

TRENCHLESS TECHNOLOGY SYSTEMS

***An Environmentally Sound Technology for
the Installation, Maintenance and Repair
of Underground Utility Services***



IETC Urban Environment Series

Trenchless Technology Systems

An Environmentally Sound Technology for the Installation, Maintenance and Repair of Underground Utility Services

Introduction

Water and sewage infrastructure and other utility services represent a significant investment on the part of most municipalities. For well over 100 years, the distribution networks for utility services have been located underground in pipes or ducts that are laid, repaired or replaced by trenching from the surface. In cities and urban areas, these distribution networks are located underneath roads. This often makes access difficult, particularly in areas congested with traffic and buildings.

When pipeline infrastructure is not well maintained, inefficiencies occur. For example, in water distribution systems, this can lead to leakage and possible water shortages. In sewage systems, cracked and damaged pipes can cause wastewater seepage, leading to contamination of groundwater. These problems often give rise to related health and environmental impacts.



Underground congestion

The oldest underground utility services are usually found close to the surface. Services installed later are most often found below or interwoven with the initial installations. Construction and repair work carried out from the surface inevitably disrupts traffic, business and other services. This disruption has a negative impact on the local environment in terms of air quality, noise, and other pollution, as well as on local vegetation and buildings. This, in turn, diminishes the quality of life for local residents. The provision and maintenance of safe and efficient utility services requires more environmentally sound technologies and approaches to ensure public support.

Trenchless technologies, which minimise the requirement for surface excavation, can significantly reduce the environmental impacts of underground utility service installation, maintenance and repair. By minimising surface disruption, traffic congestion is significantly reduced, thereby reducing air and noise pollution. Furthermore, trenchless technologies can take advantage of existing pipeline materials and can minimise wastes caused by earth and pavement excavation.

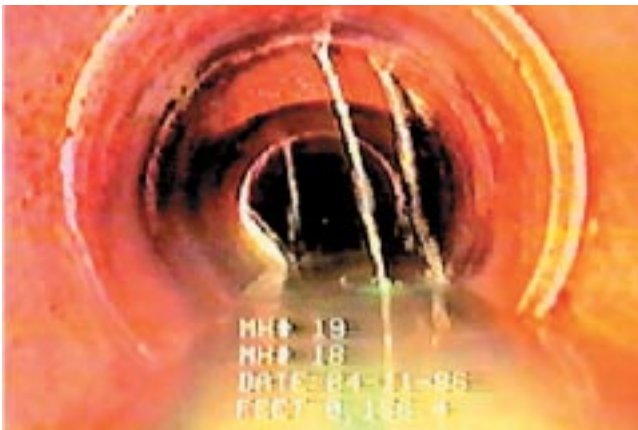
An increasing number of trenchless technologies have been demonstrated and numerous projects have been successfully completed, highlighting the benefits of this environmentally sound approach to underground utility installation, repair and maintenance.

The Development of Trenchless Technology Systems

Until recently, city administrators and planners believed that the use of construction techniques involving surface trenching was the only option for the construction and repair of utility services. It was assumed that existing services were in good condition unless there was evidence to the contrary. In

reality, gradual deterioration went unnoticed and failures occurred without warning, in many cases requiring urgent response.

Over the last 25 years, it became apparent that little was known about existing utility services. Installation drawings, where they existed, gave little information on pipe capacity or materials used. Furthermore, the condition of the pipe linings was unknown, leakage and infiltration were unmeasured and related health issues were often not addressed.



Infiltration was unmeasured

Research was also initiated to obtain information on pipes and ducts too small to permit entry of service personnel. A major breakthrough came with the development of closed circuit television (CCTV), used in conjunction with remote-controlled tools. This enabled engineers to see the internal condition of pipelines, identify voids and perform repairs to underground services. The demand for these techniques quickly increased around the world, and a new area of civil engineering, known as trenchless technologies, began to emerge. The field of trenchless technology is still developing - even today, the majority of underground utility services are installed, maintained, repaired and extended using "open cut" methods.



