INSPECTION AND DETECTION FOR PIPES AND DUCTS BOTH GRAVITY AND PRESSURE.

Introduction

The various Trenchless Technologies described in this website are highly cost-effective and environmentally-friendly when used correctly, but they can only be so with a full knowledge of the condition and location of pipes to be renovated and, for some technologies, the location of any adjacent services. For new installations using trenchless technologies the ground condition and locations of existing services is essential in order to establish a clear path to follow for the installation.

For rehabilitation techniques knowledge of the current condition of the service is necessary so that the correct renovation product or technique is specified to restore the condition to the desired level and for the required service life.

The inspection and detection techniques covered in this section enable engineers to plan and execute a full range of the necessary surveys and inspections that will provide the basic information needed to ensure a successful trenchless project.

The technologies include:

Inspection:

CCTV:

Application

CCTV is utilised for inspection of pipes and ducts that cannot be entered into by man-entry means either because they are too small or for safety reasons. These may be sewers, water mains, gas mains, culverts, rising mains etc. Normal practice is for the product carried by the pipe to be removed and excluded from the pipe, although some systems will operate in gravity pipes that are partly full. Systems are available for <25 mm diameter up to man-entry sizes and above and can be used over almost any length, this being dependant on the length and capacity of the umbilical cable to carry image data and the camera system to pull the cable through the inspected pipeline.

Limitations are that the pipeline should be as clean as possible to ensure the best view of the inner surface with obstructions removed when encountered, which could lengthen the time taken to complete a survey or its completion altogether if it is not possible to remove the obstruction.

Benefits

CCTV enables engineers to view the inner surface of a pipeline without the need for man-entry operations which would normally include confined space working and its associated requirements. It can highlight defects and provide a permanent record of the state of the asset at the time of the survey, as a baseline against which to measure any future deterioration in subsequent surveys. This can be achieved in a variety of formats using CCTV alone or in combination with other technologies to provide a more substantial survey result.

Furthermore, once a pipeline has been renovated, CCTV can provide a record of the new state of repair against which future surveys can again be measured. Data and images from currently available systems can often be accessed via the internet or Wi-Fi from almost any location enabling survey data to be viewed almost immediately after a survey is completed. This enables immediate responses to be made if any pipeline shows such serious defects that such a response is necessary.

As well as its inspection capabilities, CCTV can also be used as a viewing tool to enable control of robotic repair systems that may be used within a pipe environment ensuring that the operation is correctly applied and is proceeding as planned and can provide a permanent record of the operation should there be any dispute later.

Technology Description – what it is

Since its introduction in the early 1970's, Closed Circuit Television (CCTV) technology has made major advances in its technical capabilities.

CCTV methods and their variations have been adapted for all pipeline inspection circumstances including potable water mains and other pressure pipes such as oil and gas pipelines and sewer rising mains, as well as gravity sewer surveys. The latter, for instance, are required as part of a strategic investigation e.g. flooding, investigate suspected structural problem, locate infiltration and exfiltration, pre-adoption, fire-fighting, location of hard blockages and collapses, locate and inspect manholes, locate and identify connections, check effectiveness of cleaning work and sewer renovation quality.

There are three basic options for deploying CCTV survey techniques:
Winching – Not often used because more easily transported and operated systems have become available. The camera system is attached to a winch cable that has been passed through the pipeline and by which the camera is moved through the pipe. Generally there is no size limit for a winched operation and the skid mount configuration may overcome some silt levels. However there needs to be good communication between winch operator and CCTV viewing technician to ensure the survey is completed successfully, and speed control may be more difficult potentially resulting in significantly more multi-pass runs to ensure that all defects are found.

Rodding – This is a simple to use and quick option in (usually) shallow sewers, however the cameras may be limited to smaller diameter pipes, up to a maximum of 150 mm (6 in). The length of a survey is limited by the length of rod carried on the dispenser carriage which is normally in the form of a flexible coiled 'rod' which also houses the power/data cables. Rod mounted systems also utilise self-levelling cameras which retain an upright (correct view) image of the inside of the pipe irrespective of the orientation of the camera head in the pipe. These systems tend to be used in well-cleaned pipes as they may be affected by the presence of silt or sludge in the invert of a pipe as they move forward, thus clouding or obscuring the camera's view. It may be useful to utilise a centralising brush around the rod if the pipe diameter is such that the camera would not provide an acceptable image of the soffit of the pipe as it runs along the invert.
Crawler-mounted – In medium and large diameter pipes this is probably the most widely used configuration. The CCTV camera is mounted on a self-propelled tractor unit that can be remotely-controlled by the surveyor from a single access point whilst monitoring and recording images on a TV screen/storage system.

The speed of survey is very controllable. Current technology allows crawler systems from most manufacturers, with the correct wheel configuration, to be used in pipes from a minimum diameter of 100 mm (4 in). Advances in camera and lighting technology now permit surveys in pipes of over 2 m diameter.

Whichever system is used the modern CCTV survey is usually recorded direct to electronic storage with the facility for the surveyor to add comments and defect notes at any stage of the survey for examination later by the client engineers. The advances in Internet connectivity and Wi-Fi availability also enable survey results to be delivered directly to a client's cloud storage facility or its own web-based storage platform for retrieval and immediate assessment should the survey highlight the need for such attention.

Specially designed software today facilitates this recording (including images, defect assessment, distance down the survey line and notation process) as well as offering immediate access to survey results to the client software.

Preparation

Whether a pipeline should be cleaned or not prior to a CCTV survey depends on the needs of the survey. If a sewerage system, for instance, is known to have frequent blockages and/or surcharged conditions, it is more appropriate to survey without cleaning in order to determine the service condition as well as the structural condition. However, if a structural condition survey is required where significant defects are known or anticipated, cleaning of the pipeline in advance is necessary.

The camera itself should be clean, particularly the lens, in good operating condition and capable of producing an accurate image of the condition of the pipe. Generally in order to observe a round pipe, the camera should be positioned along the central axis of a circular pipe although this is not usually possible for diameters greater than 2,000 mm without additional equipment such as larger diameter tractor wheels or extending/telescopic camera support – care therefore is needed when reviewing a 3,000 mm diameter pipe say, in order to avoid mistakenly identifying an ovoid pipe! For egg-shaped pipes, the camera should be set at ⅔ of the vertical height.

The camera speed should allow all defects to be seen while not causing the operator to become distracted – these speeds (together with all defect coding etc.) are provided in the WRc document 'Manual of Sewer Condition Classification'. The preferred speed is dependent on the pipe size and ranges from 0.1m/s for pipes less than 200 mm diameter, 0.15 m/s for pipes of diameter 200 mm to 310 mm, and 0.2 m/s for pipes greater than 310 mm diameter – or as agreed with the Client's representative.

Lighting must be evenly distributed around the internal surface of the pipe, illuminating the pipe for approximately 2m ahead of the camera so that the image is of good colour and contrast.

In addition to CCTV cameras there is the potential on crawler-mounted systems to attach laser profiling systems that can measure the profile of the pipe as separate additional information for the client that may be used in the determination of any repair renovation or replacement requirement.
Also sonar imaging can assess pipe conditions below the water line and when used in tandem with a camera system and provides a composite image of the above and below water line conditions – see also the section on TISCIT.

Pan and Tilt

It is now very common for crawler systems to use Pan & Tilt cameras that allow closer inspection of defects, joints and lateral connections, providing a 360° view of a pipe's internal surface so that its structural integrity can be better assessed. Pan & tilt at features such as joints, lateral connections, etc. is recommended for all sewer surveys. In addition, fish-eye lenses permit a full 180° view without camera rotation; zoom lenses allow the inspection of a defect further in the distance when the survey is halted due to debris for instance.

The survey and assessment software available is continually changing and can ensure data entry is more accurate as well as providing service and structural condition grading. Some camera suppliers are also providing software to give panoramic views of a pipeline which can be viewed as 'flat' pipe and also as a predicted external 3-D view (see also Digital Scanning/Sett). Artificial Intelligence software to analyse the images is now available and this could soon eliminate the arduous task of reviewing and coding all the images produced (Software).

Digital Scanning or SETT

The Digital Scanning or SETT uses a digital, high-resolution scanner to produce a forward image of the pipeline under inspection, as well as a 360° image of the interior wall of the sewer at 90o to the survey route. A 360° scanning camera is mounted on a robotic, remote-controlled, wheeled tractor which travels through the pipe at a constant speed usually about 13 metres/minute (approximately 0.2 m/s).

The camera continuously scans the pipe's inner surface creating a series of adjacent section views covering the pipe's circumference. Specially developed computer software processes these scanned sections and stores them for further analysis as a single complete record of the survey run.

This makes it possible to view 100% of the pipe wall at the same angle and light intensity thereby minimising operator error that could result from image misalignment, light reflections, and shadowing. When the forward view is combined with the scan a three dimensional perspective can be produced.
The system consists of data collection and data processing components and the processing can be designed to automatically recognise pipe joints and lateral connection positions within the survey data. Pipe defects can be subsequently viewed by an analyst quickly and efficiently, immediately after the survey is completed. In some cases the potential defects are highlighted automatically to be checked by the analyst.

Survey runs can be completed far more quickly than is possible with conventional CCTV surveys. The automated data capture, at higher resolution than standard video recording, also ensures that the survey data is acquired with consistently higher detail than is achievable with standard CCTV survey techniques. This means that the data analysis is easier, faster and of a higher quality than that of traditional inspection systems. However it is a series of static images put together and does not show movement such as at small leaks or infiltration clearly, if at all.

TISCIT (Totally Integrated Sonar and CCTV Inspection Technique)

TISCIT (Totally Integrated Sonar and Camera Inspection Technique) technology utilises sonar and CCTV technologies together to create a unique and valuable inspection.

TISCIT technology combines CCTV with sonar imaging to provide a comprehensive inspection of large diameter pipes. This dual sensor system allows the operator to inspect a pipe regardless of flow conditions as well as without removing sediments from the pipe invert. CCTV operates above the water level and sonar sensors below it. A laser profiler is also included for the above-water level survey in some systems.

From low flow to surcharged, a TISCIT inspection will provide the most information possible. Remotely controlled cameras capture high-quality video and pictures of internal pipe conditions while the sonar provides information below the water surface including:

- Structural defects
- Cracks
- Fractures
- Broken Pipe
- Collapsed Pipe
- Offset joints
- Operational & Maintenance Issues
- Fats, Oils & Grease (FOG)
- Roots
- Infiltration & Inflow
- Sediment Accumulation
- Construction Features & Defects
- Intruding Service Lines
- Active Service Laterals
- Defective Point Repairs
- Cross-Bores

The sonar sediment report can also be a valuable tool that graphs the results of the TISCIT inspection, indicating the exact amount and location of deposits in a pipeline. This also allows the owner to calculate the amount of capacity potentially reclaimed by cleaning the pipeline.

Stationary Zoom Cameras

Instead of traversing a sewer with a movable CCTV camera, it is possible to carry out sewer inspection with a stationary camera with a high powered, remotely controlled zooming function and powerful lighting. The camera is lowered into a manhole on a telescopic pole, and then it is used to zoom in up to 40 m either side of the manhole, capturing images and video.

This enables rapid inspections to be carried out over a limited distance from a manhole making it a cost effective screening tool before deploying other inspection techniques.

Lateral Inspection

Various equipment manufacturers also now offer crawler mounted systems that are capable of inspecting not only the mainline pipe but also the lateral connections. In some instances this may be done to a limited extent with the pan & tilt camera type (see pan & tilt section).

Other systems offer independent extendable camera arms that can be played out into the lateral connection. This may be achieved using the camera on the end of a rod that allows the camera head to travel into the lateral directly to show images of the inside of the lateral pipe over a distance depending on the construction of the system. The images and data can be viewed, notated, stored and shared using the same software that the mainline inspection would utilise.

CCTV Software Options

Modern CCTV systems usually have on-board a digital recording system for the images produced by the CCTV camera. Software systems are available that allow the operator to input additional data such as industry standard defect codes and other notes that can then be saved with the images and other survey information collected in the camera's view such as a laser profile or sonar survey results.

For several decades the results of a pipeline survey have used industry recognised standard codes to define the defects seen on a survey. In more recent years this information has become increasingly required very quickly post-survey. Some software providers have developed systems that can not only capture and store the information but also pass this data via the internet or WiFi connection directly to the client's desk via a web-based cloud storage facility for immediate access and potentially immediate response in a severe pipe damage situation.

Software also exists that will analyse results semi-automatically, manage manhole survey reports, handle laser survey results, map defects onto CAD and map-generating and GIS systems. The software requirements of individual users will depend on the level of information required for the end use of the survey, so each client will have different needs and therefore levels of survey data recording requirements.

Leak Detection:

The tracing and location of leaks has become a major area of operation for water companies and others that utilise pipelines for fluid transport, including gas.

There are in general three main options that are available to locate leaks in pipes:

Acoustic – listening to the noise produced by a leak which produces a sound wave that propagates along the pipe material and through the fluid itself. This is known as noise correlation.

Pressure – detecting the change in pressure within the fluid column after it passes a leak point.

Tracer gas – this will also leak through any damage into the surrounding ground and can be detected from the surface over the leak point.
Alongside sophisticated modern technologies it is not uncommon to see water engineers out at all hours of the day, but more especially at night, with a metal rod and listening bud on the end probing water mains at access points or meter locations to listen for that all-telling noise that highlights a leak somewhere nearby.

Leak noise detection and correlation from surface

Noise correlation from surface outside of the pipe works by matching sound waves against each other. This is done by using sensitive microphones attached at strategic points on a pipeline network. By monitoring the sound waves travelling through the pipeline and noting the difference in arrival time at the microphones of matched sound signals, and knowing the approximate travel speed of the sound waves through the pipe material and fluid, a measure of the distance of the sound source from the microphones can be estimated. This identifies the location of the possible leak. Monitoring from a number of locations can help pinpoint this sound source more accurately. Portable systems or static monitoring systems can be used for this type of location operation.

Portable systems tend to be used where leaks (often visible at surface) have been reported and the precise location of the leak needs to be established prior to undertaking a pipeline repair. Network monitoring systems are used to ensure that leaks that may be less obvious are located before significant damage is done or before they are sufficiently large to appear at surface, thereby minimising fluid loss to the network owner.

In the case of gas pipes another method of leak location is the boring of small

monitoring the gas level in the substrate. In principle the higher the concentration the closer the probe hole is to the leak.

Leak detection from inside the pipe

Where access to the pipeline is limited, for example long lengths of pipeline with few access points, it may be necessary to locate any leaks from within the pipeline. This is still achieved using acoustic methods to locate leak noise.

