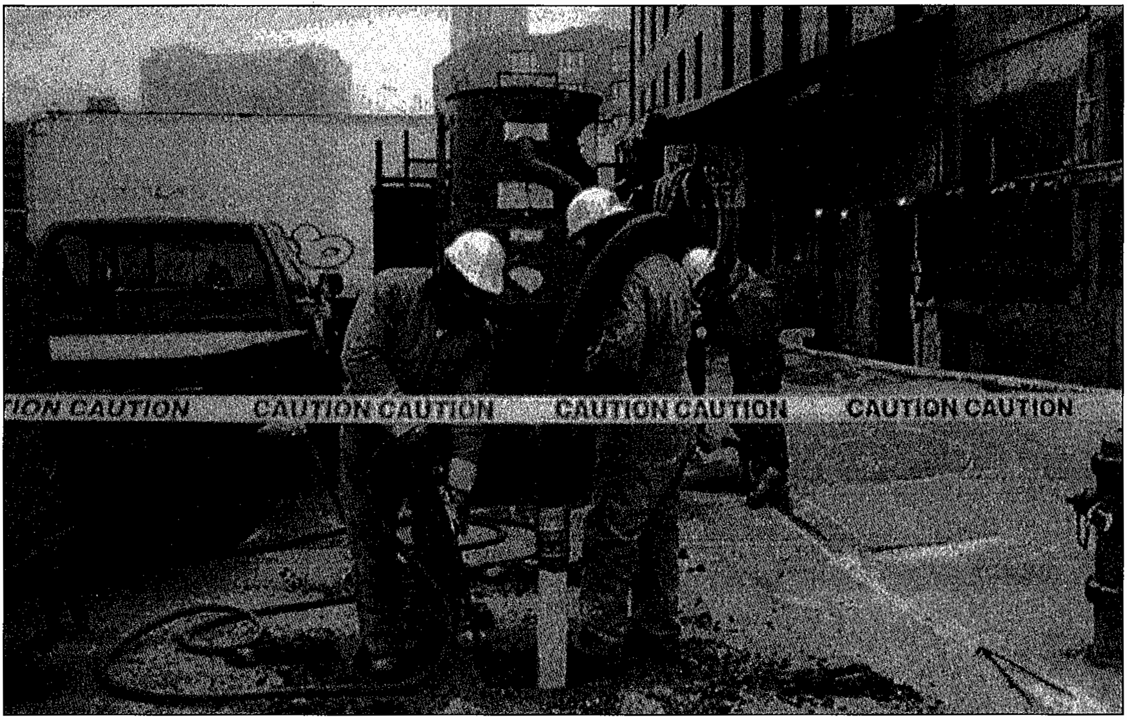

FIGURE 2. Non-destructive air-vacuum excavation with compressed air knives and vacuum excavators is used to locate the horizontal and vertical depth of existing utilities.

tional surveying techniques and digital mapping into one service. It is broken down into three individual tasks described as:

- Designation;
- Location; and,
- Data management.

This approach minimizes the risk of damage to utilities and provides a work program that makes available horizontal and vertical data in the form of electronic files to design and construction personnel and alerts them to the specific locations of buried facilities.

Designation. The designation process involves obtaining the approximate horizontal location of subsurface utilities using various utility detection methods such as electromagnetic, radio frequency, magnetic and/or direct induction.

Location. Locating the utility lines involves the use of non-destructive air-vacuum excavation at key locations identified during the designation process (see Figure 2). The use of compressed air knives and vacuum excavators ensures the integrity of the utility line during the excavation process. The exploration holes are round in shape and approximately 0.3 meter (1 foot) in diameter, thus eliminating the need for shoring since the holes are not meant for human entry. When uncovered, the line is measured and located (horizontally and vertically) using conventional survey methods. This technique verifies the horizontal and vertical location of the utility line.

