OVERVIEW

Thorough surveys and site investigations are essential to all civil engineering projects, and especially to below-ground activities where the risk of encountering something unforeseen is at its highest. The various techniques now available should greatly reduce the chances of encountering major surprises in the course of trenchless installation, renewal or repair.

All trenchless systems are designed to cope with a specific range of conditions, and none is universally suitable. Knowledge of what exists below ground therefore influences not only the cost of the project, but also the choice of system to be used. The investigations required clearly vary from project to project, but three main groupings can be identified. For repair and renovation the main need is for accurate information about the size, shape, route and condition of the existing main or service, including data on any fittings or chambers. For new installations the principal requirement is for data on soil and groundwater conditions, and the location of existing mains, services and other obstructions. On-line replacement demands information on the material and dimensions of the line to be replaced, the nature of the pipe surround and the position of the line relative to adjacent pipes and cables.

For rehabilitation projects, one of the longest established investigative tools is closed-circuit television (CCTV) which first appeared in the 1950s and came of age in the eighties when modern electronics produced higher reliability, improved performance and lower cost. Other inspection techniques such as sonar and radar can, in the right circumstances, complement or replace information obtained from conventional CCTV surveys. Sonar is used mainly for underwater surveys (for example, in surcharged pipes), and, in addition to identifying defects, can produce quantitative data on pipe dimensions and silt levels. Systems are available for inspecting a part-full pipe by using a CCTV camera above the water-line and a sonar transponder below. There is also potential for in-pipe radar, particularly if external voiding is suspected, since it allows the inspection to penetrate outside the pipe wall.

Partial collapse of a clayware sewer, revealed by CCTV inspection

Concern about leakage from sewers and the pollution of groundwater and aquifers has, in some countries, focused attention on systems which test the integrity of pipe joints. Whilst `joint test and seal' equipment has been available for some time, interest has increased in systems which test for leaks in the course of a conventional CCTV survey, using equipment integral with or towed behind the camera.

For new installations, information about soil conditions can be obtained by conventional trial-holes and borings.

In developed areas, one of the most important survey tools is the pipe and cable locator which can detect existing metallic pipes, current-carrying electrical cables and telecommunications cables. Many types are available, most allowing the use of a transmitter to induce a signal in conductive pipes, which can then be traced from the surface with the receiver. Some pipe and cable detectors can also be used as bore-tracking devices in conjunction with directional drilling and guided boring machines. Ground-penetrating radar (GPR) systems have become more user-friendly in recent times, and can often detect non-metallic pipes, cables, zones of leakage and sub-surface discontinuities such as road construction layers or rock strata.

CCTV

The rehabilitation section of the trenchless technology industry owes its existence largely to the advent of reliable and affordable CCTV inspection systems in the 1970s and 80s. Not only was it thereafter impossible to pretend that underground infrastructure was in good condition simply because defects were out of sight, but also the means of classifying and prioritising its rehabilitation became available.

One of the first recorded uses of a TV camera to survey a pipeline was in the 1950s, when a very large camera was pushed through a sewer in a wheelbarrow to convince the drainage committee of a London Borough that the brick sewer needed urgent repairs. In 1958 a usable, though cumbersome, CCTV pipeline inspection system was developed in Germany. Early cameras used cathode-ray tubes which were poorly suited to rough handling and aggressive environments, and the equipment tended to be fragile and temperamental. This changed in the 1980s with advances in electronics and the introduction of solid-state CCD (charge-coupled device) camera modules. Today's cameras are much smaller, lighter and more reliable than their predecessors, and high-resolution colour has become a standard feature in all but the least expensive units.

Today, it is common in some countries for regular inspections of main sewers to be carried out as a matter of routine, so that sewerage authorities can compile comprehensive information on the condition of the underground infrastructure, and formulate a planned maintenance programme. CCTV is also used for ad hoc inspections to identify the cause of specific problems. In addition to gravity pipelines, CCTV is finding increasing favour for the live inspection of pressure pipes.

Cameras may have fixed, forward-view heads, or heads which can pan and rotate to look directly at the pipe wall or up lateral connections. Zoom lenses are also available to give a close-up view of the pipe wall in large diameter pipelines.

Crawler-mounted zoom, pan & rotate CCTV camera

Photo courtesy of Telespec Ltd

The camera may be mounted on skids and pulled through the pipeline by a winch, or, more commonly nowadays, it can be fitted to a self-powered tractor or crawler which is controlled from the operator's console. Tractor-mounting allows single-ended access to the pipeline, subject to normal safety regulations relating to the venting and gas-monitoring of sewers.

Most CCTV equipment manufacturers can supply tractors to suit pipes from 150 mm diameter upwards. Some have elevating gantries to allow quick adjustment of camera height, whilst others are steerable to give directional control in large diameter or flat-bottomed conduits. There are also special tractors for non-circular pipes, with stabilising wheels or skids which run on the side wall of the pipe.

The tractors are electrically powered, the power supply coming to the camera and tractor from the main control unit through an armoured, multi-conductor cable which also carries the video and control signals. Some systems employ multiplexing which allows all tractor and camera control signals to be carried by a smaller number of conductors, thereby allowing the use of a smaller and lighter cable.

One of the main growth markets has been for portable systems, often supplied with a semi-rigid cable to allow the camera to be rodded up the pipe from a single access point. The camera is often fitted with a circular `brush' skid to centralise it within the pipe, although various forms of moulded plastic and metal skids are also used. The relatively low cost of some of this equipment has broadened its appeal beyond the established specialist survey companies, and it is increasingly common for local plumbing and drainage contractors to use CCTV systems to detect and ascertain the nature of pipe defects.

