Sustainable Development through Innovative Underground Infrastructure Construction Practices

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Abstract

Underground infrastructure systems require repair or rehabilitation due to deterioration or third-party damage; while new installations are performed as a result of increase population growth and/or development. In particular, water and sewer networks are the lifeline for society's stability. Unfortunately, a large percentage of worldwide population lack access to clean water and sanitation. Today, engineers are being tasked with the requirement of selecting suitable construction methods that not only offer the most economical solution, but also minimizes impact to the environment. Trenchless construction methods offer such sustainable solutions for installing new utilities and rehabilitating existing infrastructure using "green" principles. The environmental benefits of trenchless technologies for urban environments are discussed in this paper through a case study comparision between trenchless pipe replacement (or pipe bursting) and traditional open cut excavation. An emissions calculator program quantifies the impact of emitted emissions such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), hydrocarbons (HC), sulphur oxide (SO_X), and particulate matter (TM) into the atmosphere. The presented case study found trenchless pipe replacement to emit an average of 80% fewer emissions compared to the open cut alternative. These results demonstrate the merits of adopting trenchless technologies for sustainable development of underground infrastructure systems.

Keywords: trenchless technology, underground, utilities, infrastructure, construction

1. Introduction

Today, utility companies and governments are faced with the tremendous task of rehabilitating and expanding their underground infrastructure (i.e. power, telecommunications, oil, natural gas, water mains and sewer). In particular, access to clean water and sanitation are critical for societal stability. The overarching goal is to explore more feasible methods to reduce costs and provide environmental benefits. Traditionally, the installation, inspection, repair, and replacement of underground utilities involves open trenching construction methods. These operations are often expensive, particularly in congested urban areas. Contractors must cautiously dig while maneuvering around other utilities to achieve the required depth, which in turn slows down the operation. Additional costs are typically incurred by the need to restore the existing surfaces (i.e. sidewalks, pavement, vegetation) and repairs resulting from ground settlement. Aside from the associated high agency costs, open cut trenching operations often result in high user, or "social", costs due to the disruption to traffic and adverse impact on nearby businesses (McKim 1997, Boyce et al. 1994, and Thompson et al. 1994).

The solution is to adopt sustainable development practices for address these needs. Innovative construction methods and materials provide inherent benefits. Today, the use of trenchless technologies are increasing at a fast pace as engineers and governments look to implement state-of-the-art techniques for underground utility construction. Trenchless Technologies are defined as a family of methods, materials, and equipment that can be used for the installation of new, or the rehabilitation of existing, underground conduits with minimum or no excavation requirements.

2. Sustainable Development

There has been a paradigm shift from traditional construction goals of cost, quality, and time. Historically, the aim has been to minimize cost, maximize quality, and minimize schedule (time). Today, with an increasing focus on sustainability, project goals have changed to satisfy social/cultural, economical, and environmental sustainability. This paradigm shift (Figure 1) has been realized through the adoption of innovative construction techniques that generally provide cheaper, more environmentally-friendly, and socially acceptable solutions to underground infrastructure construction projects.

Six overlying issues are imperative in maintaining sustainable development as illustrated in Figure 2 (Koo et al. 2009). These include: 1) increasing demand; 2) development challenges; 3) environmental concerns; 4) social equity and culture; 5) economic benefits; and 6) natural resources. Each of these issues must be addressed to meet mandates that are currently being adopted by numerous organizations and municipalities as they move to creating more sustainable and environmentally-friendly solutions for their projects.

