NO-DIG TECHNIQUES AND CHALLENGES

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ABSTRACT

Trenchless technologies have undergone rapid development in the past 40 years and provide cost effective, low disturbance solutions for many problems in underground utility installation and renewal. The main technologies that have been developed are briefly summarized under three groupings of: (1) New installation techniques; (2) Inspection, location, condition assessment and asset management techniques; and (3) Renewal – including repair, rehabilitation and replacement technologies. The remaining challenges in each area are introduced and some of the key current research efforts to address these challenges are referenced. Following this, cross cutting research issues such as the need for more comprehensive design approaches, and better quality assurance procedures are addressed. While perhaps the rate of introduction of substantially new methods in trenchless technology has slowed over recent years, there remain many challenges and hence many potential areas of advancement in the technologies and their applications.

Key words: Trenchless technology, pipeline, utility, installation, rehabilitation, inspection, assessment, no-dig techniques.

1. INTRODUCTION

In the last 40 years, a radical change has occurred in the techniques available to utility engineers to install, maintain, repair and renew underground utility systems. A feature of many of these technologies is that they can be accomplished with little disturbance at the ground surface compared to traditional open-cut methods. Despite the wide range of types of application from inspection systems to directional drilling systems to pipe lining and grouting systems, they are grouped under the term “no dig” or “trenchless” technologies.

In this paper, a brief review of the major groups of trenchless technologies will be given together with the major challenges remaining in their application and some of the current technologies that have been or are being developed to meet those challenges.

2. NEW INSTALLATION TECHNIQUES

Methods are only briefly introduced in this section. For more details, the following general references can be consulted: Najafi (2005), Stein (2005) and Stein and Stein (2010).

Open cut installation is the traditional means of installation, repair and replacement of underground utilities and often is the comparison point for whether trenchless technologies should be considered for a particular application. Open cut construction is familiar to almost all contractors and is readily adaptable to conditions that are uncovered during construction – meaning that site investigation is less critical than for trenchless installation methods. Direct costs for open cut construction increase rapidly with depth and when excavating below the water level. Also, indirect and/or social costs due to traffic delay, business losses and pavement damage can often exceed the direct cost of construction. As existing utilities become more congested in an area and traffic conditions become more critical, open cut construction becomes less attractive.

Important challenges within open cut construction are to minimize the time of occupance of a roadway to minimize disruption, to minimize damage to the surrounding utilities, and to properly restore the road surface after construction. Various means of encouragement for good performance have been tried including lane rental charges in the construction contract (Downey 2009) and withholding of a final payment for up to a year after construction to allow inspection of proper road surface restoration.

The plowing in of small utility pipes and cables and the development of continuous excavation trenching machines are two developments that can greatly improve productivity in open cut work but their applications are mainly restricted to undeveloped land. Improvements in these techniques mainly center around installing larger diameter utilities and, for trenchers, to increase the depth of installation.

Impact moling uses a pneumatic percussive cylinder that essentially hammers itself through the ground, displacing the soil as it moves forward. The typical diameter range is from under 50 mm up to around 200 mm although most equipment in use is at the smaller end of this range. The equipment for the smaller diameters is relatively inexpensive and easy to use. Disadvantages, however, are that almost all impact moles sold are not steerable or trackable and hence only short distances from pit to pit are used. A steerable mole has been commercially available for a few years but its size and some operational difficulties have kept it from being significantly used. Research is underway to make a steerable and trackable mole in a smaller diameter (Hall *et al*. 2008). The goal is eventually to have an impact mole be able to steer itself to a “keyhole” excavation at a utility mainline to permit a low disruption installation or replacement of a utility service line.

Horizontal directional drilling (HDD) has represented a major advance in the technologies available for installing cables and pipelines in crossings of waterways and other existing infrastructure. Different techniques are used according to the nature of the ground (soil or rock) and the size and depth of the pipe to be