Data Management. Data management involves the processing of horizontal and vertical utility location information from the designating and locating operations. The information obtained is stored in a digital file. The typical vehicle for digital storage of information is a computer-aided drafting and design (CADD) file, which facilitates the use of the information during design and, in the case of this project, during construction.

The combination of excavation support system requirements, considerations for construction impact mitigation and information gathered as part of the subsurface utility engineering phase offered the contractor the

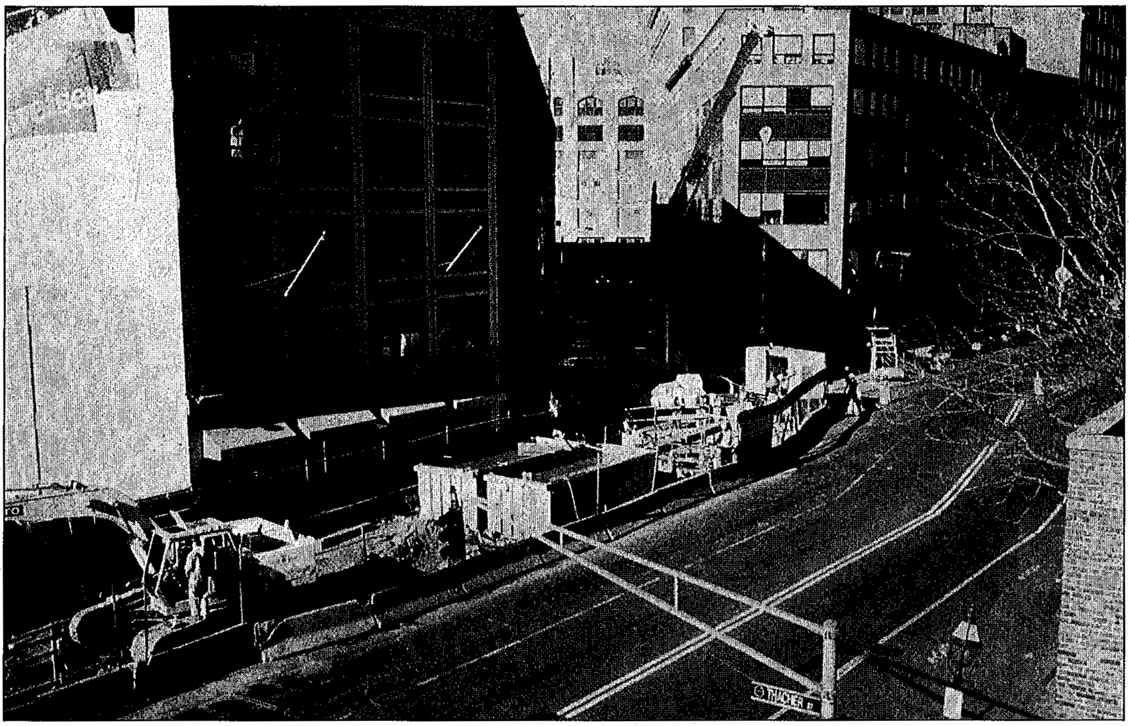

FIGURE 3. A view of the microtunneling staging area jacking pit.

opportunity to use microtunneling techniques to install a 1,200-millimeter (48-inch) diameter combined sewer in Medford Street, which is a two-lane road 8 meters (26 feet) wide with a face-to-face distance between buildings of 12 meters (38 feet). The existing utilities in Medford Street include a 600 x 900 millimeter (24 x 36 inch) combined sewer, three water mains, a 200-millimeter (8-inch) diameter gas main, and underground conduits for electric and telephone service. The proposed utility work required installing a 1,200-millimeter (48-inch) diameter combined sewer, three new 400-millimeter (16-inch) diameter water mains, a 200-millimeter (8-inch) diameter gas main, and conduits for traffic signals.