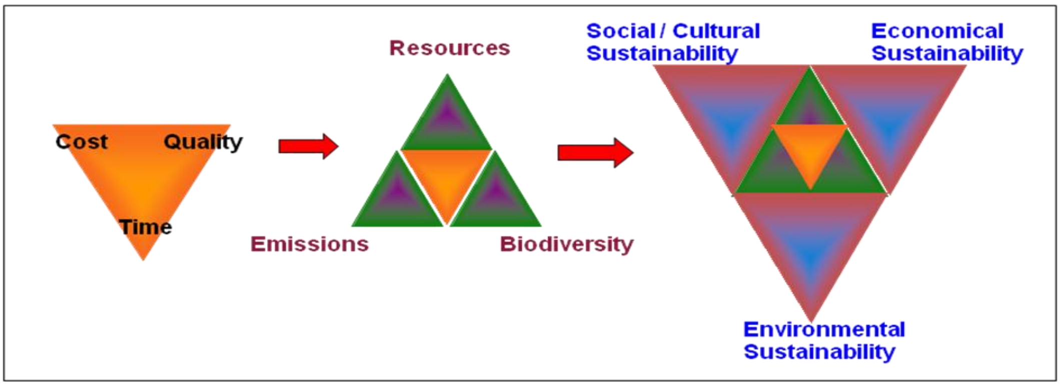


Figure 1. Paradigm Shift from Traditional to Sustainability

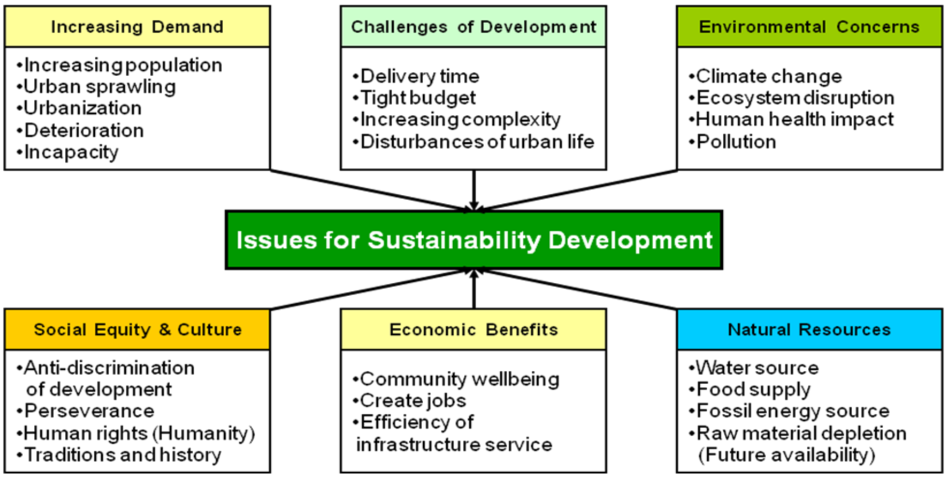


Figure 2. Factors to Consider in Sustainable Development

Faced with the urgent need to rehabilitate or replace aging utility systems on one hand, and dwindling revenues, increased environmental regulations and increased emphasis on user costs on the other, utility companies and municipalities are beginning to seek alternative sustainable methods for repairing and replacing their underground assets. The answer may be provided in the form of trenchless technologies.

2.1 US EPA Regulations

The Environmental Protection Agency (EPA) is an agency of the United States government that is charged with the responsibility of protecting human health and safeguarding the environment including air, water, and land. The EPA sets the national standards for environment protection using environmental assessment, research, and education. The agency also works with government and industry to develop pollution prevention programs and energy conservation efforts. The EPA is the pioneer in setting standards, documenting research, and educating the general public on the impacts of their activities on the environment. The agency also assumes the duty to rectify current damage to the environment and to establish new criteria to guide the public towards a “greener” (and more sustainable) world. Pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), hydrocarbons (HC), sulphur oxide (SO_X), and particulate matter (TM) were identified by the EPA as being emitted from equipment engines. Information on various pollutants and their impacts, approved methodologies, and other research outputs are readily available at the EPA website (www.epa.gov).

The EPA has compiled a database on the operation characteristics of various construction equipment. Additionally, they have also categorized engines based on their power. The emissions data are available for different categories of engines performing different activities. With the different emission control standards that are being enforced by the EPA, there is a reduction of sulfur and nitrogen emissions. To determine emissions from the equipment and vehicles, emission factors are calculated based on the test data available with the EPA. This approach helps to estimate pollution using equations that are applicable for a particular operation. An emission calculator tool was developed based on these emission factors. The user-friendly calculator determines the pollution based on the equipment characteristics and activity characteristics of the equipment.