"Open cut" a well established method

The development of trenchless technology was initially undertaken to meet specific needs in different industries and in different parts of the world. For example, research into microtunnelling in Japan was in response to a government initiative aimed at increasing sewer services in large cities. Similarly, in Singapore, government regulations and the need to provide services in densely populated areas led to the promotion and use of microtunnelling. In Europe, research into micro-tunnelling was sponsored by the German government for use in large cities on the North German Plain where ground conditions were favourable.

In the United Kingdom, where the large towns and cities had been built during the Industrial Revolution in the 19th century, the principal need was to replace and rehabilitate ageing sewers, water pipes and cast iron gas mains. In addition, the use of natural gas at higher pressures encouraged the development of pipebursting techniques.

In North America, Horizontal Directional Drilling, developed from vertical, steered, oil well drilling technology, became widely used for constructing long pipelines for the oil industry.

In 1986, at the instigation of engineers in Europe, the USA and Japan these techniques and those associated with survey and location were drawn together under the name "Trenchless Technology". Today, trenchless techniques for underground utility services can be broadly categorised according to the purpose for which they are used (i.e., new installations, replacement, rehabilitation).

Technology Options

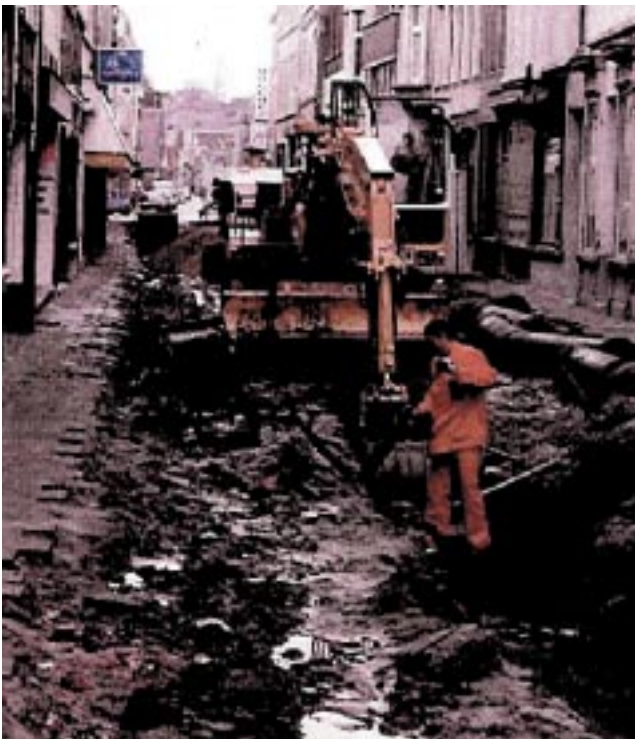
The two technology approaches currently available for access to underground utility services are Open Cut and Trenchless.

For access by open cut there are four stages:

- Excavation of the trench, removal of spoil and temporary support of other services;
- Laying and jointing the product pipe or service;

- Refilling the trench and compacting the selected spoil or filling material;
- Restoring above ground infrastructure.

All four stages are characterised by the amount of physical work to be undertaken. Typically, 50 times the amount of spoil to be occupied by the product pipe or service has to be moved - once during excavation and again during refilling. Furthermore, much of the work in all four stages is labour intensive, involving different skills that require co-ordination between several companies and authorities. Thus, a large project can extend over a long period and be very disruptive in social, economic and environmental terms.



Disruptive in social terms

Access using trenchless techniques also requires surface work, but not on the scale needed for an open cut approach. Trenchless technology projects require careful consideration of the existing condition of the underground pipes and ground conditions in order to select the most appropriate technique. The technology and approach must be determined and the surface work must be conducted using an existing access or by digging access pits. The determination of the technique, location of the access pits and the route for a new pipe requires an initial survey. This is

often viewed as an additional expense in comparison to open cut techniques. However, the cost of the initial survey stage of a trenchless project is usually offset by a shorter time on site.

Trenchless technologies present a number of other unique advantages. For example, with new installations, engineers can drill and install pipe in the most favourable stratum, irrespective of depth. For sewers in particular, there can be significant savings by retaining gravity flow and avoiding pumping stations.