Due to the narrow width of the street, the original design called for the construction of the 1,200-millimeter (48-inch) diameter combined sewer in the same location as the existing combined sewer. This required complete bypassing of flows for the existing sewer and all service connections. By using subsurface utility engineering, several small location holes were excavated to determine the exact outside location of the existing combined sewer. The contractor proposed relocating two water mains over the existing combined sewer and microtunneling the new 1,200-millimeter (48-inch) sewer at a distance of 0.3 meter (1 foot) from the existing combined sewer. The existing shaft to construct the junction chamber was used as a jacking pit and then modified to accommodate the 360 metric ton (400 ton) design jacking forces (see Figure 3). Three-meter (10-foot) lengths of fiberglass-reinforced plastic pipe were used for the jacking pipe. The pipe was designed with a 50-millimeter (2-inch) wall thickness to withstand the jacking forces for the 110-meter (350-foot) installation length.

A tunnel boring machine was used to microtunnel through the soils that generally consisted of 3.1 to 4.6 meters (10 to 15 feet) of fill underlain by 4.6 to 10.7 meters (15 to 35 feet) of organic deposits (see Figure 4). The tunneling system can cope with a wide range of soil conditions from soft clay through silts, gravels and rock — with or without groundwater — using the same cutting head. The shield has a cone-shaped crusher that produces a very high torque and an eccentric rotation of the cone. The rotation crushes excavated material (including

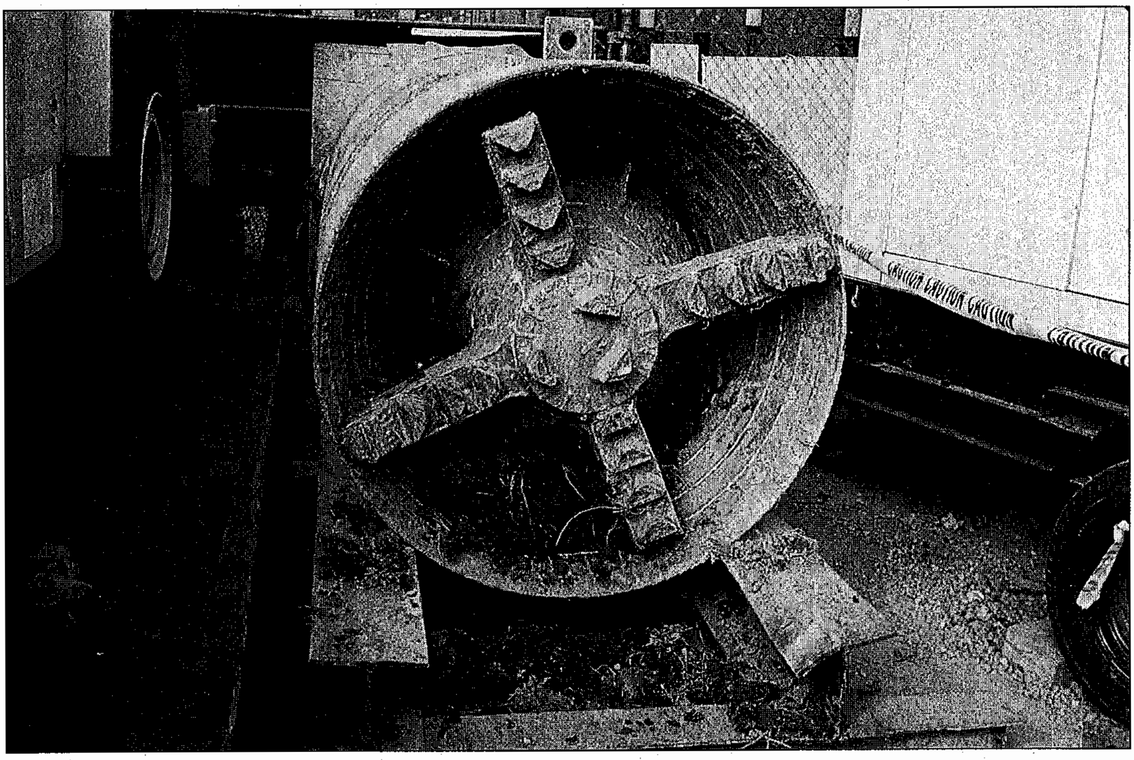

FIGURE 4. The tunnel boring machine used to install the 1.2-meter (48-inch) combined sewer.

cobbles/boulders up to 30 percent of the machine's diameter) between the cone and outer body of the shield.