2.2 Emissions Calculator Tool

An emissions calculator called “e-Calc” was developed in MS Excel using Visual Basic coding. E-Calc utilizes EPA approved methodology and test data to estimate emissions from a given underground utility project (Sihabuddin and Ariaratnam 2009). The data required for estimating emissions can easily be obtained from daily project progress reports and equipment data available from the contractor. The accuracy of the output depends on the accuracy of the input data. The user needs to input the equipment and transport data that are readily available for the project to calculate emissions. The calculator is intended as a tool for contractors and owners to estimate the impact of their construction method on the environment for a specified project. The data required to estimate the emissions from equipment include equipment characteristics such as power, model year, engine technology, useful hours and cumulative hours, fuel characteristics, activity characteristics (i.e. representative equipment cycle), power used and hours of use. The data required to calculate emissions from transport include transport characteristics such as model year, gross vehicle weight and mileage on the vehicle, fuel characteristics, and activity characteristics (i.e. altitude of operation, number of trips, one way distance and return distance). The utilization of the tool to calculate emissions on a trenchless pipe replacement (or pipe bursting) construction project compared to traditional open cut excavation is detailed through a case study in this paper.

3. Trenchless Technology

3.1 Background

Trenchless technology includes a family of methods utilized for installing and rehabilitating underground utility systems with minimal surface disruption and destruction resulting from excavation. Technological advances during the 1990's have changed the face of conventional utility installations. The "trenchless evolution" has made it possible to repair and install underground utilities in areas that were once deemed near impossible such as rivers and under major highways.

Until the early 1980's, these miles and miles of pipes were laid by the laborious excavation of trenches. However, the need for alternatives to the open-cut methods for installing underground utilities and other types of lines was apparent to design and construction companies, which often faced conditions where conventional trenching was undesirable and costly. A second impetus for developing trenchless technology was the recognition that although conventional open trenching methods, while effective, can be costly and disruptive in areas where significant infrastructure already exists, such as buildings and roads. To address these needs, equipment manufacturers, contractors, engineers, and consultants began developing new methods for installing, repairing, and replacing underground pipe, leading to commercialization of new repair/replacement techniques and materials.

The general public is shielded from most of the underground construction completed by trenchless technologies and that is possibly its greatest advantage. Additionally, the costs involved in traditional open cut excavation, especially surface restoration in congested urban centers, have proved good incentives for finding alternative methods of underground construction and installation. Figure 3 illustrates the use of horizontal directional drilling (HDD) in an urban center for the installation of a new utility line. This method provides a solution with minimal impact to surface activities.

Figure 3. Horizontal directional drilling in an urban environment

3.2 History of Trenchless Methods

The extensive use of trenchless construction for the installation, repair, or replacement of underground utility infrastructure is a relatively recent development. However, the use of trenchless techniques dates back to the 1860's, when Northern Pacific Railroad Company pioneered the use of pipe jacking techniques. By the 1930's, reinforced concrete pipe ranging in size from 1070mm to 1830mm in diameter had been installed using this technique. Thereafter, other methods of trenchless construction began being utilized including auger boring (1940), impact moling (1962), directional drilling (1971), microtunneling (1973), and pipe bursting (1981) (Ariaratnam et al. 1998). Table 1 presents a historical timeline of the development of various trenchless technologies. Photos of several technologies are shown in Figure 4.

Table 1. Trenchless Technology Development Timeline

Technology	Year Introduced	Country Invented
Pipe Jacking	1860	United States
Auger Boring	1940	United States
Impact Mole	1962	Germany
Horizontal Directional Drilling	1971	United States
Cured in Place Pipe (CIPP)	1971	United Kingdom
Microtunneling	1973	Japan
Pipe Bursting	1981	United Kingdom
Pipe Ramming	1980's	United States
Guided Moles	1990's	Germany
Pilot Tube Microtunneling	1995	Germany
Axis Vacuum Guided Boring System	2008	Australia/United States