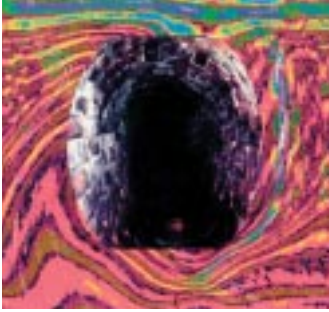
Site Assessment and Technology Selection

Whatever construction method is used, the chance of success for any underground utility project is greatly improved by an understanding before work starts of the condition of existing services and the ground in which they are laid or to be installed. This is particularly true for trenchless projects where the project design is based on a site investigation report. For open cut projects, the trench itself is often "the investigation" and "the plan" usually involves solving problems as they occur. There is now a large body of practical evidence showing that managing projects on this basis can lead to unexpected changes in materials and support services, delays and occasionally accidents. Environmental impact is difficult to predict and minimise without an adequate project plan.

Recent advances in the design and use of CCTV camera technology have considerably reduced the cost of surveying water and sewage networks, and information on conditions below the water level can be obtained using special surveying sonars. Ground Penetrating Radar has also been developed and can be used from the surface to detect



Portable CCTV

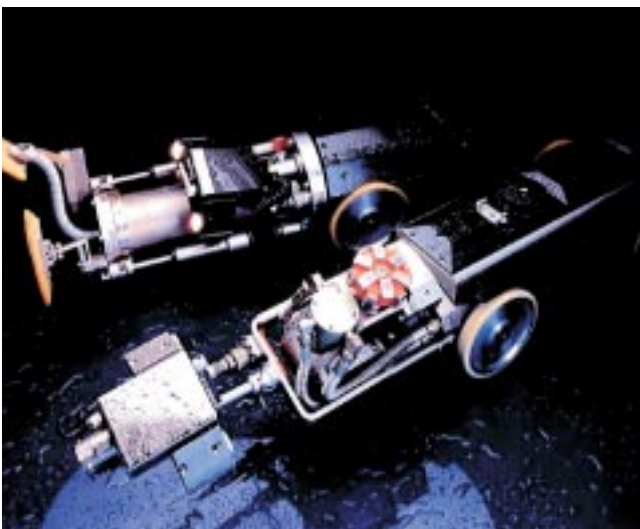


Ground Penetrating Radar

buried objects, voids and leakage from defective pipelines. Locators, using magnetics, are now regularly used to detect underground services. These devices, used in conjunction with vacuum excavation techniques, have simplified and reduced the cost of site investigations.

A traditional rule for most underground projects is that cost usually rises in direct relationship to the depth of work below the surface. As a result, the first consideration has been to make any new installation as shallow as practical, and any access to an existing service as short and direct as possible.

For trenchless projects, experience has shown that there is little relationship between cost and depth. For work on existing services, the access points already provided can be used and work can be planned to reduce disruption. Trenchless techniques have also been developed for the remote repair of damaged services so that direct access is not needed. In addition, techniques are available to make services more resistant to earth movements due to land settlement and earthquakes.



Remote repair robots

For new projects, the nature of the ground and depth of the water table can influence the chosen technology and process to be

used. By using trenchless technologies, project designers can take advantage of the most favourable ground conditions irrespective of depth, allowing for the installation of new services in areas where open cut methods were previously impossible. For example, services can be installed beneath the shear plane in areas liable to land slip, or deep in areas close to water courses which are liable to flash flooding and erosion. Services can also be installed below the permafrost in very cold climates, beneath areas of cultural or environmental significance, and under rivers and lakes which in the past have been natural barriers to open cut methods.



Drilling under permafrost

The ability to drill and install pipe at greater depths can help to simplify designs by allowing longer pipe runs with shallow gradients, thus avoiding the need for pumping stations and sumps. This also facilitates pipe installation below already congested underground areas close to the surface in towns and cities.

Trenchless technology has therefore pushed back the boundaries of all forms of underground work required to support human settlements. Where previous work was limited to the depth dictated by safe open cut methods, depth is no longer the limiting factor. Where services already exist, they can be refurbished; and where new services are required, they can be constructed beneath the existing infrastructure. The ability to "renew" and optimise rather than construct additional underground services has clear environmental advantages.

Environmental and Social Considerations

Underground utility projects generally arise from the need to:

- Provide new or extended networks of pipelines or ducts;
- Increase existing network capacity;
- Transfer services from above ground to below ground;
- Replace defective pipelines;
- Rehabilitate existing pipelines by enhancing and taking advantage of residual structural capacity.