Manuscript received November 13, 2010; revised December 3, 2010; accepted December 13, 2010.
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installed. In basic principle, however, a pilot bore is steered and tracked over a combination of straight and curved sections of the borehole until it reaches the planned exit point. The borehole is then enlarged using reaming equipment until it is of sufficient size to allow a pipe or cable to be pulled into the hole created. The hole is kept open during the installation process using drilling mud that also serves to remove the cuttings from the drill bit or reamer. Steering in smaller shallow systems uses a "sonde" behind the drill head to transmit signals to the ground surface where they are picked up by walkover locator equipment. In deeper installations, or where walk over is not possible, a "wireline" tracking system is used which tracks the direction of the boring with respect to the earth's magnetic field (or a specially created magnetic field). Deviation of the boring is carried out in soil by rotating or not rotating a slanted face of the drill bit during advance of the borehole. In rock, a "bent sub", as used in the oil industry, will drill in a curved path when the overall drill string is not rotated but will drill approximately straight when both the drill bit and the drill pipe are both rotated at the same time. Equipment is now available for installing pipelines of up to 1.5 m in diameter over moderate lengths, smaller diameter pipelines over lengths exceeding 2,500 m, and, at the other end of the range, highly portable surface-launched or pit-launched equipment for small diameter pipe and cable installation in urban conditions. In urban installations, the main challenge is to avoid damaging existing utility installations. This requires accurate knowledge of where all the existing utilities in the vicinity of the drill path are and careful excavation and verification procedures to make sure that no existing utilities have been damaged. Research is proceeding on "see-ahead" systems that could provide a last line of defense in this regard (*e.g.* Kieba and Allouche 2007). The intent is to be able to identify a pipeline or cable ahead of the drill bit in sufficient time to be able to stop the drilling operation. Challenges remain in retaining borehole stability in difficult ground conditions – especially in ground with many cobbles and boulders and in long and/or large diameter installations.

Pipe jacking installation of pipes has been in use since the end of the 1800s but early pipe jacking was carried out with a person at the face to excavate the soil. In the 1940s, auger boring methods were developed that used a rotating auger within the pipe to turn an excavation head and move the excavated soil back to the starting pit. Auger boring was one of the first non-person entry trenchless methods but its steering capabilities were limited and it could not be used where soil type or groundwater levels would make the excavation face unstable. In the 1960s, a method of creating a pressurized chamber at the excavation face using mud slurry that would both support the face and transport excavated material through a pipeline to the surface was tried. The first trial in England was unsuccessful but the method was picked up in Japan and Germany and evolved into what is known as microtunneling. Originally, the method was a size-based description for a remote-controlled tunneling machine of a diameter that was too small for a person to enter the installed pipe (less than around 900-1000 mm). In North America and many parts of the world, the term is now used more as a method description (*i.e.* a person does not need to enter the pipe for normal operation) than a size-based description. In larger sized machines, the use of "earth-pressure-balance" (EPB) machines developed in larger diameter tunneling also is possible. These provide face support by balancing the advance rate of the machine to the rate of excavation and using the machine face to support the soil in front of the machine. The main challenges to these methods and, in particular, for the non-person entry diameters is the ability of the pipe jacking process, once started, to reach the target pit and to avoid over or under excavation of the ground which would cause ground settlement or heaving. Pipe damage caused by high thrust forces and/or poor steering control also has been a problem. The more sophisticated machines entail high investment and mobilization costs and hence are difficult in cost terms to use for small projects. Curved microtunneling and pipe jacking has become quite common in Europe and parts of Asia but is still hardly used yet in North America. Advances fall mainly into continued progress on the capabilities of the microtunneling equipment, improved directional control using gyroscopes, better handling of difficult ground conditions (*e.g.* sticky clays and high strength boulders), and better design procedures for predicting and managing pipe stresses due to curved alignment or poor steering control. One can also see many of the advances in microtunneling being adopted in the simpler auger boring machines – in particular giving them better steering control.

Because of the high cost of full microtunneling machines and the lack of very close directional control in HDD, a hybrid method has been gaining popularity. This is known either as the pilot tube method or as the guided boring method (GBM). In the basic technique, a slant-face tool is thrust through the ground displacing the soil and being steered in a similar fashion to HDD steering. The direction is controlled, however, using a camera theodolite sighting down the inside of the drill pipe. After the initial connection is made between the launch and reception shafts, the hole can be enlarged using temporary casings and augers before the final pipe is installed (without being subjected to high thrust forces). The comparatively low cost of the equipment and speedy mobilization on site make this an attractive option where the distances between shafts can be relatively short. The method is continuing to evolve – with options for rock excavation and increasing confidence in using the method for longer drives in suitable soils. In addition, the ability to place a pilot bore on accurate line and grade has been interfaced with both pipe ramming and auger boring methods to provide improved alignment control for these methods.