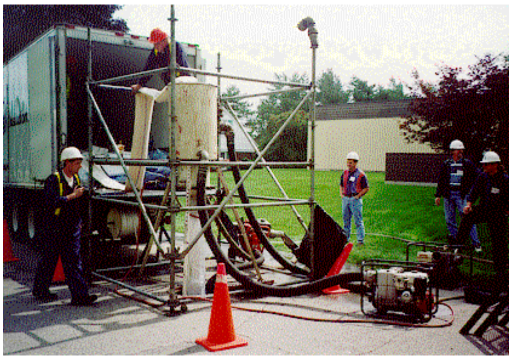


Figure 4. CIPP lining (left) and Microtunneling (right)

4. Environmental Benefits

4.1 Case Study Demonstration

In order to demonstrate the environmental benefits of trenchless technologies, it is necessary to have similar project specifications in order to compare two underground utility construction methods. To compare emissions generated from two different utility construction methods, a case study on a project with trenchless pipe replacement (or pipe bursting) and traditional open cut options is demonstrated. A contractor that employs both methods provided a breakdown of task durations and equipment details. It should be noted that the actual project was completed using pipe bursting methodology. Equipment and activity data were collected onsite by monitoring the construction operation.

The project consisted of upsizing a 200mm clay wastewater line to a 250mm high density polyethylene (HDPE) line in the Town of Los Lunas, 26 miles north of Albuquerque, New Mexico. The installation depth was 2.1m and length was 106m spanning between two manholes. It should be noted that there were two marked 100mm service laterals along the alignment.

4.2 Option 1: Trenchless Pipe Replacement

Trenchless pipe replacement (or pipe bursting) involves excavation of an entry pit for pulling the new pipe and service pits for re-connecting the service lateral. Service pits at the lateral locations provide access for re-connection to the main after the installation. The existing pipe was burst using a pneumatic method of pipe bursting illustrated in Figure 5. Additional information on the pipe bursting process can be found in Bennett et al. (2011).

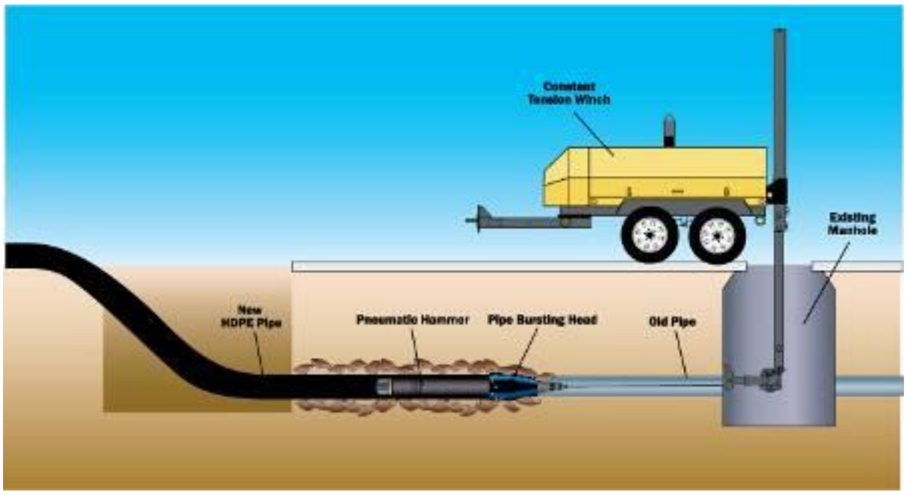


Figure 5. Pneumatic Pipe Bursting Operation

The crew started working on the entry pits and service pits one day prior to the actual pipe replacement operation. Initially, the existing wastewater line was inspected using Closed-Circuit Television (CCTV) and the lateral connections were identified and marked on the site. The lateral crossings required two service pit locations. The entry pit for pulling in the new 250mm

HDPE pipe was excavated near one of the manholes. Twelve meter sections of HDPE pipe were fused using a butt fusion technology on site. Traffic flow was restricted to one lane along the length of the alignment. Excavated materials from the entry and service pits were used during the backfilling operation.