All of these projects require some surface access. If carried out using trenchless methods, the reduction in both the surface area required and the time for which surface space is needed in comparison to traditional open cut methods is a major benefit to both local residents and businesses, as well as to the broader public.

It should be recognised that all construction activities have an effect on the environment, and that any damage to the environment or loss of quality of life has to be paid for by society in terms that are usually not directly measurable financially. These costs have to be evaluated relative to the potential benefits arising from any proposed utility work.

The effects on quality of life and the environment can be described under the following broad headings:

- Frustration due to diversions, traffic congestion and accidents;
- Impaired quality of life due to noise, dirt, and reduced air quality;
- Damage to roads and highways due to the removal and replacement of spoil;
- Emergencies due to damage to other services left temporarily unsupported;
- Protests and claims due to damage to trees, buildings, monuments and religious areas;
- Disruption and loss of trade due to impaired access;
- Protests and delays due to weather dependency;
- Consequential costs due to poor installation and reinstatement;
- Claims and litigation due to damage to health and the environment.



Damage to trees

Trenchless technologies and methods can make a significant contribution to reducing these impacts and their associated costs. Properly applied, trenchless technologies provide an effective, environmentally sound alternative to the installation, maintenance and repair of underground utility services.

Financial Considerations

In addition to environmental and social factors, financial comparisons can be made between trenchless technologies and existing traditional open cut methods. However, these comparisons are often difficult because there are no universal cost comparison methods. While, technically, the best solution depends upon the ground conditions and the location of the water table, in practice the financial boundaries of a project and the degree of acceptable financial risk generally play a more significant role in the decision-making process.

The question also arises, "cost to whom?" The client is responsible for the direct costs of the contract and possibly for any compensation for loss of amenity or trade by local residents and businesses. This often means that costs are borne by local citizens and future generations. Furthermore, certain government financial policies can distort the real costs of installing, maintaining and repairing utility services. This can lead to the misconception that open cut is cheaper, when in fact a full accounting of the environmental and social costs may indicate otherwise.

The direct costs of both the trenchless and the open cut methods in terms of materials, time

and equipment can be established relatively easily. Indirect costs such as reinstatement of the surface, long term repairs to roads and buildings due to delayed settlement, useful life of the service after the work and degree of risk for unplanned or additional emergency work which may arise during the project can often exceed the direct costs. In some countries, these costs are ignored, while in others they play a significant role in the decision process. Nevertheless, an advantage of trenchless methods is that there are generally less indirect costs because surface access is less disruptive, projects (once started on site) are shorter, and hence the social and environmental costs are considerably reduced. When compared to conventional open cut methods, trenchless technologies offer a number of distinct environmental, social and financial benefits which are supportive of sustainable urban development objectives.

Strategic Considerations

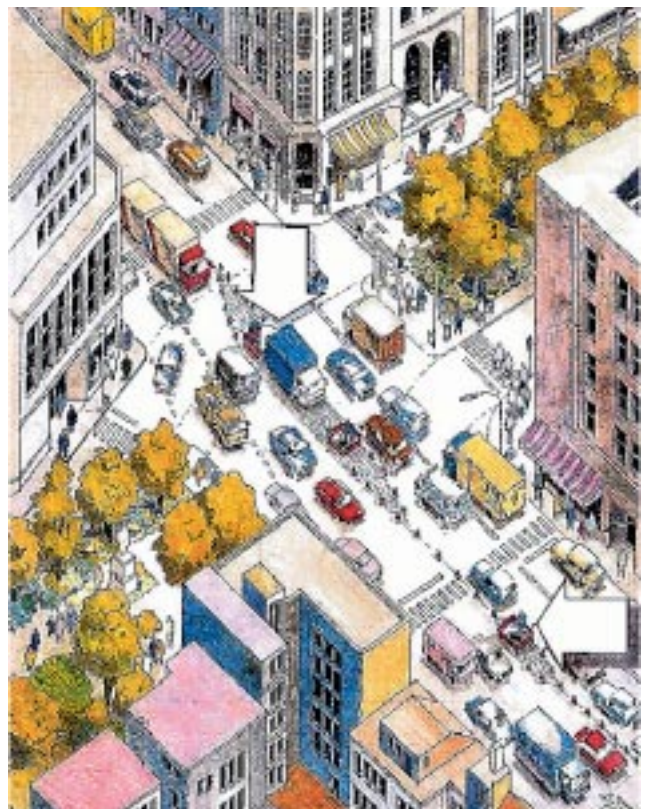
In the more developed regions of the world in particular, surface construction work disrupts roads, buildings and other infrastructure. The duration of these disruptions is a major source of frustration for local residents, business and the public. This has resulted in growing opposition to construction work in general, including concern about damage to the natural environment, as well as an increase in claims for compensation.