Pipe ramming equipment uses a pneumatic percussion hammer to drive a steel casing through the ground. A prime advantage is that, in most cases, the ground can remain inside the pipe as the pipe is rammed – thus removing problems of face collapse and making the method one with low risk of ground movements in most soil conditions. The method is most applicable to crossing type installations especially when a bore needs to be made through a road or railway embankment. The equipment is relatively inexpensive and the success rate is high. Pipe ramming equipment has also been used as an assist to other trenchless installation and replacement techniques including HDD installations (installation of entry and exit casings and pipe pullback assistance) and pipe bursting (replacement pipe installation assistance).

Another hybrid approach that has emerged for large diameter pipeline installations is the pipe thrusting approach. The equipment for this approach includes a microtunneling machine installed at the front of a steel pipeline. The pipeline is then thrust into the ground at a shallow angle by a surface-based thrusting unit that grips the outside of the pipe to thrust it forward. In this way, a continuous steel pipe can be installed (as compared to the sectional pipes required for pipe jacking). The microtunneling head is used for both steering and excavation and the process is installed from one main working site only.

The final area to mention for installation techniques is their use as pre-support for large diameter tunnels and caverns. Microtunnels, for example, can be used to install pipe arch supports for tunnel crossings and metro station caverns and HDD techniques can be used to probe ahead of tunneling operations to detect dangerous ground conditions. This is an area where considerably more development of new approaches can be expected as techniques are adapted and their capabilities proven in reducing risk or cost in difficult large-scale excavations.

3. INSPECTION/LOCATION/CONDITION ASSESSMENT/ASSET MANAGEMENT

This is a very broad section to review in a short contribution but it is a critical part of the application of renewal technologies in managing underground utility assets. Several recent reviews of technologies in the various sectors have been recently made and these references will provide an entry point into the related research and performance studies (*e.g.* Feeney *et al*. 2009; Thomson and Wang 2009).

The last 40 years have seen the introduction of closed circuit television (CCTV) cameras for underground utility pipe inspection as well as a rapid improvement in lighting, image quality and data handling (*e.g.* digital capture vs. cumbersome tapes). Separate cameras, remotely launched from the mainline unit have also been developed to enter lateral services from the mainline. More recently, optical and laser scanning systems together with computer graphics manipulation have allowed interior pipe surfaces to be unwrapped graphically for clear depiction of a pipe's condition. The scanning systems can also be used to determine host pipe deformation which is important to determine for flexible pipes and not easy to determine from simple CCTV footage. Image processing is being developed to automatically detect different kinds of defects for condition assessment. There is also a trend towards automatic data capture in the field with interpretation and defect coding being done later in the office environment. In water systems, various leak detection and pipe condition inspection systems have been developed including leak noise correlators, a free swimming ball leak detection system, acoustic detectors for prestressing wire failure in prestressed concrete cylinder pipe (PCCP) and remote eddy current pipe wall inspection systems for steel and ductile iron pipes.

Determining the location of buried utilities and other underground structures prior to construction is mostly done from existing records and surface-based utility locating techniques. Direct exposure and recording of the accurate surveyed position of a utility is carried out much less frequently. Despite significant advances in utility locating equipment and the adoption of computer tomography analysis from the oil exploration and medical fields, the knowledge of existing utility positions and condition is far from adequate (Sterling *et al*. 2009). A structured approach to determining and managing utility positional information is provided by the Subsurface Utility Engineering (SUE) approach which classifies the pedigree of data collected as well as the values assigned to utility position data (ASCE 2002). "One call" systems before construction have also reduced the number of utility hits but the overall knowledge of existing utility positions remains poor and there is no magic technique on the horizon that will find all types of utilities at all common depths of interest. This problem is particularly acute for trenchless methods of installation since they are steered remotely and currently often blindly along a predetermined path. If an unrecorded and undetected utility lies in the path of the boring, then there is a threat to safety in the vicinity of a strike and a possibly high cost of damage. The challenges in this area remain daunting for significant technical improvements that can deal with varied site conditions. However, research efforts are underway to pursue multi-sensor approaches and the finding of deep utilities as well as in a pilot study that aims to develop and test 3-D GIS approaches to combining multiple utility data in a structured system. The key issues in this last project are to prevent unauthorized release of utility data and preserve utility independence but at the same time to provide utility installers with the best information available on utility position and avoid having to "re-find" every utility whenever a new construction is undertaken in an area. Information on the ongoing research of the Strategic Highway Research Program can be found at the SHRP2 website under projects R01 (A), R01 (B) and R01(C) (http://www.trb.org/ StrategicHighwayResearch-Program2SHRP2/Public/Pages/Renewal_Projects_303.aspx) and information on a U.K. initiative on Mapping the Underworld can be found at (www.mappingtheunderworld.ac.uk).