4.2.1 Site Activities

The entry pit and service pits were excavated using a Volvo BL70 backhoe. The size of the entry pit was 3m x 2m and had box shoring to prevent caving in. The excavated service pits were each 1.5m x 1.5m. A winch was placed at Manhole 1 (MH 1) and the new pipe was installed from Manhole 2 (MH 2). The winch was positioned above MH 1 and the winch cable was pushed towards the entry pit. The bursting head was connected the winch cable as soon as it reached the entry pit location. The other end of the bursting head was connected to the new 250mm HDPE pipe using a swivel. The swivel helps to prevent any torque transferring from the bursting head to the pipe during installation. The existing 200mm clay pipe was burst by the bursting head while the new product pipe was simultaneously pulled through the expanded borehole created by the bursting head. At the end of the pull, the head was disconnected from the pipe. Then the head was adjusted to move inside the existing pipe to exit at the entry pit. Minimal backfill and road restoration activities were required at the excavation locations. The backfill was done in 300mm layers and a hand-held compactor was used to compact the soil in the service pits. At the entry pit, a soil compactor with a drum size of 900mm was used for compaction.

4.2.2 Field Data Calculations

The construction operation at the site of the pipe bursting for upsizing the existing 200mm clay pipe to 250mm HDPE pipe was studied. The actual equipment operating times and usage were recorded for calculating emissions. Project details were inputs into the emissions calculator tool to determine the estimated emissions.

4.3 Option 2: Traditional Open Cut Construction

Open cut construction is the traditional method of installing underground utilities. In the open cut method of installation, the entire alignment of the new pipe must be excavated to facilitate pipe placement and a large site area, in comparison to the pipe bursting method, is required for movement of equipment. The contractor’s estimator was consulted to provide project productivity estimates if the project had been completed using open cut methods. Since the contractor performs both open cut and pipe bursting projects in New Mexico, the details on activity durations were readily available from their database. Details of the non-road and on-road equipment required for the open cut construction were obtained from the contractor’s equipment inventory.

4.3.1 Site Activities

The site activity commences with excavation a 1.2m trench wide of the entire stretch of the alignment. Since the excavation is 2.1m deep, shoring is required to be placed along the entire trench alignment. For the purpose of dust control, a water tank of 15,000 litre capacity was required to spray water at the site. The excavated material was used to backfill the trench. Similar equipment to those used in the pipe bursting option were used for compaction and paving. As with pipe bursting, 12m sections of HDPE pipe were fused using a butt fusion technology on site.

4.3.2 Field Data and Calculations

The construction operation at the site for replacing the existing 200mm clay pipe with a 250mm HDPE pipe using tradition open cut was studied. The actual equipment operating times and usage were recorded for calculating emissions. Project details were inputs into the emissions calculator tool to determine the estimated emissions.

4.4 Comparison of Emissions

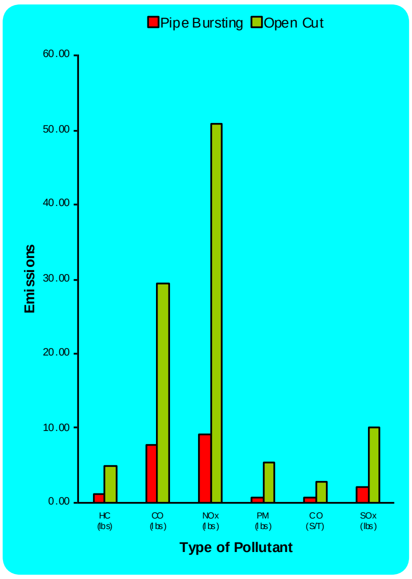
The total emissions calculated from the two utility methods are compared in Figure 6. The results reveal the emissions from the open cut option to be approximately 80% greater than those generated from the pipe bursting operation. The total project time including mobilization and demobilization was three working for the pipe bursting option, while the estimated duration for completing the project specifications using open cut was seven working days. In addition to time, cost, and social benefits, trenchless methods such as pipe bursting provide a better environmental benefit as evident by the major reduction in airborne emission compared to open cut. It is anticipated that future project requirements will include a component of emission assessment in addition to cost during the design and method selection.