In developing regions, the use of open cut methods is still widely accepted and frequently justified based on the employment of a high number of unskilled workers. The political advantages of creating work and supporting the local economy often outweigh all other considerations. Increasingly, however, mechanical and electrical equipment is being used for all types of construction. Accordingly, strategies are required to transfer new technologies and skills to local engineers and workers.

The health and safety of workers, equipment operators and the public is well recognised worldwide and many countries have intro-

duced legislation requiring the use of safe working practices. In the case of underground utilities, the closer workers and operators are to mechanical and electrical equipment, or the more they have to work in confined spaces, below the surface, or close to moving traffic, the greater the risk of accidents. With trenchless projects, surface excavation is confined to relatively small entry and exit pits or shafts and it is often possible to locate these away from hazardous areas and road traffic. Trenchless projects also make extensive use of machines and processes remotely controlled from the surface, thereby separating workers from high risk worksite areas.

In general, in comparison to the use of open cut methods, trenchless projects are characterised by minimal surface disruption over a much shorter period of time. For a well managed trenchless project, the public may not be aware that major construction work is actually going on below them. There are unlikely to be any restrictions on the general public during working hours and less social disruption. Thus, trenchless projects are less hazardous and are generally viewed as being more environmentally sound.



Little to be seen on the surface

Trenchless Technology Applications: New Installations

The trenchless technology sector is continually being refined and developed. Improvements cover both larger and smaller diameters, longer drives, greater accuracy, faster and curved driving, different soil conditions and the ability to work deeper into water tables. Records for new installations in terms of size, distance and routing (direction) are being broken all the time.

The various systems for new installations can be broadly categorised into Horizontal Directional Drilling (HDD) or Guided Boring, Microtunnelling & Pipejacking, and Impact Moling.



Drilling of the pilot bore (top) and backreaming (bottom) to enlarge the hole and install the pipe.

HDD is used throughout the world, particularly in North America. It is generally a two or three stage operation, initially to create a pilot bore which is subsequently enlarged by reaming to the desired size. The drill is usually surface launched and fluid lubricated. Machines range from compact, mobile rigs for small bores in confined spaces to very large units for large diameters and drives of more than 1km. HDD is fully steerable but, until recently, the degree of accuracy has not been suitable for gravity sewer installations. The technique is now being improved and a

number of successful sewer installations have been completed in North America. The technique is widely used for water supply and cable ducts, as well as for gas and oil pipelines.

There are many variants of Pipejacking, in which the product pipe is forced into the ground by jacks mounted horizontally in a launch shaft. The run is completed when the pipe string reaches an exit shaft. Both shafts are often used later as service access points. The ever-increasing length of runs and fewer access points is reducing project costs, making this technique increasingly popular.

The equipment used for pipejacking is sometimes termed Tunnel Boring Machine (TBM). TBMs can be categorised as:

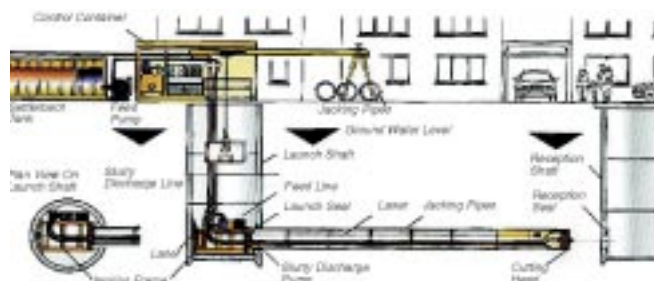
- Auger TBM, in which the spoil is removed by an auger through the incoming pipe.
- Slurry TBM, in which the spoil and ground water are removed by pumping as a slurry.