Condition assessment has benefited from the introduction of standardized coding for defects together with the training necessary for CCTV camera operators and others to make consistent interpretations across city crews and among different cities. Asset management software has developed powerful database, analysis and integrated work flow management systems in the past two decades. The principal challenge now for asset management is to be able to collect the appropriate data for input into the model and not just to use standard assumptions for replacement costs or the lifetime of rehabilitated pipelines. A related issue is to be able to properly match the level and cost of data collection to the cost of poor performance and/or failure of the system.

Other challenges in this arena are to be able look into and beyond the visible surfaces within a pipe. Sonar has been used for some time to investigate the pipe surface degradation or debris build-up below the water level in a storm or sanitary sewer. In-pipe ground penetrating radar (GPR) has also been used to search for voids outside a pipe or for loss of exterior pipe wall. More recent research is underway to use ultra wide band (UWB) pulsed radar for the same purpose (Jaganathan *et al.* 2007). For critical pressure pipes including gas mains, sewer force mains, and critical water mains, inspection systems are needed that reduce any out of service time to a minimum or can operate within the pipe under normal conditions. The same problem exists for large diameter sewers which always have high flow conditions and often have very poor access.

4. RENEWAL – REPAIR, REHABILITATION, REPLACEMENT

A variety of new technologies for the renewal of underground pipe systems have emerged in the past 30-40 years – allowing a full new service life to be given to an aging pipe with minimal excavation. Two recent studies are available that discuss the state of technology for renewal of sanitary sewers (Sterling *et al.* 2010) and renewal of force mains (Morrison *et al*. 2010). A third report on renewal of water distribution systems is expected to be released during 2011 as part of the same research initiative. Each report contains technology data sheets on all the significantly used classes of rehabilitation technology in North America. In addition, a white paper produced as a part of the same project discusses the current challenges and technology gaps (Sterling *et al.* 2009b).

Individual repairs are still often done by open cut work but there are various internal joint seals or short pipe lining sections that can be inserted from within the pipe. Some require person entry to complete the seal installation but some can be done remotely allowing their use in non-person entry pipes. This latter category includes cured-in-place pipe (CIPP) short liners and expanded stainless steel liners. Full relining of pipe sections can be done by several methods according to whether the pipe is a pressure pipe or a gravity flow sewer pipe. The most popular method is the CIPP process mentioned above. This was first used in 1971 in London and is now used widely around the world. In the original process, a felt fabric was impregnated with a thermoset resin and then inverted within a sewer pipe before being cured with hot water into a new "pipe within a pipe". Since that time, various improvements and adaptations to the process have occurred to ease or speed installation, provide better quality assurance and reduce costs. Such advances have included the use of steam or UV light for curing, the use of vacuum impregnation for introducing the resin into the liner and the use of higher strength reinforced fabrics for large diameter liners.

Other types of liner system include various forms of temporary diameter reduction or folding of plastic pipe liners prior to insertion in the host pipe and then reforming or expanding the diameter of the liner once it is in place. In one newer technology, a smaller diameter PVC pipe is specifically designed to be expanded once sliplined and heated within the host pipe and, in another, a flexible polymer pipe liner is thermoformed to fit the internal surface of the pipe before being cured into a structural liner. Other pipe renewal approaches include various forms of grouting to seal infiltration leaks into gravity sewers.

Trenchless pipe replacement is an alternative to pipe rehabilitation and can offer the opportunity to upsize a pipe at the same time. Its principal advantages are that a new factory-manufactured pipe is installed and the same alignment for the new pipe is used – making reconnections easier and saving space in congested utility areas. The main process used involves either bursting or slitting the old pipe from within, displacing the existing pipe material and then pulling a new pipe into the void created. A conical shaped displacement head provides the necessary displacement and can be oversized to allow a larger pipe to be installed than was originally in place. Cutting wheels and/or fins are used to slice the wall of ductile pipes before expansion. In most systems, the force for the expansion comes from either a high tensile force exerted on the bursting or splitting head or the pneumatic impact of a compressed air driven bursting head. Special measures may be needed where the inevitable ground movements may damage nearby utilities or structures. These may include local excavations to prevent the transmission of damaging movements or the use of pipe excavating systems to remove the old pipe (*e.g.* pipe reaming or pipe eating).

5. CROSS-CUTTING ISSUES

With such a wide variety of trenchless methods that still have the capacity for improvement and extension, there are many research and technology advances that can be made. Some issues for individual methods were mentioned above but in this section a few cross-cutting issues will be identified.