In essence, instead of the microphone being located on the outside of the pipe it is placed inside the pipe and rodded or winched through, or the fluid flow is utilised to carry the device along the length of the pipe being investigated. As the microphone passes leak locations it picks up the increased noise level. The device is monitored by its distance into the pipe thus identifying the location of the leak. It should be noted that it may be necessary to complete a full utility survey prior to undertaking the leak detection work to correctly establish the route of the pipeline as changes in direction and depth may mean that accessing the pipeline may occur in the wrong place if the pipe is not on the expected line.

Another option for leak detection from inside the pipe is to monitor the pressure loss within the fluid after it passes a leak point. A specially designed pressure sensor is passed through the pipeline from a known access point on a pipeline. The pressure in the fluid is used to drive the sensor forward just sufficiently to move it. When the sensor passes a leak the pressure drops so that it is no longer sufficient to drive the sensor forward. The distance from the access point to the stop point indicates where the leak is located. Again it may be necessary to map the pipeline length fully prior to using this system or it may be possible add a locating sonde (similar to the walk-over directional control systems used in HDD) to the pressure sensor, which can be detected from surface to pinpoint the leak location.

Electric Leak Monitoring

Electric Leak Monitoring, also known as Focused Electrode Leak Location (FELL), is used in working pipelines. Essentially, a probe is passed through the pipeline within the fluid and an electric current is applied to the probe head. This is connected to an electrode driven into the ground close to the pipeline. Where no leaks are found the electricity is retained within the pipe. Where the probe passes a leak, electricity leaks out into the surrounding ground. This completes the circuit to the ground electrode and the voltage can be measured to provide a measure of the size of the leak. The location of the leak is indicated by the distance the probe has passed into the pipeline as with other systems described above.

Permanently installed leak detectors

The modern requirement to manage leakage effectively over time has led to a significant increase in the installation of permanently installed leakage monitoring systems. These systems may be installed to monitor a single length of pipe or with strategically placed microphones they may monitor whole networks within an area. The data produced can be either collected by personnel visiting the sites with Wi-Fi connectivity to a data storage system or may be connected directly to the main office using internet or Wi-Fi connection. Manufacturers provide specific software to analyse the data and highlight any anomalies that may be present that would indicate the presence of a leak and its location within the network. Various manufacturers offer such systems.

Condition Inspection:

Direct Pipe Wall Condition Inspection

Inspection of pipelines may be necessary to measure pipe condition, for example corrosion, loss of wall thickness, reduction in stiffness or other effects of stresses.

Remote Field Eddy Current (RFT) is a method of non-destructive testing using low-frequency AC to find and measure defects in metallic pipes. An RFT probe consists of an exciter coil (also known as a transmit or send coil) which sends a signal to a detector (or receive coil). The AC current is passed through the exciter coil which creates a magnetic field. The field travels outwards from the exciter coil, through the pipe wall, and along the pipe. The detector is placed inside the pipe two to three pipe diameters away from the exciter and detects the magnetic field that has travelled back from the outside of the pipe wall. In areas of metal loss, the field arrives at the detector with a faster travel time and greater signal strength due to the reduced path through the metal. Measuring the distance of the emitter into the pipe highlights the location along the pipe length of the defect.

Near Field Eddy Current (BEM or NFT) technology uses two coils – a transmitter and a receiver. Typically the receiver coil is close to the transmitter coil, taking advantage of the transmitter's near-field zone – that is, the zone where the magnetic field from the transmitter coil induces strong eddy currents, axially and radially, in the tube wall. The probes operate within the same frequency range as Remote Field Eddy Current (RFT) probes. NFT is specifically suited to detecting corrosion, erosion, and pitting inside ferrous metal pipes.

Magnetic Flux Leakage (MFL) – Magnetic flux leakage (also known as TFI or Transverse Field Inspection technology) is a magnetic method of non-destructive testing used to detect corrosion and pitting in metallic pipes. The principle uses a powerful magnet to magnetise the steel in the structure. Using an MFL tool a magnetic detector is placed between the poles of the magnet to detect the leakage field. At areas where there is corrosion or missing metal, the magnetic field 'leaks' from the metall. Trained specialists interpret the recording of the leakage field to identify damaged areas and to estimate the depth of metal loss. Typically, an MFL tool consists of two or more bodies, one carrying the magnet and sensors and the other containing the electronics and batteries. The magnet body houses the sensors that are located between powerful rare-earth magnets. The magnets are mounted between the brushes and tool body to create a magnetic circuit along, within and through the pipe wall. As the tool travels along the pipe, the sensors detect interruptions in the magnetic field. Interruptions are typically caused by metal loss which in most cases indicates corrosion, and the dimensions of the potential metal loss are identified. Features other than corrosion will also be highlighted, for example manufacturing defects and mechanical damage such as shovel gouges. The technology indicates length, width and depth of the defect as well as its radial position around the pipeline. The sensors detect the changes in the magnetic field in the three directions (axial, radial, or circumferential) to enable the anomaly to be characterised. The sensors are typically oriented axially which limits data to axial conditions along the length of the pipeline. An MFL tool can take sensor readings based on either the distance the tool travels or on increments of time. The choice depends on many factors such as the length of the run, the speed that the tool intends to travel, and the number of stops or outages that the tool may experience. The second body contains the electronics tool and the batteries, and in some cases an IMU (Inertial Measurement Unit) to tie location information to GPS coordinates. On the very rear of the tool are odometer wheels that travel along the inside of the pipeline to measure the distance and speed of the tool.

Ultrasonic methods (UT) – Ultrasonic non-destructive testing is a method of characterising the thickness or internal structure of a structure under test through the use of high frequency sound waves. The frequencies used for ultrasonic testing are many times higher than the limit of human hearing, most commonly in the range from 500 KHz to 20 MHz. Ultrasonic testing is widely used on metals, plastics, composites, and ceramics. High frequency sound waves are very directional, and they will travel through a medium (like steel or plastic) until they encounter a boundary with another medium (like air), at which point they reflect back to their source. By analysing these reflections it is possible to measure the thickness of a structure, or find evidence of cracks or other hidden internal flaws. In ultrasonic testing, an ultrasound transducer connected to a diagnostic machine is passed over the object being inspected. The transducer is typically separated from the test object by a couplant which may be oil or water, for example. There are two methods of receiving the ultrasound waveform, reflection and attenuation. In reflection (or pulse-echo) mode, the transducer performs both the sending and the receiving of the pulsed waves as the sound is reflected back to the device. Reflected ultrasound comes from an interface such as the back wall of the object or from an imperfection within the object, for example a pipe crack. The diagnostic machine displays these results in the form of a signal with an amplitude representing the intensity of the reflection and the distance, based on the time of flight of the reflected signal. In attenuation (or through-transmission) mode, a transmitter sends ultrasound through one surface, and a separate receiver detects the amount that has reached it on another surface after traveling through the medium (pipe wall). Imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

Coating Defect Surveys and Pipe Current Mapping – There are two main techniques for the undertaking of a Coating Defect Survey: Direct Current Voltage Gradient (DCVG) survey; and Pearson Coating Survey.

DCVG is an accurate and economic means of locating coating defects. When a DC current is applied to a pipeline in a similar manner to cathodic protection, ground voltage gradients are created due to passage of current through resistive soil. Well coated pipelines have a high resistance to earth. Where there are defects, measurable voltage gradients can be detected at ground level and the larger the defect, the greater the current flow. By applying a DC current to a pipeline at a regular pulsed frequency using interrupters enables coating defects to be distinguished. Defects found by a DCVG survey can be sized and mapped by GPS coordinates.

The Pearson Coating Survey is a survey technique to detect external coating defects, which employs an AC signal impressed onto a pipeline and compares the potential gradient between two mobile earth contacts. At coating defects increases in voltage gradient occur which are noted and recorded as the survey progresses.

Pipe to soil potential – stray current mapping – pipe-to-soil potential is the voltage potential generated between a buried pipe and its surrounding soil as a result of electrolytic action and a cause of electrolytic corrosion of the pipe. Detection of this phenomenon is achieved using stray current mapping which is a safe and cost-effective way of mapping the magnitude and direction of stray current interference on a pipeline. When pipe coatings are damaged a destructive chemical reaction occurs at the point of the defect, this causes current to flow from the pipe to the ground. This current and any other in the pipeline from other sources is known as stray current. These can significantly contribute to the corrosion process. Stray current mapping devices allow survey that can completely map and accurately pinpoint where current discharge is taking place from above ground without connection to the pipeline. Various systems are available and can be single survey or term monitoring systems which are used over several hours to determine the stray current activity.

MULTI-SENSOR ROBOTS

Multi-sensor robots for use in pipelines essentially utilise combinations of some of the technologies listed on a single carriage or crawler. This can include CCTV, sonar and laser profilers in sewers. They can also utilise in-pipe GPR (Ground Penetrating Radar), also known as Pipe Penetrating Radar (PPR), and LIDAR (Light Detection And Ranging).

Sonar Surveys

Category

Inspection and Detection for pipes and ducts both Gravity and Pressure. Laser profiling projects a laser line onto the internal circumference of the pipe being inspected. This is viewed and the image captured by a CCTV camera. The resulting image can be measured to provide an accurate profile of the inside of the pipe. This shows any ovality, encrustation, loss of wall material due to corrosion, etc.

Application

The laser profiler is usually used in conjunction with a CCTV inspection system that is crawler-mounted. These systems may be used in sewers, water mains, gas mains, culverts, rising mains etc. Normal practice is for the pipe to be empty, as for CCTV, although some systems will operate in gravity pipes that are partly full but Will provide data only for the area above the surface of the liquid.

Systems are available for use with crawler-mounted CCTV systems in the full range of diameters in which they operate, above and can be used over almost any length, this being dependant on the length and capacity of the umbilical cable.

Limitations are that the pipeline should be as clean as possible to ensure the best view of the inner surface with obstructions removed when encountered.
Benefits

Laser profiling enables engineers to view and measure the changes in diameter of the inner surface of a pipeline without the need for man-entry operations It can highlight defects and provide a permanent record of the state of the asset at the time of the survey, as a baseline against which to measure any future deterioration in subsequent surveys, thus adding to the data recorded by using CCTV alone.

The system can be used to determine the extent to which a pipeline has deformed and therefore the type of renovation or replacement technology that might be employed to provide a working solution to any problems occurring in the pipeline. Data and images from currently available systems can often be accessed via the internet or Wi-Fi from almost any location enabling survey data to be viewed almost immediately after a survey is completed. This enables immediate responses to be made if any pipeline shows such serious defects that such a response is necessary.

Technology Description

Since its introduction in the early 1970's, Closed Circuit Television (CCTV) technology has made major advances in its technical capabilities. The addition of a Laser profiling system enables variations in the pipe profile to be determined.

Crawler-mounted CCTV camera systems are usually employed with Laser Profilers as the CCTV image of the projected laser line is what provides the basis on which to measure deformations recorded by the Laser system. During the course of a CCTV survey the laser projects a circular ring onto the inside of the pipeline wall. If the pipe is still circular (or any non-standard shape) the ring profile remains constant in the CCTV image. If the pipe shape changes the shape of the laser ring changes in accordance with the deformation encountered. Thus the change in ring shape indicates the change in the inner profile of the pipeline.

This knowledge is required if a renovation technique is to be employed, particularly where the renovation product is solid state and inflexible to provide the minimum dimensions of the pipe into which the renovation product must fit. For flexible pipes, such as GRP, PE and PVC, it also provides indication of potential incipient structural failure.

Specially designed software facilitates this recording (including images, defect assessment, distance along the survey and notation process) as well as offering immediate access to survey results to the client software. Armed with this information the design engineer may then design the appropriate renovation method.

This add-on may also be used in conjunction with other additional survey technologies such as Sonar surveying.

Laser Profiling

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Sonar:

Sonar surveying enables survey of pipes that are partially full of liquid. Sonar surveys below the surface of the liquid and provides data of the profile of the pipe invert. This may show siltation and pipe defects that cannot be detected by CCTV.

Application

Sonar surveying is utilised for inspection of pipes and ducts that cannot be entered by man-entry means either because they are too small or for safety reasons.

Systems are available for use on crawler-mounted CCTV systems or floated survey carriages from diameters into which the survey system will fit up to man-entry sizes and can be used over almost any length, this being dependant on the length and capacity of the umbilical cable to carry image data and the camera system to pull the cable through the inspected pipeline.

The pipeline should be as clean as possible but not necessarily totally clean as the sonar will detect siltation but this may obscure defects in the pipe invert.

Sonar system may be used independently or more usually in association with a CCTV survey system with the CCTV imaging the pipeline above any product flow level and the sonar imaging the condition of the pipeline below the product level and any silt in the invert.

Benefits

Engineers w sonar survey data can to view the inner (usually invert) surface of a pipeline without the need for the pipe to be completely empty.
Data and images from currently available systems can often be accessed via the internet or Wi-Fi from almost any location enabling survey data to be viewed almost immediately after a survey is completed. This enables immediate responses to be made if any pipeline shows such serious defects that such a response is necessary.

Technology Description – what it is

Sonar survey methods may be used in a wide range of pipeline inspection circumstances, including pressure pipes as well as gravity sewer surveys and is particularly applicable in pipes where total cleaning or emptying is just not possible due to access or operational limitations.

Usually crawler-mounted or floatation system mounted along with a CCTV survey system, the sonar survey sends a sound wave from the sonar transducer through the coupling medium of the liquid in the pipe to the pipe wall. The reflection time of this sound wave indicates the distance of the pipe wall from the transducer. If the pipe wall is undamaged the reflected sound will show no discrepancy between the expected and recorded reflection time. Where displacement is found in the pipe wall at a crack or similar defect the sound reflected will arrive at the receiver at different than expected times and the image profile will show this as a deformation in the image created by the sonar software.

This allows defects to be highlighted that cannot be viewed with a visual CCTV system.

Advances in Internet connectivity and Wi-Fi availability also enable survey results to be delivered directly to a client's cloud storage facility or its own web-based storage platform for retrieval and immediate assessment should the survey highlight the need for such attention.

Specially designed software facilitates this recording (including images, defect assessment, distance down the survey line and notation process) as well as offering immediate access to survey results to the client software.

TISCIT (Totally Integrated Sonar and CCTV Inspection Technique)

TISCIT (Totally Integrated Sonar and Camera Inspection Technique) technology utilises sonar and CCTV technologies together to create a unique and valuable inspection.

TISCIT technology combines CCTV with sonar imaging to provide a comprehensive inspection of large diameter pipes. This dual sensor system allows the operator to inspect a pipe regardless of flow conditions as well as without removing sediments from the pipe invert. CCTV operates above the water level and sonar sensors below it. A Laser Profiler may also be included for the above-water level survey in some systems.