Microtunnelling is a more advanced form of Pipejacking, using a separate miniature TBM and controlled from the surface. Specially designed pipes are jacked in behind the machine, which uses the leading pipe face to push forward as it cuts.



Arrival of a microtunneling TBM at a reception shaft

Initially used for large gravity sewers of 500mm diameter and upwards in Japan where a high degree of accuracy was required, the method has been further developed for the installation of PVC ducting down to





Abn Impact moling hammer

150mm diameter. Another recent development has made it possible for curved driving when using micro-tunnelling.

Impact Moling is primarily used for short drive crossings under roads for cable ducts and

small diameter service pipes. It has the advantage of mobility and quick set-up time and is often used where there is no requirement for a high degree of accuracy.



A pipe ramming operation

Trenchless Technology Applications: Replacement

Replacement of defective or overloaded pipelines has been identified as an urgent need, particularly now that so much more is known about the condition of earlier installations. In congested areas, the existing defective pipeline route may be an "asset" which can be enlarged by a replacement pipeline. Here again, considerable progress has been made in terms of the degree of upsizing, dealing with the type of construction of the existing line, difficult ground conditions and the improved durability of the newly installed line.



Schematic of pipe bursting

Replacement systems are frequently grouped under the heading Pipebursting, although there are many variations and terms such as Pipe Cracking, Pipe Splitting and Pipe Eating are also used. In pipe replacement, the defective pipeline is burst, generally by brittle fracture, using either a pneumatic or hydraulic mole, and the fragments are forced into the surrounding ground or removed through the new pipeline which is pulled in behind the mole.

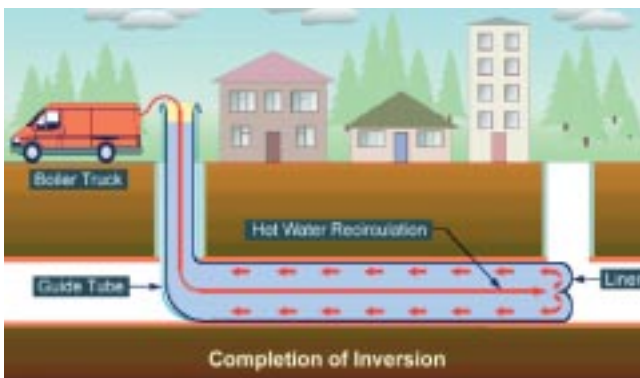
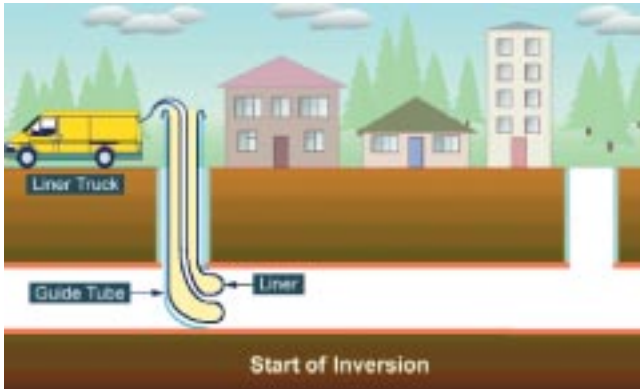
Pipebursting is usually used in soft ground conditions and is often not suitable for gravel or rock. It has been widely used in the gas industry to replace older cast iron mains which lend themselves to brittle fracture. More recently, pipe bursting has been used on defective and overloaded sewers, where the ability to increase the size of the new pipe is an advantage.

Trenchless Technology Applications: Rehabilitation

Perhaps the largest share of the trenchless market is represented by the requirement to rehabilitate defective pipelines with some residual structural and physical life, which can be used as a structure for the new line. Examples of rehabilitation techniques include Cured-in-Place Lining (CIPP), Close-Fit Lining, Sliplining, and Spray Lining, all with their own patented variations, as well as various other localised repair techniques. Variations relate to the material used, wall thickness provided to offset structural or physical defects, the rate of rehabilitation, and the minimum time of shut-down for the existing service.