As the shield is pushed forward, the soil is compacted into the face of the machine where the cone crushes the soil and forces it through the throat of the shield and into a slurry chamber. Bentonite slurry is used to pump the excavated material to the surface into holding tanks that separate the bentonite excavated material for reuse. Fifty-millimeter (2-inch) diameter grout ports were installed in each pipe to pump a bentonite slurry to lubricate the exterior of the pipe during the jacking operation. Slurry pressure was measured at the face of the tunnel boring machine and was adjusted to balance for the soil and groundwater pressures. Line and grade were monitored by laser, with alignment and deviation displayed on the control panel screen in the operations station.

Settlement points were installed on the roadway surface at 15-meter (50-foot) intervals along the centerline of the pipe alignment and at 3 meters (10 feet) to each side. Any deviation in excess of 12 millimeters (0.5 inches) would require adjustment in the slurry pressure to control surface movements and to minimize impacts to adjacent utilities. The tunneling operation for the 110-meter (350-foot) long sewer took 14 days to complete.

This relocation effort has demonstrated that installing utilities in an urban area using trenchless techniques is both feasible and cost effective. When these techniques are used in combination with subsurface utility engineering, conflicts with existing utilities can be minimized. The greatest concerns regarding existing underground utility locations could then be addressed with a high degree of success.

Microtunneling is currently being considered on the next utility relocation contract to install a 1,700-millimeter (66-inch) diameter combined sewer and three 400-millimeter (16-inch) diameter water mains under the Sumner/Callahan tunnels. Also, trenchless techniques are being considered to install a 1,700-millimeter (66-inch) diameter combined sewer and a 760-millimeter (30-inch) diameter water main across North Washington Street. The use of trenchless techniques at these locations will reduce traffic detours, eliminate lane closures, reduce time of construction and reduce the need for costly excavation support systems. Other locations will be considered once the subsurface utility engineering is completed during the design phase.

Summary

The design and construction of utilities on the CA/T Project has shifted from using conventional open excavation techniques to using trenchless technologies. Through the use of subsurface utility engineering methods, the locations of existing utilities can be accurately determined both horizontally and vertically with minimal impacts to the surface. Such an accurate means of locating existing utilities permits constructing sewers and other new utilities to within 0.3 meter (1 foot) of existing systems.

The use of trenchless techniques in an urban environment offers the following advantages:

- Using subsurface utility engineering techniques during the design phase (to locate underground existing utilities) eliminates the need for expensive excavators and back-hoes in test pit excavations, thereby minimizing damage to existing utility components.
- With reliable existing utility information, new utilities can be designed using trenchless techniques with a closer separation from existing utilities (if needed).
- It can reduce the effects of traffic, vibration and groundwater drawdown at a construction cost competitive to open excavation construction.
- The method decreases the amount of soil settlement and adverse effects to adjacent buildings.
- It can speed up the negotiating and permitting process with agencies, municipalities and utility companies.
- Trenchless techniques can eliminate safety hazards and minimize service disruptions due to utility lines being unexpectedly severed.
- In many cases, there is little need to perform temporary utility relocations due to conflicts with open trenches or relocation due to the age of existing utilities.

Project constraints limiting building settlement, vibration, groundwater drawdown and excavation support criteria became significant undertakings with the work associated with the utility installations on the CA/T Project. The project team has looked to trenchless technologies to solve many problems in constructing utilities in an urban setting. New technologies for the location of existing utilities will allow engineers and contractors to construct new utilities at closer separations and reduce the risk of any disruption of service. The experience gained on the CA/T Project has provided the engineering confidence required to advance the use of trenchless techniques on other urban projects in the future.

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