From low flow to surcharged, remotely controlled cameras capture video and pictures of internal pipe conditions while the sonar provides information below the water surface including the majority of structural defects and construction features detected by the CCTV above the surface. Sediment accumulation and locations of lateral connections are also detected. In some cases it may be possible to detect root intrusion, infiltration & inflow, and protruding lateral connections
The sonar sediment report provides graphs of the results of the TISCIT inspection, indicating the exact amount and location of deposits in a pipeline. This enables calculation of the amount of capacity that potentially may be reclaimed by cleaning the pipeline.

Laser Profiling:

Laser profiling projects a laser line onto the internal circumference of the pipe being inspected. This is viewed and the image captured by a CCTV camera. The resulting image can be measured to provide an accurate profile of the inside of the pipe. This shows any ovality, encrustation, loss of wall material due to corrosion, etc.

Application

The laser profiler is usually used in conjunction with a CCTV inspection system that is crawler-mounted. These systems may be used in sewers, water mains, gas mains, culverts, rising mains etc. Normal practice is for the pipe to be empty, as for CCTV, although some systems will operate in gravity pipes that are partly full but Will provide data only for the area above the surface of the liquid.

Systems are available for use with crawler-mounted CCTV systems in the full range of diameters in which they operate, above and can be used over almost any length, this being dependant on the length and capacity of the umbilical cable.

Limitations are that the pipeline should be as clean as possible to ensure the best view of the inner surface with obstructions removed when encountered.

Benefits

Laser profiling enables engineers to view and measure the changes in diameter of the inner surface of a pipeline without the need for man-entry operations It can highlight defects and provide a permanent record of the state of the asset at the time of the survey, as a baseline against which to measure any future deterioration in subsequent surveys, thus adding to the data recorded by using CCTV alone.

The system can be used to determine the extent to which a pipeline has deformed and therefore the type of renovation or replacement technology that might be employed to provide a working solution to any problems occurring in the pipeline. Data and images from currently available systems can often be accessed via the internet or Wi-Fi from almost any location enabling survey data to be viewed almost immediately after a survey is completed. This enables immediate responses to be made if any pipeline shows such serious defects that such a response is necessary.

Technology Description

Since its introduction in the early 1970's, Closed Circuit Television (CCTV) technology has made major advances in its technical capabilities. The addition of a Laser profiling system enables variations in the pipe profile to be determined.

Crawler-mounted CCTV camera systems are usually employed with Laser Profilers as the CCTV image of the projected laser line is what provides the basis on which to measure deformations recorded by the Laser system. During the course of a CCTV survey the laser projects a circular ring onto the inside of the pipeline wall. If the pipe is still circular (or any non-standard shape) the ring profile remains constant in the CCTV image. If the pipe shape changes the shape of the laser ring changes in accordance with the deformation encountered. Thus the change in ring shape indicates the change in the inner profile of the pipeline.

This knowledge is required if a renovation technique is to be employed, particularly where the renovation product is solid state and inflexible to provide the minimum dimensions of the pipe into which the renovation product must fit. For flexible pipes, such as GRP, PE and PVC, it also provides indication of potential incipient structural failure.

Specially designed software facilitates this recording (including images, defect assessment, distance along the survey and notation process) as well as offering immediate access to survey results to the client software.

Armed with this information the design engineer may then design the appropriate renovation method.

This add-on may also be used in conjunction with other additional survey technologies such as Sonar surveying.

DETECTION:

NSPECTION AND DETECTION FOR PIPES AND DUCTS BOTH GRAVITY AND PRESSURE.

Detection

Application – what it does/is used for [or chart showing suitable for/not suitable for.

There are many instances in the crowded underground environment where services, either operational or abandoned, are not known about or shown on any existing subsurface maps. The systems described here are those that may be utilised to locate and map these buried services to update existing plans or as a safety check before any excavation works or other activities are undertaken.

Benefits

Any unknown utility or services may be a significant safety hazard for excavation or underground works. Detection of those utilities enables engineers and planners to use current and up to date information on the positions of existing services in three dimensions to understand how they interact with each other and may interact with any planned new works. This allows planning to avoid conflicts. This minimises the potential for accidental damage, minimises extraneous costs or service outages and maximises operator safety and service security for the network owner and the end-user.

Radio & Electromagnetic:

Radio/Electromagnetic Detection essentially comprises a receiver/amplifier connected to an antenna that detects the electromagnetic field created when a current passes through a buried cable. The precise location of the cable is identified by passing the receiver over the ground in the area above the cable; the peak strength of the electromagnetic field indicates when the receiver is closest to the cable, which is usually directly vertically above it. The survey is started over a wider area and narrowed as the signal is pinpointed. The scan is then repeated at 90 degrees to the first pass to verify the location. Certain equipment may also provide an estimate of the depth at which the cable runs. This process is repeated at intervals along the potential route of the cable establishing its route in plan and the depth variations along its run. Where the service being searched for is not a power carrying cable but has the facility to carry a generated signal, for example a metal water pipe, a signal generator may be attached to it at an accessible chamber to establish an electromagnetic field which can then be followed using the same survey technique.

These tools are usually referred to as Cable Avoidance Tools (or CAT) systems; the artificial signal generation system is often referred to as a CAT & Genny.

Ground Penetrating Radar:

Where the potential buried service or underground obstacle is not current-carrying nor capable of having a signal artificially generated along it, another option is necessary to establish the route and depth profile. One option for this is Ground Penetrating Radar or GPR.

GPR is an advanced, non-invasive sub-surface imaging technique that typically uses short pulses of electromagnetic energy to look into the underground. GPR can detect through soil, concrete, tarmac, rock, wood, ice and even water. It is quick, easy to use and inexpensive in comparison with other investigation methods. It is capable of probing down to a few tens of metres (depending on the system type & ground conditions) and provides the user with a cross-sectional image of the sub-surface.

By selecting the correct frequency GPR is very good at determining the shape, size, extent and depth of a buried object. Higher frequency antennae tend to penetrate less deeply but can define near-surface objects better. Lower frequency antennae penetrate more deeply but provide less definition. GPR can be used to find pipes, foundations, voids, trenches, geological layers, reinforcing bars, etc. It works best in dry ground environments but can also work well in saturated granular soils. It does not work very well in saline conditions or in saturated clays.

As the GPR system is moved over the surface, pulses of electromagnetic energy are directed into the ground from a transmitting antenna. The energy travels though the ground where buried objects reflect/scatter part of the energy back to the surface, which is picked up by the GPR's receiving antenna. These returning signals are converted in to a GPR section (or radargram) which is displayed on a computer screen in real-time. The trained operator or sometimes a specially trained data analyst then uses knowledge, skill and experience to assess the data and interpret the features seen in the section.

This data may then be presented in different forms using software packages to display the results of the survey so that the client can interpret and understand the results.

There are however regulations as to how and where GPR may be used due to the radio emissions, so any operator or end-user needs to be fully aware of these. Several types of GPR equipment are available including single antenna, multiple antenna, walk-behind/push trolley and ride-on systems. Each has its position in the market and the selection of equipment will depend on the scale, range and type of survey that is to be undertaken.

The majority of systems are used in a format known as 'ground-coupled' which means that the antenna is in contact with the surface of the ground (more or less).

Air launched GPR is also used; the antennae are mounted on a framework that does not bring them into contact with the ground surface, or mounted on airborne transport, for example a drone. However current regulations do not allow air launched GPR to be use without specific permission from local regulatory authorities – this includes drone mounted systems.

Mapping & GIS:

With ever increasingly crowded subsurface the need to know what is running beneath any ground surface has become imperative before considering how to install, repair or renovate buried services and utilities.

This has led to the development of digital mapping software which can be interfaced with the output from various mapping and detection technologies. As well as interfacing with GPR and CAT systems output used in general utility mapping surveys (see Radio/Electromagnetic Detection and Ground Penetrating Radar), using GIS (Geographic Information Systems) and GPS it is possible to engage with the data generated using in-pipe mapping systems such as Gyroscopic Mapping technology. Gyroscopic Mapping systems usually comprise a Gyro Compass contained within a wheeled tubular device that is winched or rodded through the pipeline being surveyed.

Winching is used in longer surveys. The device includes an inclinometer and a data recording system. To complete a survey, assuming a winched operation, a winch cable is passed through the pipe over the survey length between accessible access points/manholes. The Mapping unit is attached to the winch at the start position and surveyed accurately to provide a reference starting position and elevation. The unit is then winched through the pipeline. The gyro compass senses any changes in direction and the inclinometer any changes in grade. Distance measure is also taken as the unit advances. This information is recorded on-board (it may be that for shorter surveys the data feed may be direct to the start position via a data cable).

On completion of the survey and knowing the accurately surveyed start point, the changes in direction and grade and the known distance from the start point provide inputs to mapping software or even paper plans to show the linear route between the start and end point in 3 dimensions. This identifies depth below surface at any given distance and sumps or humps along the route that may cause flow disruption. The digital data can be stored for future reference.

Cleaning Methods:

CLEANING OF PIPES AND DUCTS FOR BOTH PRESSURE AND GRAVITY NETWORKS.

Application

Cleaning is applicable to Gas, Water, Sewer/Drainage/Culvert pipes and may be used where cable ducting becomes contaminated due to inflows from outside sources. Cleaning can be achieved over all diameters of pipe irrespective of soil types.

Limitations – The main limiting factor for pipe cleaning may be the length of pipe requiring cleaning at any one time dependent on the type of cleaning system of the technology being used. Access for the equipment may also be problematic given the need for vehicle access and access to a water source, again dependent on the type of equipment used.

Benefits

Cleaning is the most basic of rehabilitation methods in trenchless technology. Simply cleaning a pipeline effectively can reinstate its specified operations requirements without recourse to other most costly and challenging renovation options. It can also be achieved usually with minimum disruption to services and the local community as well as minimal impact on the environment provided the works are undertaken with the collection and correct disposal of waste as a priority.

Technology Description

Pipe cleaning can be achieved using several different techniques some requiring technologically advanced equipment and others not. These options may include:

Drag Scraping:

SCRAPING/ RACK FEED BORING/ABRASIVE CLEANING –

Scraping is a process that involves the use of spring steel scraper blades that are attached to a winch cable that is drawn back and forth through the pipe to remove particularly hard encrustations that may not be attacked effectively using jetting or other techniques. This method can be used on a wide range of pipe diameters usually from 75 mm to 1,000 mm. Various types of scraper are available each designed to handle different forms of build-up/encrustation.

Most however do need to have an open pipe to some degree as most do require the installation and use of a winch wire to progress the scraper through the pipe.

Scrapers can take many forms but generally are either in the form of a wire brush, sprung metal teeth or circular rubber sections that are designed to fit snugly inside the pipe diameter being cleaned.

The scraper is moved backward and forwards through the pipe usually with the use of CCTV to observe the state/success of the cleaning operation until the operator is satisfied with the cleanliness of the pipe. Another form of scraper is the rotating flail which comprises a metal flail on the end of a rotating rod system operated from surface by a rod pulling/pushing machine. The rotating flail dislodges unwanted material from the pipe inner wall. Jetting is then usually used to remove this debris created.
The disadvantage of scraping/ rotating flail works/abrasive cleaning as a technique is that, unless managed very well and undertaken with the minimum of force required to make cleaning happen, severe damage can be caused to pipe being cleaned.

As well as scraper and flail cleaning, there are other forms of abrasive cleaning which involve the use of additives to a water supply or the use of abrasive cleaning materials.

These can be utilised across a range of diameters but in larger diameters are less used than say high pressure water jetting. The techniques may involve the addition of sands or gravels to a water flow which is passed through a pipe. As the additive is stirred by the turbulent flow it abrades against the pipe wall dislodging encrustations and lifting sediments into the water flow. The flow is collected and may be treated to remove detritus with the additive being recycled. The additive may also come in the form of ice which acts in similar fashion to gravel. It does not however need collecting and separating from the waste created as it melts to become part of the final water flow. Detritus is disposed of according to current regulations.

Abrasive cleaning can also be achieved using sand sheets, wire brushes or similar attachments which may be used on the end of a rotating shaft or winch cable. The equipment is passed through the pipe back and forth to affect the cleaning action. Jetting may be utilised to remove waste materials.

Water Jetting:

HIGH PRESSURE WATER JETTING

This is a commonly used technique that employs high-pressure water jets from a specially designed pressure head that is fed from a surface located pumping unit.

The jetter head is passed through a pipe line at any desired speed and the water jets from the head are designed to hit the inner pipe wall so dislodging any debris attached to it.

The jets also pick up and remove any sediment in the pipe invert combining them into the outflow of water from the pipe. The pressure of the water ensures that all debris and silt are removed from the pipe in the direction of travel of the jetting head. Some water jets are also designed to be powerful enough to cut through root intrusions. Where water jets are insufficient to achieve root removal specially designed robots are available with low volume, very high pressure jets or rotating blades that will make removal possible. Further pressure jetting is then used to remove the debris created.

Recent developments have made these systems much more environmentally friendly with the introduction of Recycling jetters. These units not only operate with the jetter hoses to clean the pipes but also vacuum/suction equipment to recover the waste produced in the cleaning process. This recovered water is then filtered with the detritus being placed in a waste tank on board the jetter rig with the filtered water being returned to the jetter pump for reuse. Ultimately this has two advantages: first there is a much reduced need for a supply of clean water for the operation to successfully complete and second, the potential for waste spillage into the environment downstream of the work site is minimised.

An important aspect of the use of high pressure water jetting as a cleaning technique is that the correct jet nozzle should be utilised for the particular job in hand. Depending on the nature of the cleaning required nozzles are available for simple sediment removal through to hard encrustations and root cutting (as mentioned previously).

It is vital that for most pipes a thorough inspection is undertaken to establish the type of cleaning required before selecting type of cleaning nozzle or even range of nozzles that needs to be used. Consultation with experience contractors and equipment manufacturers will also aid in this selection process.

A wide range of jetter units is available from a number of manufacturers in a range of sizes and capacities to suit most pipe cleaning applications.
It should be noted that high pressure water jetting can be utilised in both pressure and gravity networks. The correct equipment and nozzle selection will depend on the type of network being cleaned as the deposits being encountered will be different for the type of pipe involved. This may also affect the form of disposal that will be required by the regulations depending on the type of waste created by the cleaning processes used.
There is a high pressure water jetting option that places the high pressure jets right against the pipe inner wall where water pipes and other pressure mains require cleaning. This ensures the highest pressure at the point of

cleaning instead of a reduced pressure that might occur with a nozzle located in the centre of the pipe diameter.

FLUSHING

Pipeline flushing is achieved in one of two ways. The first is the use of high volume/low pressure water where a volume of water is pumped into a pipeline to pick up loose sediments and scale which is passed downstream to a collection point for disposal.