The rehabilitation of small diameter underground pipes is a new area where the cost competitiveness of trenchless technologies is well recognised. Many utility pipelines, sewage in particular, become defective due to the corrosiveness of modern effluents. They also suffer from overloading and loss of capacity. One of the advantages of rehabilitation is that the new lining materials have a much lower surface friction coefficient, thus it is often possible to increase the capacity of the refurbished pipe without increasing its diameter.

In CIPP, a fabric impregnated with polyester or epoxy resin is inserted into the defective pipe and inflated to fit against the pipe wall. It is then cured by hot water, steam or ultra-violet light. The system has many variants and can be designed to provide different wall thicknesses to meet particular needs. One advantage is that the lining adjusts to variations in the size of the pipe. It is widely used for the rehabilitation of gravity sewers, including laterals, and usually results in no loss of capacity.



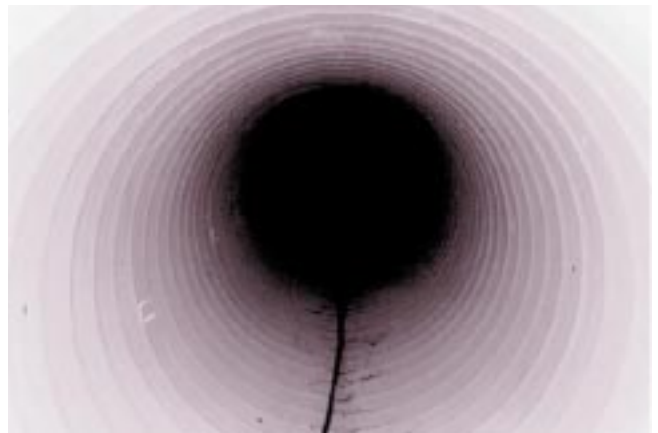
Inverting a CIPP liner (top). Curing the liner resin by hot water circulation (bottom).

Close fit linings take many forms. The lining is deformed through a swage (a metal die) or manufactured in a folded state so that it can be pulled into the host pipeline. Various methods can then be used to allow the lining to revert to its full size or to the shape of the host pipe.

Spirally wound liners are a form of close fit in which a PVC strip is fed through a small access into the defective pipe. The PVC strip is then helically wound into place against the pipe wall using a winding machine operated from within the pipe. This technique is particularly useful for emergency repairs and for adding strength to pipelines which have been weakened.



Installing Spiral Wound Lining



A completed spiral-wound lining.

Sliplining involves putting a pipe within a pipe and grouting the resulting annulus between the new lining and the old pipe. This causes a reduction in capacity and the process has now been modified using polyethylene to reduce the thickness of the liner and to minimise the size of the annulus.

Spray linings using cement or resin are widely used on water pipelines. Spray lining materials have to be used carefully and approved by regulatory authorities due to the potential for releasing solvents and residues. Spray linings are suitable for dealing with leaks but not where there are structural defects.

Localised repair techniques make use of robots in conjunction with CCTV cameras to clean, prepare and fill cracks and voids with epoxy mortar. This is often a cost effective way of dealing quickly with an isolated problem in an otherwise sound pipeline. The ease of transport and mobilisation of the equipment is an advantage.

Future Directions

The creation of the spectrum of trenchless techniques over the past 25 years has been dramatic. However, although trenchless technology systems have an excellent track record, many planners, designers and engineers are not yet accustomed to using them.

Accordingly, there is a need for further technological refinements, better information dissemination, and greater public awareness and understanding regarding the appropriate use of trenchless technologies and their contribution to environmentally sustainable urban development.

Copyright © 2001 UNEP-DTIE-IETC/ISTT

This publication may be reproduced in whole or in part and in any form for educational or non-profit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. UNEP-DTIE-IETC and ISTT would appreciate a copy of any publication that uses this publication as a source.

No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from UNEP-DTIE-IETC/ISTT.

NoDig - why dig trenches when there are better solutions?

Environmentally Sound Technologies (ESTs) encompass technologies that have the potential for significantly improved environmental performance relative to other technologies. Broadly speaking, these technologies protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. The adoption and use of ESTs carefully considers both human resource development and local capacity building.