In new installations, the main advances desired are to be able to go farther, install more accurately, install larger diameters, cope with wider ranges of expected and unexpected ground conditions, and, if possible, reduce costs. Often more than one trenchless method may be possible and method selection may depend on contractor preference or equipment availability. Software to help in identifying suitable methods under given general site and job conditions has been developed, *e.g.* the NUCA TAG system (2004) as well as software for planning HDD bore profiles (available from HDD manufacturers) and software to assess social costs (Matthews and Allouche 2010) or carbon footprint of different construction techniques (Ariaratnam *et al.* 2009). Adequate site investigation for trenchless installations remains a problem because of the extent of geological conditions to be characterized and the relatively small project budget relative to large-diameter tunnel projects covering the same distance. Design methods for new installation techniques are reasonably well developed but may not yet capture properly all of the complex loading conditions that may occur during the remote installation processes. More monitoring of installation loads, stresses and strains against site and equipment parameters would help increase knowledge in this area and guard against installation and post-installation failures.

In the area of inspection, location, condition assessment and asset management, the cross cutting issues are to collect the necessary amount of good quality data and to use that data effectively in an asset management system. In recent work on evaluating the current condition of CIPP liners after up to 25 years of service, it was disappointing to find that the original test data for the as-installed liners was no longer available for comparison. Establishing the real service lifetime of a rehabilitated pipe is a critical part of effective asset management and the asset management system should be used as a repository of the data needed to improve the assessment of remaining life as more data becomes available. Significant advances in the capability of methods to provide improved pipe condition assessment are expected in the coming years. One major challenge will be to justify any additional costs for assessment in terms of the ability to reduce overall system life cycle costs.

In renewal of pipeline systems, one of the major challenges is to fit the various proprietary systems into a comprehensive approach to renewal that can provide equivalent performance using different techniques along with the equivalent quality assurance/quality control (QA/QC) procedures to deliver that performance in the constructed product. Most renewal systems have a variety of ways in which they can fail or cause damage to surrounding structures or the environment – either during construction or later in service. Few of these, however, are explicitly and systematically dealt with in design standards or dealt with in an equivalent way for different techniques. The strong performance of lining systems to date indicates that the standards are providing a good product but this may be due to overdesign in some aspects that effectively cover potential problems due to other failure modes. For example, the main parameter controlling the thickness of pipe liners installed in gravity sewer systems is the long-term strength against buckling due to external water and/or soil pressure. Maximum water levels and conservative assessments of the effective long-term modulus of the plastic liners are typically used giving a normally conservative design. Less formally and quantitatively considered are issues concerning partially defective liners (density, porosity, wrinkling, *etc*.), thermal change impacts, *etc*. These are typically assessed individually for each technique or measures are written into individual specifications. For pipe bursting, broad method specifications are still less well defined with many aspects of the installation left up to the judgment of the contractor or equipment supplier in the absence of an experienced owner or consultant. A more comprehensive approach would be to analyze all the various potential failure modes and establish the limit states for failure or loss of serviceability. Appropriate factors of safety according to the risk and consequences would be applied to guide the design as is done as a standard practice in structural engineering, for example. The benefit would be to allow different methods to be specified to provide equivalent service and reliability in a consistent manner and hence to provide competition on a level playing field among different systems.

A more pressing problem though in some countries using rehabilitation technologies is for the system owners to take more responsibility for the quality assurance of their renewal technologies. In the developmental years of pipe rehabilitation, design and quality control were principally provided by the developers of the technology and their licensees. Knowledge of the technology and experience provided were high and the equivalent knowledge and experience of system owners was often low. Under these conditions, the contractor/technology provider was largely trusted to provide a quality rehabilitation system. As patents have expired and some relining systems have become more of a commodity, there is less assurance that proper quality procedures will be followed by all contractors bidding for the work. To meet these circumstances and also as good quality assurance practice, the owner needs to make sure that the materials used meet specifications, the design is appropriate for the site and existing pipe conditions and that the field installation processes are properly carried out. A simple CCTV inspection of the final installation may not reveal deficiencies that will degrade the lifetime performance of the liner.

6. CONCLUSIONS

Trenchless technologies have undergone rapid development in the past 40 years and provide cost effective, low disturbance solutions for many problems in underground utility installation and renewal. While perhaps the rate of introduction of substantially new methods in trenchless technology has slowed over recent years, there remain many challenges and hence many potential areas of advancement in the technologies and their applications.

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