Pigging:

PIGGING – SOFT PIGS/ABRASIVE PIGS/ICE PIGGING

Pigging as a cleaning technique can have two functions. First where other cleaning methods have been utilised, a close fit pig may be passed through a pipe to make a final cleaning run to ensure that all possible debris has been removed. These would tend to be soft pigs made from flexible materials, plastics or sponges. Secondly, where a limited amount of cleaning is required some pigs are designed with abrasive, rough outer surfaces that in themselves may offer sufficient cleaning for the pipe.

Pigs are normally pushed through pipelines using either compressed air or water pressure, between two access points or may be operated via a winch cable. The technique of Ice Pigging is also possible whereby a flow of water is passed through the pipe which has a high degree of solid ice as a component. The ice particles act like a form of gravel and abrade the pipe wall to remove scale and detritus and stir sediments into the flow. It does not however need collecting and separating from the waste created as it melts to become part of the final water flow. Detritus is disposed of according to current regulations.

Air Sourcing:

AIR SCOURING

Air scouring is a particular form of abrasive cleaning that works by using filtered compressed air, injected into the mains via hydrant or air insertion point to propel a small volume of water at a high velocity.

When the valve upstream of the air entry point is opened slightly, the filtered compressed air mixing with water creates a vortex that travels through the isolated section removing sediments, bacteriological slimes or biofilm and soft mineral scale through a scour point at the other end of the pipe. Once water exiting the pipeline is clear, cleaning is complete and the water supply is restored to the pipe section.

Renovation:

Pipeline Replacement:

Application

Pipeline Replacement is applicable to all pipelines and ducts including networks which have both gravity and pressure operating regimes. It can be utilised to replace water mains, gas mains, oil pipelines, industrial pipelines, rising mains (pressurised sewer mains), sewers, ducts and culverts.

The application of any particular replacement technique is influenced by several parameters that include the system capabilities, the location and construction of the existing asset, ground conditions and the design of the replacement asset. Some of the key aspects that need to be considered are:

- Depending on the system used, replacement operations can be applied over a range of existing pipe diameters and varying lengths.
- The techniques may be limited in application by the prevailing ground conditions i. e. some techniques may not function in specific soil conditions or where pebbles, stones and boulders are present. When planning a pipeline replacement operation, a full ground investigation should be undertaken that also includes the position of any other utility apparatus that is in close proximity to the pipe to be replaced.
- Some techniques are limited by the construction of the pipes that are to be replaced and depend on whether they are made of brittle or ductile material. These limitations will be addressed within the following sections that cover the individual techniques.
- It is also possible with most of the pipeline replacement systems to upsize the existing pipe to a greater diameter and consequently improve the operating capacity. Up size replacement is dependant on the ground conditions being suitable.
- Some pipe replacement systems may create interaction between the pipeline being replaced and other nearby utilities and services through ground movement and vibration. If the adjacent utility assets are too close to the asset being replaced their operation and structural integrity may be affected by the replacement process. Interaction of this type should be avoided wherever possible.

Benefits

The benefits of pipeline replacement systems include:

- The replacement pipeline utilises the bore of the existing asset.
- Upsizing can be achieved to increase capacity or in the case of ducting make available more space for other services.
- Minimal footprint requirements to complete the operation as the systems can be utilised through relatively small access and reception pits or existing pipeline accesses such as chambers and manholes.
- Minimal excavation results in reduced disposal of excavated material, lower requirement for imported backfill material leading to fewer traffic movements with an overall reduction in the carbon footprint of the works
- The techniques can replace ageing networks relatively quickly and efficiently, with minimal interference to customer supplies.
- Reduced time on site limits traffic disruption and inconvenience to the general public.

Pipe Bursting:

Pipebursting uses systems that break the existing pipe structure, expand the size of the void created to enabling the replacement pipe to be inserted into it. This can be achieved in one of three ways:

- Dynamic Pipebursting (pneumatic machine system)
- Static Pipebursting (hydraulic rod system)
- Expansion shell bursting (hydraulic machine system)
-

Dynamic Pipebursting utilises equipment that is based on that used for Impact Hammer installations.

The dynamic pipebursting machine consists of a pneumatically powered impact hammer that is fitted with an expansion sleeve that is sized to provide the required void to accept the replacement pipe.

For size for size replacement the expansion sleeve is greater in diameter than the pipe being replaced and for upsizing the sleeve is sized to ensure the replacement pipe can be readily installed.

A winch cable is passed through the existing pipe and is attached to the front of the pipebursting machine. The winch is then used to draw the pipebursting machine into the existing pipe.

As the impact hammer is operated its forward thrust reacts against the force within the winch cable and advances the pipebursting machine forward into the pipeline. It fractures and fragments the old pipe and displaces the fragments radially outwards into the surrounding ground.

The soil adjacent to the pipeline is compressed to provide a void of sufficient size to accept the new pipe which is introduced directly behind the pipe bursting device. The winch cable also acts as a guide to ensure that the pipebursting machine maintains its position within the bore of the existing pipe and does not deviate into the surrounding ground.

The replacement pipe is usually attached to the rear of the pipebursting machine and is pulled into position as it advances. Once the pipe bursting machine arrives at the target excavation it is detached from the replacement pipe which is then ready for connection to the pipeline network.

The following should be noted in relation to the operation of this system:

This system operates best in compressible soils such as soft clays. Hard clays and dry well graded sands pose the most challenging conditions as these soils are much more difficult to displace.

The pipe to be replaced should be constructed of a brittle material such as cast iron, vitrified clay, unreinforced concrete, asbestos cement etc. Pipes made from ductile materials such as steel or ductile iron can be replaced but special pipe splitting equipment is required which is detailed below. It should be noted that there is the potential for the broken shards of the existing pipe to be orientated so that they are not fully pushed into the surrounding ground and any sharp protruding edge or point can cause surface scoring on the outer circumference of the replacement pipe. This is a particular problem when a semi-rigid pipe such as those manufactured in polyethylene are selected as the replacement pipe. Care should be taken in selecting the SDR rating of the replacement PE pipe to ensure that it has adequate wall thickness to operate at its design pressure rating should any minor surface scoring occur during installation. Polyethylene pipes with a hardened outer skin are available which can be used to help overcome this potential problem.

Static Pipebursting utilises a hydraulically powered push/pull rig that can advance and retract metal rods through the existing pipe applying significant tonnage to the rods as they are retracted. The pipebursting rig is set up in a launch access pit or manhole (smaller machines are available to suit this latter application). The replacement process commences with the rig used in push mode to introduce a string of steel rods inside the pipeline to be replaced. Once the reception point has been reached, the bursting head, which is a static steel expander cone, is fixed to the lead rod.

The replacement pipe is then attached to the bursting head and the rods are drawn back to the launch point with the rig in pull mode. This action fragments the existing pipe, pushes the shards into the surroundings ground, creates the required void and simultaneously installs the new pipe. The previously prepared new pipe string which is usually a polyethylene pipe is attached to the bursting head via a swivel. Once the bursting head arrives at the launch pit the assembly is removed and the new pipe is in position and ready to be connected to the rest of the network.

As with Dynamic Pipebursting there may be interaction between the broken shards of the old pipe and the replacement pipe so similar precautions should be taken when selecting the new pipe.
Repair collars that may be in place on the existing pipe can cause a problem as they are usually not made of a brittle material that the bursting head can fracture. However, the bursting head can be designed so that it incorporates cutting blades that will allow these potential obstacles to be overcome. They are designed to cut through these collars rather than break and fracture them, eliminating the threat.

Another form of Static Pipebursting is the use of a cable-based system. Here instead of using bursting rods to apply the bursting force when pulling back a bursting head a wire cable is used. These systems are normally used on small diameter pipes over relatively short distances and they have the following advantages over other rigs:

- They are lightweight and compact
- They have a small footprint and can be used from small excavations or chambers
- They are easier to transport, install and use because once in place, unlike bursting rods, the cable does not have to be handled by the operator during the bursting process.

The operation of this system is very similar to that of rod based systems.

Expansion Shell Pipebursting utilises a specially designed machine which is usually hydraulically powered to provide lateral bursting power, but they have no forward motive power.

The unit must be winched through the existing pipe to allow it to be used to complete the pipe replacement. This system is not favoured for replacing long lengths of small diameter pipes as it is far more time consuming than the dynamic or static pipe bursting systems. Its main application is for sewer replacement as due to the bursting heads short length it can be introduced into the existing pipeline via existing manholes eliminating the need for expensive deep access excavations.

For the operation, a winch cable is passed from the reception point through the existing pipe to the launch access pit or manhole. The expansion shell bursting head is attached to this cable and placed inside the existing pipe. The new pipes which are normally short length with integrated push fit joints are attached to the rear of the expansion shell unit.

A hydraulically-powered pushing unit is used to push the replacement pipes behind the expansion shell unit as it advances. A tensioning system can be used to ensure that the replacement pipe joints remain intact during the replacement process. The expansion shell equipment is pulled into the pipe and the short distance that it is moved into the pipe is a function of its length. The hydraulic mechanism within the bursting head is activated and this causes the shell to expand. This expansion exerts significant lateral force onto the old pipe which fractures and fragments it and pushes the shard into the surrounding ground. The shell is then retracted to its normal position and winched further into the existing pipe by a distance that is equivalent to the length of the shell bursting head and the process is repeated. This procedure is continued over the full length of existing pipeline being replaced until the shell bursting head reaches the winch access pit. The shell bursting head is then removed leaving the new pipe in place ready to be restored to service.

Careful consideration of the ground conditions should be made before selecting this system with the short length pipe option as the following problems can occur:

- In very wet soft conditions, such as running sand, joint sag may occur due to the pipes sinking under their own weight. In addition, expansion shell machines have open channels when in the expanded position and this can allow sand to enter into the machine and stop its operation.
- In conditions where high skin friction is expected, such as very soft clay, there is the potential to damage the replacement pipe joints due to the exertion of jacking forces that are greater than the design joint strength during pipe installation.

Again, as with Dynamic and Static pipebursting, there may be interaction between the broken shards of the old pipe and the new pipe so similar precautions should be taken when selecting the new pipe.

Pipe Splitting:

Pipe Splitting is undertaken using the same hydraulically-powered push pull rig and steel rods that are utilised for Static Pipe Bursting. However, for pipe splitting the bursting head is specifically designed to cut the existing pipe as opposed to fracturing it. The reason for this is that the existing pipe that is to be replaced is not of brittle construction but is made from a ductile material such as steel, ductile iron, UPVC or polyethylene.

In this instance the splitting head is designed to score the inside of the pipeline, in one or more positions around the inside diameter. The cutting section of the bursting head can be built with either angular cutting blades or with a series of cutting rollers that increase in diameter to form a sloping roller blade.

Once the existing pipe is scored, the expansion cone section of the bursting head tears the scored sections apart and pushes the remains into the surrounding ground.

The new pipe is pulled in behind the splitting head assembly as with Static Pipebursting.

It should be noted that the cut edges of the existing pipe have the potential to damage the replacement pipe and care must be taken to ensure the old pipe is opened up sufficiently to accept the new pipe.

Pipe Eating & reaming:

Pipe Eating is a form of pipeline replacement that more or less completely removes the old pipe from the ground, leaving no shards or waste material behind.

Often this technique is used to replace clay or concrete pipelines. Usually to achieve a pipe eating replacement a microtunnelling machine is used that is set up to follow the line and grade of the existing pipeline.
As the microtunnelling machine advances it cuts out the old pipe together with any of the surrounding ground that is being removed to create a void of sufficient size to accept the replacement pipe.

The new pipe is jacked in behind the microtunnelling machine and is used to move it forward through the ground.

Once the microtunnelling machine arrives at the target pit it is removed together with any temporary works that had been used to support the installation works to leave the new pipe in position ready for incorporation into the pipeline network.

Pipe Reaming is another form of pipeline replacement that more or less completely removes the old pipe from the ground, leaving no shards or waste material behind. In this case a horizontal directional drilling rig is used to achieve the pipeline replacement (suggest link here to HDD section). The drilling rig advances its drill rods through the existing pipeline until it reaches the target access point. A reaming head is attached to the drill rods with the new pipeline fixed to it via a swivel.

The replacement pipe can be polyethylene, ductile iron or steel. As the drill rods are pulled back the reaming head destroys the existing pipe. The fragments together with any of the surrounding ground that is being cut out to create a bore of sufficient size to accept the replacement pipe are removed using the drilling fluid. Once the reamer reaches the launch access, it is removed, and the new pipe is then available for connection to the pipeline network.

The advantage of this technique is that if a very significant upsize is required, a preliminary reaming run can be made to remove the old pipe followed by as many further reaming runs that may be required to upsize the bore to the required size to accept the new pipe. Drilling fluid can be utilised to maintain the expanded bore between reaming runs.
When very large upsizing is required consideration needs to be given to other existing services that are in close proximity to the bore route to avoid any potential damage or loss of service.

Pipe Extraction:

Pipe Extraction is the complete removal of the existing pipeline from the ground without the need to break it, cut it (other than at access points) or destroy it in any way. The techniques are usually used for the replacement of smaller diameter, service connection pipes constructed of lead, copper and steel.

This technique usually involves a winch being set up at one end of the pipeline to be replaced and its cable is passed through the existing pipe to a target access point usually near the property being serviced by the pipe. Some systems use a cable that has a series of teeth embedded in it which when pulled in one direction lay flat to allow the cable to be installed into the pipe. However, when the cable is pulled in the reverse direction, they expand outwards to bite into the inner surface wall of the pipe creating a high drag. When the winch cable is continually pulled towards the launch access pit, the cable teeth are attached to the pipeline, so the pipeline is extracted from the ground. The new pipe is attached via a swivel to the winch cable end at the target access location and pulled into the void created as the old pipe is extracted. The old pipe and the extraction cable are wound around the winch drum and can be separated later for recovery and disposal.

Once the new pipe reaches the winch pit it can be disconnected from the winch cable and can then be connected to the existing local pipeline network and returned into service.

In another version of this technique, instead of using gripper teeth attached to the winch cable, the cable is fixed in place with a grout or adhesive along the full cable length prior to the pull-back commencing. The existing pipe and winch cable are extracted and retrieved, and the installation of the new pipe is undertaken in the same way.

In some circumstances using a standard pipebursting technique as described above can result in fragments of old pipes such as asbestos cement or cast iron being left behind in the ground. This may result in contamination of the ground which can pose a health risk. If this is a potential problem, then the pipe extraction technique can be used.

This system is similar to Static Pipebursting as a hydraulically powered push pull rig is installed in a launch access pit and steel rods are pushed through the existing pipe. The rods are then fitted with a head that allows the existing pipe to be pulled out of the ground in one piece at the access pit rather than it being broken or fragmented. As the existing pipe arrives at the access pit it is broken down using a specially designed breaking head allowing it to be removed easily from site. The new pipe is installed simultaneously as the old pipe is extracted so the replacement is achieved in a single operation.