COMPARISON CHART

Pipe Bursting VS Open Cut

Emissions		
Total	Pollutant	% Red (-) or Inc. (+)
1.21 lbs	HC	-75.0%
7.64 lbs	CO	-74.1%
9.19 lbs	NOx	-82.0%
0.81 lbs	PM	-85.0%
0.61 S/T*	CO	-78.1%
2.04 lbs	SOx	-79.9%

Equipment		Transport	
Hydroguide Winch	1.0 hrs	Transport Truck	32.0 mi
Air Compressor	0.8 hrs	Transport Truck	32.0 mi
Backhoe	6.5 hrs	Haul Truck	32.0 mi
Hand Compactor	1.0 hrs		
Soil Compactor	0.8 hrs		
Paver	0.3 hrs		
Asphalt Compactor	0.3 hrs		



Emissions		
% Red (-) or Inc. (+)	Pollutant	Total
0.0%	HC	4.84 lbs
0.0%	CO	29.48 lbs
0.0%	NOx	50.92 lbs
0.0%	PM	5.39 lbs
0.0%	CO	2.78 S/T*
0.0%	SOx	10.15 lbs

Transport		Equipment	
40.0 mi	Water Truck	26.5 hrs	Excavator
32.0 mi	Transport Truck	20.0 hrs	Water Pump
32.0 mi	Transport Truck	6.0 hrs	Loader
32.0 mi	Transport Truck	6.0 hrs	Soil Compactor
		1.5 hrs	Paver
		1.0 hrs	Asphalt Compactor

Average Emission Reduction (Pipe Bursting) = 80%

* 1 S/T = 2000 lbs

Figure 6. Comparison of emissions for pipe bursting and open cut construction

5. Conclusions and Recommendations

It is imperative that we address an ever-expanding underground infrastructure to meet the comforts demanded by today's population, while maintaining environmental sustainability. With access to clean water and sanitation lacking my many of the world's population, it is more and more important that utilities be addressed. Trenchless technologies facilitate the completion of complex underground infrastructure projects in congested areas in a safe, economical, and sustainable manner with minimal disruption to surface traffic, businesses, or environmentally sensitive areas. These families of technologies have application in the rehabilitation of existing lines and installation of new systems. Comparison of two methods of installing a wastewater line demonstrated the environmental benefits of trenchless technologies. Trenchless pipe replacement (or pipe bursting) was compared to a traditional open cut option to gauge the merits of adopting trenchless techniques. Using eCalc, an emissions calculator, an 80% savings in airborne emissions was realized for the pipe bursting option. It is anticipated that the utilization of trenchless technologies will continue to expand with the demand for employing sustainable development practices.

References

Bennett, R.D., S.T. Ariaratnam, and K. Wallin (2011), *Pipe bursting good practices 2nd Edition*, North American Society for Trenchless Technology, Liverpool, New York, ISBN 978-1-928984-04-7.

Ariaratnam, S.T., J.S. Lueke, and E.N. Allouche (1998), Trends in the use of trenchless technologies in municipal applications: the Canadian perspective", *Proceedings of the CSCE 26th Annual Conference*, Halifax, Nova Scotia, June 10-13, Vol. I, pp. 167-175.

Boyce, G.M., and E.M. Bried (1994). Estimating the social cost savings of trenchless techniques. *No-Dig Engineering*. 1(2), pp. 2-5.

Koo, D.H., S.T. Ariaratnam, and E. Kavazanjian (2009). Development of a sustainability assessment model for underground infrastructure projects. *Canadian Journal of Civil Engineering*, 36(5), pp. 765-776.

McKim, R.A. (1997). Bidding strategies for conventional and trenchless technologies considering social costs. *Canadian Journal of Civil Engineering*, 24(5), pp. 819-827.

Sihabuddin, S. and S.T. Ariaratnam (2009). "Methodology for estimating emissions in underground utility construction operations", *Journal of Engineering Design and Technology*, Emerald Group Publishing Ltd., 7(1), pp. 37-64.

Thompson, J., T. Sangster, and B. New (1994). The potential for the reduction of social costs using trenchless technology. *Proceedings of the 11th International No-Dig'94 Conference*, Copenhagen, pp. A2.1-A2.20.

Tighe, S., T. Lee, R. McKim, and R. Haas (1999). “Traffic delay cost savings associated with trenchless technology.” *J. of Infrastructure Systems*, ASCE, 5(2), pp. 45-51.