The use of the special breaking head to break the old pipe into manageable pieces means that the operational personnel do not have to handle the pipe pieces whilst the operation is in progress. Any remaining pipe shards can be removed mechanically or manually from the access pit once the new pipe installation has been completed. Over longer distances the break-up of the old pipe can be achieved at intermediate pits so this minimises the amount of any potentially contaminated pipe material within any individual pit. If there is a need to recover broken pipe materials by hand, then there may be a requirement, depending on the type of contamination that is expected, for personnel to use specialist PPE to manage any personal health risks.

Live Mains Insertion:

Live Mains Insertion is a technique that falls between Pipe Replacement and Lining Techniques.

It is considered by some operators as a renovation system that is a companion method to dead mains insertion or sliplining. To others it is a technique that falls into the Pipe Replacement sector as it replaces an old pipe with a new pipe that has no structural reliance on the old pipe once the insertion is completed.

Live mains Insertion is primarily used in the gas industry to replace old metal low pressure gas pipelines with new plastic (PE) pipes within the diameter range 3 in (75 mm) and 18 in (450 mm), without the need to take customers off supply during the operation to provide the new pipe. The installation operation is achieved by using a specially developed pipeline access system known as a Glandbox™.

The old main is kept live throughout the insertion process and the new PE pipe is gassed up (pressurised) to maintain gas supplies to customers. When inserting PE up to 180 mm diameter it is usual to 'gas up' the PE replacement pipe prior to insertion and use a live head to allow gas to pass between the PE pipe and the annulus.

The replacement PE pipe for diameters up to 180 mm is normally supplied in a coil. Above this diameter, where straight sticks of PE pipe are used instead of a coil, it is possible to carry out the procedure without first gassing up the replacement PE pipe.

The installation process uses either a pipe pushing machine that is set in the launch excavation or a pipe handler that is attached to an excavator to insert the PE replacement pipe into the old main. A 'live' head, designed with holes to allow for the flow of gas, is fitted to the end of the replacement PE pipe.

This pipe is then pushed into the gland box until the plastic membrane within is pierced. Gas is then allowed to flow into the replacement PE pipe and the PE pipe is pushed to the end of the replacement section. During this operation the gas supply to customers is maintained. The PE replacement pipe is then connected to the gas network pipe and the existing main is kept live to supply customers via the annular space until it is operationally convenient to transfer the services to the new PE main. The use of pipe pushing machines and/or pipe handlers and pipe coil trailers is necessary for the safe, efficient implementation of live mains insertion.

Customer services are transferred to the new PE pipe sequentially using polyurethane foam flowstop technology to block the annular space. This is the only time customers will not have a gas supply and this is only for the time it takes to transfer the service pipeline to the new PE pipe. However, there is a need to utilise traditional excavation techniques to remake the service connections. But the use of the flowstop technology does allow the contractor to plan and minimise these excavations to meet the needs of customers and the local area infrastructure.

Some contractors have utilised keyhole vacuum excavation techniques to make the service connections, over the past few years this option has become more widely adopted by clients and their contractors but has not yet found it mark as an industry wide standard practice.

New Installation:

New installation of pipes, cables and ducts for gravity and pressure networks.

Application

These techniques are designed for the new installation of pipes, cables and ducts.

Benefits

Benefits are those found with all trenchless techniques including reduced impact on the environment, reduced impact on the local population, reduced traffic disruption etc.

The technologies include:

Impact Moling:

Impact Moling

(using Impact moles – also known soil displacement hammers, pneumatic impact moles or piercing tools as they may also be known in some parts of the world.)

Category

New installation or replacement of pipes and ducts or cable laying pressure networks.

Application

Applicable to gas, water and cable. Depending on the equipment manufacturers' ranges, diameters available run from 45 mm to 300 mm with the capacity to install product over lengths of up to ±30 m. The mole diameter is usually significantly larger than the product diameter (15 to 20%) to ensure that the product will fit into the bore and minimise any friction/drag that might impede the advance of the Impact hammer.

Limitations of the system include they must be used in compressible soils as the technique is a soil displacement operation. In most cases impact moles are not steerable although some steerable options do exist but are rare in use. This means that set up and implementation must be carried out very precisely before the impact mole is launched into the ground. The direction of the mole may also be seriously affected by obstacles in the ground such as boulders, unknown utilities etc.

Benefits

Impact moles offer a quick relatively easy option for the installation of shorter, smaller diameter pipeline and ducts where the ground conditions are not expected to be problematic and may be useful in short road or rail crossings or under waterways.

Technology Description

The Impact Mole is one of the original and simplest of the trenchless technologies. Assuming the pre-installation ground and route investigation has been assessed correctly, the installation of a product pipe using an impact mole is relatively simple and straightforward.

Impact moling is frequently used to install gas and water service pipes to properties from an access chamber or excavation thus eliminating the need to dig a trench across an obstruction such as a road. Cables can also be installed in this manner with or without ducting, although the provision of a duct is generally regarded as a safer method of cable installation and protection.

Impact Moles displace the soil through which they pass to create a void into which cables or socket-less short or long plastic pipes can be pulled over lengths generally up to ±30 m.

If the soil is sufficiently compressible the technology enables the crossing of highways, rail track etc. and installation of house connections for gas, water and other pipe or duct based utilities. Over short distances to ±30 m, with the right ground conditions, impact moles can be accurate and on target. The Impact Mole is placed on a starting cradle and launched from a pit and, by means of a telescopic sight, aim is taken and the height and sides of the machine are adjusted to provide the line and level for the installation.

The mole is moved forward by a compressed air or hydraulically driven piston – the forward movement relies on external friction, consequently if this is missing, such as in loose and/or soft soils, external static support may be required to provide a thrust. Current practice is that the product pipe or cable is attached via a swivel directly to the rear of the mole prior to commencing the bore. This means that as the mole advances the product pipe or cable is laid directly into the ground so no further stage is required to complete the installation.

Most moles are non-steerable with the mole head creating the bore hole and the length of the body of the mole helping to keep the mole on its line and level as it advances through the bore hole. The distance travelled through the ground is usually monitored by marking the chainage on the on the power hose as it advances.

There are two basic non-steerable systems available:
The Rigid System: The piston applies impact directly on to the mole casing and drives the complete hammer and the attached pipe/cable forward with one blow.

The 2-Stroke Method: The piston first strikes a floating head located at the front of the mole with a shaft passing through the mole shell advancing this head into the ground. The piston then strikes the casing so that the body of the mole moves forward, a two-step action.

The 2-stroke-method claims to improve the penetration of the mole into the ground and maintain better directional stability.

Whichever head configuration is used it is vital that Impact Moles are used at a depth sufficient to negate any potential for ground arching or heave at the surface. The ground cover should be at least ten times the diameter of the casing (i.e. for every 100mm diameter of mole – 1 m depth should be allowed). Moles are also equipped with a reversing gear to reverse the mole from the bore should it be necessary such as encountering an obstacle.

On some moles it is also possible to install a locating sonde that can be tracked from surface. However this is not normally used for steering purposes just monitoring.

Steerable Mole

Steerable impact moles are also available and use a similar method of steering as used for auger bore pilot bores and horizontal directional drilling (HDD). A steerable mole has a slant face rather than a chisel-tip face and the direction of the mole is managed by the positioning of the slant face head. The operator steers the mole by rotating the face in the desired direction, again similar to HDD technology.

A sonde located in the transmitter housing close to the front of the mole allows it to be tracked at ground level using a walkover tracking system. Use of these moles has however been somewhat limited over the years as the drive lengths tend to be short so any realistic need for steering is negated.

Pipe Ramming:

Category

New installation of pipe and duct which may be used as a main pipeline or carrier pipe for other services for gravity or pressure networks.

Application

Pipe Ramming is applicable for gas, water, cable, sewer and fibre installations particularly where the rammed installation is being used as a carrier pipe for other services. Ramming is achievable in diameters up to around 4.5 m depending very much on soil type and the selection of the ramming tool which has to be matched the prevailing conditions and requirements. Installation lengths may be up to 100 m again depending very much on prevailing ground conditions
Limitations are that the installation is not steerable and care should be taken in the set-up of the ramming hammer to ensure the best outcome of the process. Thorough ground investigation should also be undertaken to ensure that ramming is the correct process to use given potential obstacles that may be encountered.

Vertical applications such as piling and HDD assist and rescue are also possible.

Benefits

Ramming can offer:

- less disruption and damage to surfaces worth conserving and minimal restoration as it eliminates trenching and open face ramming eliminates potential ground heave even at shallow installation depths
- low social costs as the trenchless installation technique does not impact greatly on traffic management or the local population
- no jacking abutments or auger cutters required
- the soil core remains in the pipe during ramming (unless closed face ramming is used), which means that there is limited ingress of water when rivers or high water table areas are encountered
- minimal depth of cover required so shallower excavations possible unless closed face ramming is used where there may be some degree of ground heave as spoil is compressed around the outside of the rammed pipe
- adaptable for all pipe diameters with special ram collets which sit between the pipe being rammed and the ramming hammer

- a technique that is widely acknowledged and accepted as a realtively simple technique
- short set-up and installation times
- a wide application range.

Technology Description

Whilst basically the same principle as impact moling, in pipe ramming the ramming hammer is used in a different way altogether. As opposed to using the impact energy to displace soil directly around the outer shell of the hammer unit, a ramming hammer's energy is used to push a steel pipe section into the ground from a start pit. The pipe installed can be used either as a pipe in itself or as a carrier conduit for separately installed services.

On a typical installation the first section of steel pipe is placed in the start pit on the correct line and level for the installation. The ramming hammer is attached, via a series of size adaption collets, to the rear of this pipe. The hammer is operated and the reciprocating piston drives the pipe section forward directly into the ground. Ground conditions on such a project are vital to the success of such work and should be very well understood before attempting such an installation.

Normally, installations are achieved using an open-ended pipe so that the cutting edge is only that of the pipe (which is often fitted with a cutting edge or shoe before commencing the ram). The ground into which the pipe is rammed then forms a plug inside the pipe. When ramming over the required distance is complete or at discrete distances along the ram this spoil is removed using compressed air pressure, water jets or scrapers, ultimately leaving the steel pipe in place as required. As with impact moling the ground conditions and unexpected obstacles can cause the pipe to deflect from the required course. So, the system is often used only where precise line and level tolerances are not required. Therefore for gravity sewer applications it can only be used as a casing pipe within which a sewer is laid to the required gradient.

Ramming can also be achieved using closed end pipes where ground conditions may not be conducive to open ended techniques. Here the soil is compressed around the advancing pipe in similar fashion to that achieved during impact moling. This is a less utilised technique due to the potential for interference with nearby services and possible ground heave as the soils around the closed end hammer are compressed/pushed aside.

Using ramming techniques it is also possible to achieve pipeline replacement given that the rammed steel pipe may be installed at a diameter greater than that of the original pipe (which is in deteriorated state) by ramming it concentrically around the old pipe but along the same route. The soil and old pipe can then be removed from within the newly rammed pipe leaving the replacement pipe in-situ once cleaned out.

HDD Assist/Rescue

Ramming hammers also has application in the Horizontal Directional Drilling (HDD) sector. The use of the ramming hammer in this instance is designed to add impetus to the drill string over and above that capable by using the drilling rack driving force alone. This may be to add force at the drill head to overcome particularly difficult ground conditions or during pullback to add pulling force as the product pipe is being drawn in.
In cases where during HDD operations the drilling string becomes stuck, the use of a ramming hammer attached to the string may be sufficient to aid release of the drill string thereby negating to dig out or abandon the drilled bore.

Further to this ramming may also be used as a preliminary operation prior to or as an assist to HDD operations where near surface ground conditions require that a lead pipe is installed from surface down to the drilling horizon to prevent loss of the pilot bore due to bad ground conditions such as gravel beds. Here the ramming hammer is used to install a steel pipe angled at the attack inclination required by the drilling rig. The pipeline installed would normally be of a diameter large enough that it will accommodate the final product pipe diameter being drawn into the bore by the HDD machine.

Microtunnelling:

Category
New installation of pipes, cables and ducts for gravity and pressure pipe networks.

Application
Suitable for the installation of gas pipes, water pipes, cable ducting, sewer pipes, culverts etc. in a diameter range from 150 mm to approximately 3,000 mm (above this the bore tends to be described as a Tunnel).
The length of bore that can be installed depends on the ground type, the route (if curves are included), the diameter (larger diameters can be bored further), the selection of the machine used for the boring operation and its thrust capacity. The pipe type can also have a significant bearing on drive length.

Microtunnelling can be achieved in a broad range of ground condition

from soft, alluvial soils to hard rock. There are variants of machine type, face support and spoil management to deal with unstable soils and high groundwater heads. Limitations are: the thrust capacity of the jacking frame which may limit effective bore length; the compressive strength of the pipe; and the abrasiveness and friction coefficient of the soil through which the bore is undertaken.
The two former are dealt with through effective design and the latter can be managed with lubrication of the external pipe surface during installation.

Benefits

Microtunnelling has the advantages that:

- It minimises the need to excavate long trenches especially in urban environments
- The impact on landscapes and cityscapes is minimal
- Operations are less weather-dependant than open cut trench construction
- Faster operation than open cut construction with less disruption to the surroundings
- Significantly reduced need for large volumes of site traffic to remove excavated soil and return with new backfill material as the volume of spoil removed is only that of the pipe itself plus a small overcut
- It minimises disruption to the site locality, residents and businesses and tends to be operational for a shorter amount of time overall
- Carbon emissions from both installation and site traffic are considerably lower than open cut construction
- It is more environmentally friendly

Technology Description

Microtunnelling is a non-disruptive trenchless pipeline installation technique that utilises microtunnel boring machines (MTBMs), usually remote controlled from the surface, to install pipes underground.
The first microtunnelling projects took place in the late 1970s. The MTBM is guided by a steering system which allows the operator to follow the desired route by using steering pistons located just behind the cutterhead. The guidance system may be line of sight laser or more complicated technology specially designed to allow curved bores both in the horizontal and vertical planes. Depending on the type of installation required, potential users of microtunnelling should consult with specialist tunnel navigation system manufacturers or the MTBM manufacturer for the most appropriate system before commencing the project.
The MTBM is advanced through the ground using specially manufactured jacking pipes which are placed in a jacking frame in a launch shaft at one

end of the pipeline route. Pistons in the jacking frame push the pipe and MTBM forward at a controlled rate to ensure effective and safe progress of the MTBM as it cuts the soil.

As each pipe advances the MTBM through the ground one pipe length at a time, the pistons of the jacking frame are withdrawn to allow the next pipe section to be added to the pipe string. This process continues until the MTBM reaches the reception shaft at the far end of the route.
Microtunnelling Options:
There are essentially four main types of microtunnelling technology including:

- Pilot Tube Microtunnelling
- Auger Microtunnelling
- Slurry Microtunnelling
- Earth Pressure Balance Microtunnelling

The latter three systems are full face boring techniques as all the spoil excavation takes place at the same time unlike the multi-phase Pilot Tube technique.
Which method is used depends on the soil and groundwater conditions at the site. It also depends to some extent on the diameter of the bore.

Pilot Tube Microtunnelling (see also Guided Auger Boring)
This is a multi-stage operation that begins with a guided/steerable small diameter pilot tube being installed to create a pilot bore that follows accurately the desired pipeline route. Once this has been completed successfully the pilot tube is used to guide a steel casing of the finished bore diameter along the route. Inside this casing is an auger which excavates the ground around the pilot tube to the desired bore diameter for the pipeline being installed. The spoil is collected using the rotating auger and returned to the launch shaft for collection and disposal. The auger may also be installed in the pilot tube if this is of sufficient diameter with the spoil being transported to the reception shaft for removal.

If required there are independently powered cutting systems that can be placed in front of the final pipe string which assist in excavating the ground the final required diameter. This would normally be used in ground considered too hard for the standard pilot bore machine to handle.

Once the bore has been enlarged to the correct size the final pipes are jacked through the route expelling the steel casings into the reception shaft for use on a later project. When the final casing has been removed and the final pipe section jacked into place the installation is complete and the Pilot Tube Microtunnelling system may be removed from the shaft.

The pilot tube systems are becoming more prevalent in the market as they are smaller and easier to set up. Pilot tube microtunnelling is mainly used at smaller diameters, up to DN600. The pilot tube system is most commonly used for shorter drives which fit well with sewer networks where distances between manholes are relatively short.

Auger Microtunnelling
This method utilises an MTBM that is jacked directly through the ground using the sectional lengths of the final pipeline material.
The spoil from the cutterhead is collected using an auger flight located inside the jacking pipe string or in a steel casing placed inside it. The spoil is returned to the launch shaft for collection and removal.
The pipe string advances the cutterhead one pipe length at a time with new pipe being added when the limit of the jacking frame stroke is reached. Guidance is generally achieved using a line of sight laser system.
Once the cutterhead arrives at the reception shaft the MTBM is removed as is any equipment in the pipe string and the installation is complete.
The open face of the cutterhead means that it is limited to ground conditions that are relatively free of ground water. In these conditions it is a fast, effective and economical method of accurate pipe installation.

Slurry Microtunnelling
The overall method of pushing the MTBM and pipe string from the launch shaft is as for Auger Microtunnelling but in this instance the cutterhead is not open to the surrounding soils; it is a closed-face method.
The cutterhead is sealed off from the main bore by a bulkhead and the spoil from the excavation is extracted using a slurry which may be simply water or a bentonite- or polymer-based drilling fluid/mud. As the MTBM is advanced through the ground the slurry is pumped through the cutterhead and circulated to a settling tank on surface where the spoil is separated from the slurry and the slurry is reconditioned as necessary to provide the correct consistency and returned to the slurry circulation system for reuse at the face.

The slurry system has the advantage that, given the correct consistency the slurry will act as a face support when maintained under pressure from the pumping system where ground is less competent in nature.
It also removes spoil from the face at a controllable rate which again helps face support in less competent ground. It also prevents ground water ingress into the bore which prevents loss of ground at the face and therefore precludes any loss of ground around and above the bore path.
Management of the slurry properties to remove the correct amount of spoil, provide the correct face support and minimise ground water ingress is a vital part of the success of any slurry microtunnelling project to such an extent that where ground conditions are known to be very wet or where ground variation is expected, the slurry management may be undertaken by a specialist subcontractor with expertise in the field.

Earth Pressure Balance (EPB) Microtunnelling

This again works in the same way as Auger and Slurry Microtunnelling in terms of how the MTBM and pipe string are advanced through the ground. It is a closed-face system. However instead of using a slurry circulation system the excavated spoil is retained under pressure at the face to provide the necessary face support.

This is particularly applicable to unstable ground conditions. A screw system extracts the spoil from within the face compartment only removing the spoil volume necessary to achieve advance while the remainder of the spoil remains under pressure in the cutterhead chamber. The extracted spoil is passed into either a Sludge Pump system or is loaded into an open conveyor or truck system that removes the spoil to the launch shaft for disposal.

Common Factors
Particularly with the full- or closed-face techniques, the advance of the pipe string through the ground may be affected by the settling in of the surrounding ground back onto the outside of the pipes. This is especially the case where the route of the bore contains curves in the horizontal or vertical planes. Whilst the curves may not be tight there will be an increase in friction as the pipe pass through the curvature. This also needs to be managed carefully. These effects will result in an increase in the jacking force necessary to overcome the increasing friction as the bore progresses.
The design and thrust capacity of the jacking frame must be sufficient to overcome this friction.

This effect can be ameliorated by using a lubrication system to apply a lubrication fluid such as a bentonite to the outside surface of the jacking pipes.

To accommodate this, the pipes are manufactured with lubrication ports placed through the pipes to allow the lubricant to reach the annulus between pipe and ground. Lubrication is a common procedure and is almost standard in larger microtunnelling works.

Jacking Pipes
The most common jacking pipe materials are clay, concrete and GRP although other pipe materials have been used on occasions. Jacking pipes are in discrete lengths to enable installation from jacking shafts. Therefore there are frequent joints in the pipes as new sections are added as the drive advances. It is important that these joints are designed to provide a smooth and linear outside diameter of the bore, so conventional

bell and socket joints cannot be used. The joint structure and seal and the compression seals in the joints must be correctly designed to minimise the potential for failure either during the installation process or subsequently once the pipe is in operation.

Pipe manufacturers should be consulted with full details of the expected bore route, ground conditions and machine type to be used to ensure that the correct pipe with the appropriate jacking characteristics (dimensional accuracy, axial load capacity, joint design, etc.) is used on any particular project.

On longer drives at man-entry diameters there is the option to install intermediate jacking stations at intervals along the pipe string. This allows shorter lengths of the pipe string to be advanced at any one time reducing the jacking forces necessary to move the pipe string forward thereby reducing the necessary load capacity of the jacking pipes being used to create the installation as well as reducing the required capacity of the jacking system itself.

Other Microtunnelling Options

There have been variations in microtunnelling over that past 40 years, with new methodologies still being developed. These have included a system where a set of steel cylinders are jacked into place behind the MTBM instead of the final product pipe. Once the bore has been completed the steel cylinders are pushed out of the bore by the final product pipe as it is jacked into place from the launch shaft.

This adds a step so is slower and more costly than direct installation but it does eliminate the potential for jacking pipe failure and the problems this may cause if a pipe fails in mid excavation in the middle of the pipe string. It also reduces the cost of the pipe since it does not need to be designed to resist the full axial load of jacking.

A more recent development is a system that is designed to install very long steel casing pipe directly into the ground. The system uses the standard slurry MTBM for the excavation/boring activity but this is advanced through the ground using a welded steel pipe that is jacked forward using a specially designed thrust unit at the surface that grips it externally so does not require the usual intermittent stoppages as when shorter lengths of segmental pipe are uses as in standard microtunnelling. The operation can therefore be continuous over a long distance which also eliminates the potential for ground settlement around the pipe which can cause restart problems where long lengths of pipe sit in the ground stationary during pipe changes.

Pipe Jacking:

Category
New Installation of tunnels, pipelines for gravity systems, conduits and culverts.

Application
Applicable for installation of gas, water, cable, sewer, surface water channels in man-entry diameters up to 3 m or more over lengths limited only by the ground conditions and by the designed jacking pipe strengths and pipe string design. Pipe jacking is suitable for ground conditions from soft but self-supporting soils to rock.

With open-face systems there is a risk of groundwater entry and loss of face support in cohesionless soils under groundwater so closed-face systems or microtunnelling are likely to be preferred in those conditions. Pipe jacking requires man-entry into the tunnel and all health and safety requirements for confined space working must be observed.

Benefits
Pipe Jacking is a trenchless technique that allows buried pipelines tunnels and service conduits to be installed without the need to excavate large trenches thereby minimising disruption to traffic, the environment and local populations.

Technology Description
Pipe Jacking is a technique similar to microtunnelling but utilised only at larger, man-entry diameters. The ground excavation machine or shield is advanced through the ground along a pre-determined route by jacking it forward from a launch shaft using specially designed high-strength jacking pipes. Navigation is achieved using specialist systems which may be laser targeting for straight drives or more sophisticated for drives with included curves.

The difference between Pipe Jacking and microtunnelling is that Pipe Jacking is normally undertaken in pipes/tunnels where man-entry is possible such that the control of the excavation shield is achieved from within the shield as opposed to remotely from surface.
Pipe Jacking can be undertaken using closed face or open face tunnelling options with a variety of cutter head options.

Closed Face – This method operates using either a Slurry Face Support and spoil removal medium or an Earth Pressure Balance technique (see microtunnelling). With both systems excavated spoil is to some extent retained in the excavation face cavity. Slurry techniques use a water/bentonite/polymer slurry mix that is pumped through the cutter head to remove excavated spoil. The pressure maintained at the face gives a degree of face support and the thixotropic nature of the slurry can be altered to improve face support characteristics. The Earth Pressure Balance technique keeps excavated spoil under pressure in the cutter head cavity to provide the face support necessary with only sufficient spoil being removed using a screw feed to allow the machine to advance.

Open Face
A variety of open face options are available for Pipe Jacking works.

- **These include:**
- **Hand Excavation:** excavation of the face by hand with shovels or hand-held power tools. Spoil is collected using hand tools or mini excavator diggers for loading onto a conveyor or into transport trucks or rail cars.
- **Rotating Cutterhead:** similar to the closed face option but an open that does not isolate the face from the tunnel, excavates spoil which is collected at the face foot by gathering arm loaders for placement onto a conveyor or into spoil transport trucks/railcars for removal to the launch shaft and surface.
- **Excavator Arm:** a backhoe bucket digs the spoil from the face for loading onto a conveyor or into spoil transport trucks/railcars for removal to the launch shaft and surface.
- **Roadheader:** similar to the excavator arm option but using a roadheader attachment to cut the face.
  Advance of the Pipe jacking shield is controlled by a driver positioned in the shield using controls that advance the pipe string from the jacking frame located in the launch shaft.

On longer drives there is the option to install intermediate jacking stations at intervals along the pipe string between new jacking pipes. This allows shorter lengths of the pipe string to be advanced at any one time reducing the jacking forces necessary to move the pipe string forward thereby reducing the necessary load capacity of the jacking pipes and also the thrust capacity of the jacking frame at the launch shaft and is reaction system.

Horizontal Directional Drilling:

Category
New installation of pipes, cables, ducts mainly for pressure networks. Gravity networks may be possible also.

Application
Applications in gas, water, cable duct, rising sewer mains as well as gravity pipelines. Lengths can be variable depending on the installation required and very importantly the ground conditions on site.
Bore lengths range from a few metres to over 1 km with diameters available from as little as 50 mm (2 in) to several hundreds of millimetres. Ground conditions that can be drilled range from soft clays, sands and

gravels to mixed grounds and hard rock depending on the equipment used.

Limitations
It is important to understand the ground conditions that will be encountered during the pilot boring and back-reaming operations, the length and diameter of the bores required in order to select the correct drilling rig for the job in hand.
The correct tooling, support equipment etc. also needs to be assessed and provided to ensure that any bore proceeds as smoothly as possible. Each project will require a significant amount of pre-project ground investigation to be carried out, planning and consultation with utility owners and contractors, machine manufacturers and support equipment providers such as drilling fluid removal (possibly specialist subcontractors) may be needed to best design the project parameters for a successful outcome.

Benefits
HDD offers the potential to install new or replacement pipelines, ducts and cabling without the need to excavate large pits and long trenches on the surface making the HDD process environmentally friendly compared to open cut techniques.

The installation, when correctly planned and using the right equipment, can install networks from small to large diameters over a short to long distances safely and with minimal disruption to the surroundings, local businesses and the general public can carry on with their daily business at a lower cost compared with traditional methods when all aspects of the traditional operations are taken into account (including site waste disposal traffic management, possible compensation claims etc.)

Technology Description
HDD is one of the most versatile trenchless methods used for the installation of many product pipelines including service connections, mains pipes, cables, crossings under highways, rail tracks, watercourses, runways, landfill sites etc.

HDD is a multi-phase operation which uses a special design drilling rig which initially bores a pilot hole through the ground along a pre-determined route. Once completed to the satisfaction of the client, this pilot bore is then expanded as necessary using various sizes and types of back-reamers to enlarge the pilot bore to the final diameter into which the product pipe or cable will be installed. This expansion process can be completed in stages depending on how large the product pipe/cable is, normally the final diameter of the bore is between 30-50% larger than the product pipe/cable that is to be installed.

Pre-reaming operations are required for larger bores and can be achieved by adding drill rods to the rear of each successive pre-reaming operation so that once one reaming pass is completed another can take place with a larger back reamer until the final size is achieved.

Depending on the ground type the pilot bore drill head and the reamer cutters can be designed for anything from soft clays through sands and gravels to mixed ground conditions (often using a slant/angled drill face) and hard rock (mainly utilising roller cone bits or button bits). Consultation with specialist HDD contractors, machine manufacturers and equipment providers will determine the correct tooling and systems for any bore being carried out.

Once the final diameter is achieved a final back reamer is attached to the drill string to which is attached via a swivel, the product pipe or cable is attached with a Dee Shackle. The final pull-in installs the product pipe/cable into the bore to complete the process.

Generally, HDD is best suited for installing pressure pipes and ducts/conduits where precise grades are not required. However, with the correct skills of the operator and the right locating systems on grade bores are also possible.

Over the years since it first appeared on the market HDD machine technology has seen many and often rapid developments. In recent years numerous additional functions, automated steps, improved mixing units, advanced power transmission, optimised tooling, etc. have been the basis of such developments, in many instances modern machines are now able to achieve bores that previously would have required larger, more powerful HDD machines.

Machine Types

The application of the technology for utility service projects has been taken largely from the oil and gas industry which developed the method to drill to/from offshore installations. For utility applications, various rig types have been developed depending on the application to hand. These include: Mini, Midi, Maxi and Mega rigs

An HDD set up comprises of a suitable HDD rig size to be able to undertake the job in hand equipped with sufficient drill rods for the length of the bore required along with a suitable drill bit for the ground conditions and bore expansion back reamers to provide the correct diameter into which the product pipe or cable will be installed.

The selection of drilling rig is totally dependent on the ground conditions and type, the length and diameter of the bore and the product type being installed. Users will have to investigate and consult with experienced operators and equipment suppliers to ensure the correct combination of rig and tooling and back-up equipment is selected for the job in hand – bearing in mind that no matter how similar it is likely that no two will be exactly alike.

It is usual for the drilling process to be supported using a drilling fluid system which is pumped down the drill rods to the drill head. The drilling fluid may on shorter bores simply comprise a flow of water, often the drilling fluid is a specially formulated drilling mud comprising a mixture of water/bentonite/polymer additives depending on the project circumstances.
This fluid is usually design for three main purposes:

- Flushing the drill cuttings out of the bore during the pilot boring operation and keeping the cuttings in suspension whilst the cuttings are transported out of the bore.
- Lubricating the bore and creating a filter cake for stabilization of the bore walls.
- It is very important that the Sonde/Transmitter is kept cool during the pilot boring operation as overheating the Sonde/Transmitter can be costly to the drilling contractor.
- Cooling of the drill bit during the pilot boring operation.
- Providing ground support for the bore walls to ensure that bore does not collapse behind the drill head as it advances.

This aspect of the drilling operation may be very specialised and might require the employment of a specialist contractor to design the fluid to suit the ground conditions and to maintain the drilling fluid properties to that specification during the drilling operation. This usually requires the use of specially designed drilling fluid mixing systems, holding tanks, the selection of the correct additives to provide the right balance of cutting removal, cooling and bore support and pumps.

If the drilling fluid is to be recycled, as is often the case on most of the larger drilling machines, there is a need for a recycling system this will have shakers and cyclones to separate the solids from the bentonite prior going back into the mixing system before new bentonite being mixed and the process is repeated keeping the drilling/backreaming/hole opening to continue.

Guidance
HDD as the name suggests has a directional control component that makes the system useful to the buried services and utility industries. This directional control is achieved using specially designed drill head location technology. There are two forms of guidance which are used depending on the type of installation being undertaken, the ground conditions, the obstacles that occur along the route of the bore and the local environment (potential interference sources).

Walk-Over Locating System

The sonde emits a radio signal on a known frequency that is detectable on surface using a suitably tuned receiver, usually hand-held by an operative walking over the drill head location.

The receiver is designed to not only locate the strongest sonde signal by the operator passing it over the expected sonde location but can also provide an indication of sonde depth, direction of the sonde/transmitter housing heading, temperature of the Sonde/transmitter, signal strength giving the operator accurate readings.

The sonde housing rotates with the drill string and emits a signal that enables the drilling rig operator to understand where the drill head is beneath the ground its depth and importantly its orientation both vertically and horizontally.

This position can then be compared with the planned bore route and steering corrections made as necessary. The drill head is normally angled so that when rotating it will follow a straight course. If, however the drill head is kept as a known angle to the direction of the bore it will 'steer' the drill head in a known direction thereby bring any deviation back to zero and maintaining the planned course. This is effective in softer ground only where the drill head can be advanced without the need to cut ground. Where rock boring drill heads are used it is usual to have the drill bit and the steering sub/bent sub separate. This orientates the drill bit in the direction required so that it can continue to rotate and drill whilst maintaining a steering action.

Where obstacles may be too dangerous to allow personnel access (busy roads, motorways, rivers etc.) Some guidance systems allow the receiver to be place in a known location ahead of the drill head where it can still receive information that is sufficient to guide the drill operator provided the distance between sonde and receiver is not too great. Adjustments can then be made to ensure the correct course once the drill head can be Walked Over once the obstacle has been negotiated.

Where there may be interference caused by say overhead power lines this system may be affected and provide incorrect readings on the receiver – users should be aware of this potential.

In circumstances where interference is too great to adjust for or where depth is greater than the receiver can be successfully utilised or where obstacles are so large as to negate the use of any type of Walk-Over system, the other option is the Wire-Line system where there is a physical connection between surface and the drill head.

Wire-Line systems

Wire-Line systems do not have a surface receiver as such and rely on instrumentation located behind the drill head that is connected to surface by a physical hard-wire. The instrumentation generally comprises some form of inclinometer with a gyro compass or similar to provide orientation data for the drill head.
The operator compares this data with the expected data for the advance achieved to the point of measurement and steers the drill head accordingly to adjust any misalignment.
This may be a highly skilled technology requiring expert analysis and steering adjustments on very long bores. It is often the case that a specialist subcontractor may be used for this aspect of such a bore.

Ground Preparation

Whilst in most cases HDD can be started directly into the ground if geology is such that there is a possibility of damage or failure of the bore it may be necessary to prepare the launch site of the HDD rig prior to commencing drilling. For example, although not exclusively, if the surface geology is a gravel layer over laying the soils through which the bore will ultimately pass, it may be necessary to inset a guide tube through the gravel from surface to the main soil horizon to prevent loss of drilling fluids and to stabilise the bore wall. The diameter of such a tube may be such that not only will the pilot bore be effectively completed but also the final diameter of the larger reamer will pass through the tube unhindered. This is an option, if ground conditions dictate, that may be necessary on both the start and reception ends of a bore. A full geological investigation should be completed to avoid complications on site prior to starting work.

Drilling Options

There are generally two options for initiating an HDD bore: **Pit launched** and **Surface Launched.**

Pit Launched HDD
This option is not as widely used for initiating an HDD bore as Surface launched but does have its place in the sector due to the relatively smaller footprint for the site set-up. As the name suggests this option utilises the HDD machine from within a start pit or shaft.

Where site access is limited but where there is sufficient room to excavate a small shaft a small dimension drill rig may be positioned in the base of the excavation or shaft, also by using this method the bore can be started on a level plane orientated more or less in the direction the bore will follow. In most cases this option is used for shorter smaller diameter bores beneath roads and rail tracks and smaller waterways.

Given the limited space within the shaft the drill rods used tend to be shorter, but the process is basically the same as any other HDD operation. If space is very limited it may be that operators' station is on the surface with access to the machine only being necessary for insertion or extraction of drill rods.

Most recently development now also include the option to use HDD from within existing manholes using a specially developed rig which operates almost entirely from surface through the manhole access including feeding and extraction of the drill rods. This means of course that no additional ground excavation is necessary to complete an installation. Guidance in these instances is usually of the Walk-Over variety.
This section may be used a tool tip against the highlighted Surface Launched wording in the sentence above or may be used as a continuation of the paragraph.

Surface Launched
For surface launched HDD projects the drill rig is usually larger and longer than those found in pit launch works. The rig is set up along the direction of the bore and the planned exit position with its drill rack angled between 8° to 16°.

Any additional drill rods, reamers, swivels etc. as well as the prepared product pipe/cable are positioned at the reception side of the bore in readiness for use on completion of the pilot bore. When drilling fluids/muds are used, the launch pit is generally deepened to capture the cuttings returning, contaminated spoil laden fluids with a similar pit at the reception side to catch fluids once the pilot bore is completed.

The drill string comprises of a series of drill rods designed to fit the drill rack which advances the drill string and drilling head using a combination of rotation and thrust operations either through a rack and pinion, chain system or a hydraulic ram (although the latter in modern machines is now rarer).

When using the smaller rigs, the need to use a drilling fluid/mud may not usually be necessary again this will depend on the geology/ground conditions particularly for service pipe and cable installation apart perhaps in areas of poor ground conditions. For smaller drilling operations, the returned material can be removed by vacuum technology for disposal.
However, for economical and efficiency reasons, for larger projects it is normal practice to recycle the drilling fluid as described previously.

Larger rigs require much larger operating sites and significantly more back-up equipment and consumables so there may be significant logistical obstacles to overcome and to maintain supplies, remove waste and access machinery etc. so launch site should be chosen with care in consultation with expert operators.

Longer bore will also require significant ground area on the reception side of the bore to allow for pipeline/cable preparation and lay-out prior to installation as well as access for the delivery of product and other equipment required during the back reaming/hole opening operations that may be necessary. The logistics of a larger diameter long HDD installation should not be underestimated.

Category

New installation of pipe/cable/duct for gravity and/or pressure networks.

Application

Applicable to gas, water, cable , sewer installations in diameters from 90 mm (3½ in) to >1,000 mm (40 in) over lengths of up to 100 m depending on soil type. Generally used in softer soils but with the correct boring heads harder soils and soft rock may be bored.

Limitations may be that accuracy of this steered boring system is taken to be about ±25 mm over a 50 m length so any installation that requires higher accuracy may require a more accurate system such as microtunnelling.

Benefits

As with other jacked pipe systems benefits include reduced impact on the local environment and economy with minimal disturbance to the local populous. The machines used are compact and no slurry is created. A variety of jacking pipes may be installed using the technique but usually clay or concrete provide the main options.

The process is quick and efficient and overall costs are usually less than those associated with more complex microtunnelling systems. The method also requires a much smaller footprint than the more complex options. As with microtunnelling the ground through which the bore passes is fully supported during the process.

Technology Description

Guided Auger Boring should not be confused with Auger Boring as it is a steered installation process which allows the bore to be maintained reasonably accurately on a design line and level thereby enabling gravity lines such as sewers to be installed.

The process begins by sinking a launch and reception shaft at either end of the desired bore route to the size required for the operation of the machine. The Guide Auger Boring machine which comprises a jacking frame and usually a thrust backing is located in the launch shaft aligned on the desired bored route.

An optical (laser) guidance system is installed and aligned on the desired line and level of the bore.

The bore is a multi-phase operation comprising first a pilot bore similar to the pilot bore used in HDD installations. The drilling head is angled to allow the steering of the head as it advances. Constant rotation provides a straight line advance whilst a non-rotational advance steers the boring head in a desired direction using friction on the slanted face against the ground to force the steering action. Any deviation from the desired line is indicated to the operator on a screen at the control point showing orientation of the head and which is then set for recovery steering to bring the head back on alignment.

This process continues until the pilot bore reaches the reception shaft. Usually at the launch shaft the pilot drill rod is then replaced with a casing within which is an auger with a cutting head at the advancing head end. This is advanced through the ground, excavating the bore to the desired final diameter for the pipe being installed. The auger chain removes spoil from the bore to the launch shaft for collection and disposal.

As each section of the auger assembly is advanced into the ground so the next section is added and advanced again until the auger reaches the reception shaft/pit. The alignment of the bore is maintained by the pilot drill string that remains in the ground ahead of the auger assembly.

Once this phase is completed the product/casing pipe is then placed in the jacking frame and advanced into the bore created by the auger assembly. As the pipe is advanced the auger assembly, including the casing, is dismantled and collected at the reception shaft/pit for reuse. Once the pipe string reaches the reception pit and all the auger and casing has been removed the installation is complete and the machine can be removed from the launch shaft.

If being used directly as a product pipe the installed pipe is then connected to the network it is to become part of. If the pipe is to be a casing pipe then the product pipe(s) or cables are installed as necessary.

Advances in Capability

As well as the standard pilot/auger/pipe installation technique, in recent years the machine manufacturers have devised options that enable bores to be completed in hard ground and at larger diameters. These generally take the form of a powered cutter head that is used instead of the auger during the second phase of the installation process.

The powered cutter head has a separate power feed that enables it to excavated larger diameters or harder ground than the standard systems. This results in its application range overlapping with microtunnelling in certain situations.

Category

New installation of pipe/cable/duct for gravity or pressure applications.

Application

Auger Boring can be used for the installation of casing pipe for gas, water, cable , sewer pipeline installations in diameters from about 100 mm (4 in) up to 1,800 mm (70 in) over lengths from a few metres up to 100 m although longer bores up to 200 m have been known. Generally Auger Boring is best applied in soft soils with no or low ground water head, although with special adaptation and equipment rock boring in soft rock can be achieved.

As the system is not sealed ground water head can lead to ground loss through the auger chain.

The systems are non-steerable or have very limited steering capability, so may not be suitable for applications in which line and level accuracy may be required. Auger Boring does also require sufficient space to install the launch pit and boring machine on at least one side of the route being bored.

Benefits

Auger boring is beneficial where road rail or other crossings are required where trenched options would be highly disruptive and inconvenient to the road and rail users, local population and businesses. Auger boring is a non-displacement technique which enables installation without ground heave.

The system is relatively simple to operate with an experienced crew and is relatively non-intrusive to the environment.

Technology Description

Auger Boring is a technique, usually non- or limited steer, for the bored installation of a casing pipe into the ground. Product pipe or final services are then installed within the casing pipe as required. Auger Boring is a Pipe Jacking technique but as the casing pipe is an integral part of the construction methodology it is necessary to understand this concept separately.

The technique is normally found to be cheaper than full microtunnelling or pipe jacking but does have limitations on the range of ground in which it

can operate. In its standard form, in particular very wet ground, it has its limitations as high water tables and flowing ground water can cause ground loss along the auger chain as the excavation assembly is not sealed.
However, with special adaptation it can operate in a variety of ground including rock provided a special rock cutting head is applied to the assembly. Depth limits are dependent on the size of excavation required to allow access for the auger boring unit and the practical length of pipe that can be installed from what is usually quite a large dimension launch shaft/pit.

The excavation technique uses a rotating auger chain/flight fitted with a cutter head. The cutter head is driven by, and is positioned at the lead end of, the auger string that has been established within the casing pipe.
The auger diameter is just less than the full diameter of the casing to allow rotation within the casing. If conditions allow or require for a small over-cut, the cutter head may be positioned just outside the lead edge of the casing pipe but it is still rotated by the auger chain within the pipe.

Rotating the helical auger chain within the casing pipe allows the cutter head to excavate the ground at the face, with spoil being removed back along the auger string within the casing pipe to the launch shaft or pit. Spoil is removed by hand or mechanically or placed into muck skips for removal as it exits the casing pipe.

The system is not usually used for installations requiring very high accuracy in line and level, although experienced operators can achieve very good accuracy where ground conditions permit. Systems have been developed that allow for some limited steering capability of the cutter head or to the casing pipe to counter minor deviations as they occur.
The method is best applied in softer ground conditions like clay soils and soils containing cobbles provided they are not of sufficient size to block the auger flight.

Generally, Auger Boring systems are usually diesel or hydraulically driven and are used for non-displacement boring operations. They are designed for the installation of casing pipes from about 102 to 1,830 mm diameter over distances of up to around 200 metres although larger diameter is normally associated with longer bores; typically bore lengths are less than 100 m.

Practical operational capacity depends very much on the machine selected as a number of manufacturers offer differing systems.
The installation process requires the establishment of a launch pit dimensioned to allow the installation and operation of the auger boring machine and the required pipe length to be accommodated within it, or at least the length of pipe that it is practical to work with. As the casing

pipe is generally manufactured from steel, the welding together of lengths to create the total pipe length required is not a problem.

The auger boring machine, usually operated by a single operator using controls on the body of the machine, is set up on a set of tracks or rack and pinion system on the line and level required for the casing installation. When the auger boring machine reaches the end of its stroke, governed by the length of the track/rack arrangement, the casing pipe is released and the machine is withdrawn to its original starting point. If required, a new length of pipe is positioned with its own auger flight in place, the auger flights are connected together to drive the cutter head and the pipe ends welded to form a continuous pipe length. The excavation and thrust process is repeated in this way until the drive length required is completed with the arrival of the cutter head at a reception pit.

The drive is completed with the withdrawal of the auger flight chain from within the casing pipe and the casing being cleaned out of all remaining spoil leaving the empty casing pipe in the ground. The product pipe(s), cables or drainage system can then be installed within the casing pipe as required, on a precise line and level if necessary.

Keyhole & other technology:

Application – what it does/is used for [or chart showing suitable for/not suitable for]
For the installation of smaller diameter utilities, exposure of existing buried utilities and services and the minimum surface disruption when accessing existing utilities and services.
Minimal excavation technologies have modernised the way ground is excavated with increased safety and minimal interference with the surroundings and persons living and working nearby.

Benefits
The main benefits of these techniques are that excavation which is absolutely necessary is kept to a minimum thus reducing the necessity for disposal of large quantities of soil which may be classed as contaminated. They also enable excavations to be undertaken with minimum disruption to the locality and people and businesses present nearby. In many cases the soils/ground excavated using these techniques can be reused as backfill once the operation is completed thereby minimising the need to transport new backfill to site improving environmental advantages by reducing the need to excavate virgin fill for reinstatement and reducing the transport requirements and therefore the carbon emissions levels of the operations significantly.

Technology Description
Keyhole Excavation

This technique is designed to provide a means of accessing buried services for requirements such as repairs, service connections etc. without the need to excavate large access pits, particularly in busy traffic lanes or pedestrian areas where the disruption would be intense and costly both for the contractor and for local businesses.

Whilst developed and utilised initially by the gas industry, keyhole rigs enable companies owning and operating buried networks to access existing cables, pipelines and ducts for repairs, inspection, camera works etc. This is achieved by first using a special drilling device that cuts and removes a 'key' in the surface, whether this is the road surface or pedestrian walkway. Typically the key is between 500 and 600 mm diameter. Once the key has been cut and removed a suction/vacuum excavation unit, normally mounted on the same chassis as the drilling arm, is used to excavate the soils beneath down to the level of the service in question. The spoil is stored in the suction/vacuum excavation unit spoil tank for later reuse.

Special tooling then allows the required works to be completed on the now exposed service via this small access point. The suction/vacuum excavator enables a fast and safe dig down without the need for operatives to enter the pit. Once the service work has been completed the excavated spoil is reused in the backfill of the hole and the surface core is repositioned and bonded back into the road/pavement surface leaving the road as close as possible to its original condition. The major advantage of this type of excavation is that the works can be completed in just a few hours, rather than several days that traditional techniques may be expected to take. In addition there is no need for longer term traffic control or diversions that might otherwise have been required.

Typically the keyhole units consist of a single or twin fan, 10 to 16 tonne truck-mounted unit with something like a 1.5 t spoil tank. The fact that excavated material is reused on site means there is no requirement for transport and safe disposal of waste materials. The hose boom doubles as a crane to lift the coring equipment on and off the chassis. The units are normally self-contained and able to core, suction/vacuum excavate, complete the repair/maintenance works, reinstate and reset the core all from one single operating unit with a crew trained to manage and affect the repair works that are necessary.

Technology Description

Suction/Vacuum Excavation

The terms Suction or Vacuum excavation are to many interchangeable and the use depends largely on what term the equipment manufacturer uses to describe its product(s). The systems rely on large fans moving high volumes of air through an excavation pipe which is fast moving to the point that it will carry with it quantities of broken soil which are then deposited in a collection tank for disposal or re-use as the case may be. The air stream is then filtered to remove any other particles that are of a size that does not drop easily out of the moving air stream before expelling the cleaned air back to atmosphere.

What may be termed open circuit suction systems differ from close system Vacuum systems only in the way this volume of air movement is generated. Potential users should investigate thoroughly which system would be most beneficial in the operations on which the equipment would be used.

In areas where there are existing buried utilities and services, traditional mechanical excavation is now seen as unacceptable due to the risk of damage to these services and more importantly the potential for injury or fatal cable strikes to the workforce. The increasingly crowded underground environment with fibre networks, gas mains, water pipes, sewers, road drains etc. means the likelihood of worker/machine/service impact increases significantly. This is why techniques covered elsewhere on this website should be utilised to complete effective ground investigations before any excavation is undertaken (see the Location, Detection and Inspection subsection of this website).

These techniques also minimise the need to have on site a workforce qualified in confined space working and other safety aspects of more traditional mechanical excavation such as ground support and ground water handling.

Most systems also require or utilise additional air-powered tooling that has the ability to cut soils in to manageable sized pieces if the suction/vacuum system cannot itself be used to cut the soil.

In many cases where suction/vacuum excavation is used and the soil to be removed requires it, the initial opening of the excavation or soil breakdown at the excavation site is achieved using an air lance (also known as an air spade). This device is a nozzled tool that expresses high pressure compressed air through a nozzle directed at the soil surface to break down the soil structure, or it can be used on larger broken soil pieces to break them down, to a size that can be removed by the accompanying suction/vacuum excavation machine hosing being utilised. Given the nature of the high pressure air jet that breaks down the soil, a high level of caution is required by the operator and the correct PPE should be worn at all times as well as maintaining a safe distance between passers-by or worksite colleagues as the air lance may inadvertently throw excavated soil some distance.

There are various sizes of suction/vacuum excavation equipment available for this type of work that is selected depending on the type of work being undertaken.

The smaller capacity units, typically 0.25 to 1 m3 capacity are suitable for small excavation works and trial holing with production rates of probably no more than 5 excavations per day. These units are usually skid, trailer or crawler mounted and come with smaller diameter suction hoses from 75 mm to 150 mm diameter attached to a very basic hose support boom that is either manually controlled or utilises a basic remote control system. Often these smaller units require a separate compressor to enable the associated air tools (air knives/spades) to be used effectively. These units are often designed to be towed on a trailer or directly behind a service vehicle for transport and to access site.

Larger truck mounted systems typically comprise trucks from 7.5 to 32 tonne in weight. These machines use turbines to produce the airflow required to provide the volume of air movement that will suck up the excavated material.

There is an increasing number of companies manufacturing these machines they fall into recognisable categories and whilst designs vary they do tend to offer some very similar options and extras. The most suitable machine for the type of work expected should be investigated fully by the potential end-user with the range of manufacturers available. In the 7 to 10 tonne chassis class, units typically operate with a single fan system that provides the air movement. The units have a spoil capacity of around 1 to 2 m3. Typically used for smaller service pits and trial holing, the units have a lower performance and so are better suited to easier ground with usually around 5/10 pits per day being an average production rate. Suction hoses are typically in the 100 to 180 mm diameter range with a standard telescopic hose boom (fitted with a floppy hose) that is hydraulically operated, and may use a remote control system with the operator holding the suction end of hose over the excavation.

Larger 16 to 18 tonne chassis-mounted machines usually operate with a twin fan system and have a spoil capacity of 2.5 to 4 m3. The fans provide high performance air movement and depression (suction) typically between 30 to 36,000 m3/hour at negative pressures of 30 to 38 kPa. These units are built for use in urban areas and difficult access locations where higher operational capacity is required. Typically used for multiple utility service pits they can perform in excess of 25 excavations per day at depths of up to 10 to 15 m. They can also be operated at distances of up to 25 to 30 m away from the main unit. Hose sizes are usually 200 or 250 mm diameter with the units fitted with telescopic and/or full power hose booms operated with remote control. The full power option also means that there is no requirement for any additional input from the operator for final placement of the hose at the excavation site as the boom is fully remotely controlled.

The larger 26 and 32 tonne chassis class again utilises mainly twin 900 mm fan systems and has spoil capacity of 4.5 to 12 m3. The high performance fans produce 36 to 40,000 m3/hour air flow and up to 44 kPa negative pressure (suction). These units are suitable for a wide range of applications and ground conditions including heavy clays. Excavations that can be undertaken range from small service pits through to large excavations on civils works. Material removal works at depths up to 20 m and over remote distances from the main unit of 50 m or more.

If depth from surface and distance from the main rig to the excavation site is a problem for the more typical suction/vacuum excavation units, a range of triple and quad 900 mm fan units with the capacity to work at depths up to 50 m and distances of 150 to 200 m from the main rig depending on the materials being handled is available. These units are usually utilised to remove materials over a distance in construction, tunnelling works, site clean-up, industrial maintenance etc. reducing the need for conveyor systems, handballing etc. Various manufacturers offer these systems with capacities up to and in excess of 44,000 m3/hour air flow and depressions (negative pressures) up to 50 and 55 kPa.

Minimum Excavation:

Application – what it does/is used for [or chart showing suitable for/not suitable for]
For the installation of smaller diameter utilities and services with the minimum of surface disruption using minimal trenching techniques that do not involved significant soil removal and/or use of excavated soils as backfill.
Benefits
The main benefits of these techniques are that excavation which is absolutely necessary is kept to a minimum thus reducing the necessity for disposal of large quantities of soil which may be classed as contaminated.

They also enable excavations to be undertaken with minimum disruption to the locality and people and businesses present nearby. In many cases the soils/ground excavated using these techniques can be reused as backfill once the operation is completed thereby minimising the need to transport new backfill to site improving environmental advantages by reducing the need to excavate virgin fill for reinstatement and reducing the transport requirements and therefore the carbon emissions levels of the operations significantly.

Technology Description – what it is

Ploughing

Ploughing or Mole Ploughing (USA: plowing) is a form of trenching that effectively opens the ground to the width and depth required, allows the product pipe/duct or cable to be installed in the trench created and then backfills the trench with the excavated soils in one single operations using a specially design mobile unit.

The machines are specially designed to carry on a reel the utility pipe or cable that is to be placed underground. The machine then has a plough attachment that can be pushed into the ground to the required depth and pulled forward as the machine advances. This excavates the soil just ahead of the pipe/duct or cable which is fed from the reel into the excavation. Then once the service is in the ground and as the machine passes over the area the excavated soil is pushed back into the trench using another attachment on the unit and the operation to bury the service is complete.

The machines come in a variety of sizes and designs and usually are available as simple plough systems or as vibratory ploughs.

In essence a plough system uses a specially designed ploughshare, blade or lamella which is pulled through the ground using a strong wire cable attached to a towing unit or a wheeled/tracked towing unit, or which is attached directly to a tractor unit or specially designed carriage, depending on the manufacturer.

Some machine options allow the system to be used to install trench bedding material if required and the design of the system normally allows the weight of the ploughing unit to be utilised to compact the base of the trench as the furrow is opened.

This technique is recognised by the International Society for Trenchless Technology (ISTT) as a trenchless technique as it offers so little impact on the immediate surroundings and those living and working there.

The technique is not generally applicable to the tight urban spaces often associated with trenchless techniques because it cannot break open road and similar hard surfaces. It is better suited to open, cross-country situations. However, where grass or open soil verges of some length exist in urban areas it may be suitable provided that other services are not likely to be disturbed by the plough.

The main advantage of this system is that great distances can be achieved in a single working shift with up to 5,000 m being completed in a single day in the right circumstances. This is well in excess of the tens of metres per day achieved using more traditional open cut techniques and even outstrips significantly the output of the more recognised trenchless methods such as HDD.

Technology Description – what it is
Microtrenching

Microtrenching is highly applicable in the world of modern communications where the need for easily and quickly installed fibre optic cable is increasing. Whilst there are trenchless systems that will assist in this endeavour, there are also available very small trenching systems commonly known as microtrenchers that are available for this type of work.

Microtrenchers are generally operated to produce trenches of between 9 and 38 mm wide to depths of between 230 and 400 mm deep which in many locations runs above the general horizon for other buried services. They comprise a cutting disc (very similar to a diamond saw but large enough to meet the depth requirements for the fibre installation) mounted on a walk-behind or ride-on frame depending on the machine selected. The microtrench can be cut quickly and effectively. It is important that a thorough ground investigation is carried out however as the cut occurs very quickly and there would be no warning of any potential interaction with other buried services.

Many fibre optic systems are designed to run in protective cases that slot neatly into these sizes of trench which can be backfilled with materials once the fibre cable is in place.

However, users should be aware that the route of such a trench needs to be highlighted effectively with all other utilities and buried service providers. If not there is every possibility that someone with a bigger machine will come and carve through the often barely visible fibre route and not even notice!

Narrow Trenching

Where the trench involved requires a limited size there are more mechanised trenching options among which is the use of the narrow trencher or utility trencher. A technique developed in the USA, this involves the use of equipment specifically designed to cut a small width trench to a set depth using a toothed chain saw attachment.

These trencher units come in a variety types and sizes depending on the manufacturer and may have a selection of optional attachments that enable the one unit to be utilised for a variety of operations.

In the main the units fall into specific categories and these in turn relate the type of use/trench that is being dug and include:

Walk-Behind trenchers – the operator controls the machine from a standing position behind the unit, walking forward with the unit as the trench is excavated. These machines tend to be used for the smaller dimension trenches and can usually provide a cut of around 150 mm (6 in) wide to depths of between 600 mm to 1,200 mm (2 ft to 4 ft). Usually the cutting chain excavates the soil and deposits it to the side of the excavation using a spoil blade. This enables the machine to cut a clean trench whilst limiting the space taken to deposit the excavated soil. The cutting blade/chain is usually fitted with carbide teeth to break down the soils being excavated into a fine spoil that is easy to handle.

Ride-On trenchers – the operator controls the machine from a seat on the unit. Again the operational capacity of these machines depends on the manufacturer and unit being operated. However, an indication of the range of capabilities is that they can excavate trenches from around 1 m (3 ft) to 2.5 m (8 ft) deep with widths of between 100 mm to 300 mm. There are also special machines with tracks instead of tyres for use on less stable or wet ground conditions or rougher terrain. As well as the cutting chain there are machines that utilise a large diameter cutting wheel which is again generally fitted with carbide insert teeth to provide the cutting capability. The diameter of the wheel fitted to the machine dictates the depth to which the trench can be cut and it is often down to individual preference as to which option, chain or wheel machine, will be used or purchased by any one contractor. Furthermore the type of operation that can be undertaken by these machines can be varied depending on the ground type as they are usually available with alternative tooling such as plough attachments and even rock cutting equipment; but care must be taken to select the right tooling to fit the circumstances.