Photo courtesy of Pearpoint Inc

Modern, compact CCTV system with semi-rigid rod/cable and integral monitor

Many manufacturers of CCTV equipment who initially provided equipment designed mainly for use in sewers and drains have now turned their attention to other utilities such as gas and potable water, producing camera systems and ancillaries designed for live inspections. The compact dimensions of modern cameras allows their use in pipelines down to 50 mm diameter. At the other end of the scale, with adequate lighting CCTV can be used in pipes of over 2000 mm diameter.

Cameras designed for small diameter pipes often have an integral light-head fitted around the lens. This consists of a ring of halogen bulbs providing enough illumination for pipes up to about 200 mm diameter, depending on the sensitivity of the camera. Additional lighting can be attached to the camera for larger diameters, the only limitation being the capacity of the power supply and cable. Cameras with pan and rotate heads usually have lights built into the head itself, which point wherever the head is facing, together with more powerful lights aligned along the axis of the pipe.

Specialised systems are available to survey lateral connections from within the main pipe. They comprise a tractor-driven pan-and-rotate camera with a second satellite camera mounted on top. The satellite camera can be pointed towards a lateral and launched up the branch on its own semi-rigid cable which is fed out from the main unit. All functions are controlled remotely from a vehicle-mounted console, and the systems can operate in pipes from 200 to over 1000 mm diameter.

Cameras can also be adapted to the inspection of vertical shafts, wells, boreholes and hollow piles, some having a rotating mirror which allows the wall of the shaft to be examined in detail at any cross-section. The weight of the camera and cable is critical for deep vertical inspections, since the full load has to be lowered and lifted by the winching equipment on the surface. It may also be difficult to prevent the camera from rotating.

CCTV camera with angled mirror for inspecting wells and boreholes

Photo courtesy of Telespec Ltd

Explosion protected (or `explosion proof') devices are designed and constructed so as to prevent any operation or malfunction of the equipment from igniting a flammable or explosive atmosphere. They may be particularly desirable for the inspection of sewers which can contain methane. Perhaps surprisingly at first consideration, the inspection of live gas mains, whilst entailing stringent safety precautions, does not necessarily require explosion protected equipment. The gas within a pipeline cannot ignite in the absence of oxygen and may be regarded, therefore, as a non-explosive environment.

Unfortunately, the standards governing what is deemed to be `explosion protected' or `explosion proof' vary from one country to another, so a product that meets, for example, European requirements will not necessarily comply with those in the United States, and vice versa.

Proponents of explosion protected equipment maintain that it represents a sensible safety precaution, whilst others claim that normal gas-monitoring and sewer venting measures are adequate. The disincentives towards explosion protected equipment are its additional cost, greater size and more demanding maintenance requirements, and it remains to be seen whether these are outweighed by customer demand for the highest levels of safety. If explosion protection becomes a general requirement for all equipment used in sewers, this will have implications not only for the CCTV industry but also for other systems such as in-pipe cutters and robotic repair techniques.

CCTV DATA RECORDING AND INTERROGATION

Another area which has seen major improvements over the years is the design of control and recording equipment, and indeed of the vehicles into which mainline equipment is normally fitted. In addition to recording the survey on video tape, it is possible to obtain a hard copy of a screen image using an on-line video printer, and to input survey information directly into a computerised database. All but the simplest systems include on-screen distance readings, together with other information which can be input from a keyboard.

Photo courtesy of Pearpoint Inc.

Integrated keyboard and camera control console

Although the tapes recorded during a CCTV inspection may be viewed again if rehabilitation is proposed, the majority are never subsequently replayed. The information from them is used only to generate coded data on pipe features and defects for entry into the database which can be examined at a later stage by interrogation software. Many different database and software formats have been devised over the years, some allowing embedded graphics (e.g. video frame capture of major features and defects) and the facility to link into geographical information systems (GIS).

SONAR

Sonar survey techniques use reflected high frequency sound waves to locate and map discontinuities such as the wall of a pipe, in much the same way as nautical sonar systems locate undersea objects. Although operation in air is theoretically possible, sonar systems are almost always designed to work underwater. The sonar transponder is pulled through the pipe on skids or floats, and sends back an image of the pipe cross-section at predetermined intervals depending on the rate of forward movement and the rotational speed of the transponder.

The image is not a photographic picture of the kind obtained by a CCTV camera, but rather a diagram showing the shape of the pipe at each cross-section. The signal received by the device is influenced by the reflectivity of the surface off which the transmitted sound rebounds, and the image can show different levels of reflectivity. For example, soft silt in the invert of a pipe may be displayed in a different colour to the hard pipe surface below it. Sonar does not, however, penetrate hard surfaces, so no information can be obtained about the thickness of the pipe wall or the nature of the surrounding ground.

The other distinction from CCTV surveys is that sonar equipment can be calibrated to produce quantitative data on the pipe's dimensions. In other words, a sonar survey can indicate with reasonable accuracy the size and shape of the pipe at each cross-section, and the extent of any deformation. Fractures and other defects can also be revealed, although small cracks may not show up.

Sonar equipment is used to survey pipes which run full or part full, and where emptying the pipe or diverting the flow would be impracticable. It can also operate within part-full pipes in conjunction with a CCTV camera, so that the camera views the pipe above the water level while the sonar equipment simultaneously surveys below the water. A common problem with CCTV surveys is that the invert of the pipe is often underwater or obscured by silt, so its condition cannot be established by visual inspection. The combination of CCTV and sonar offers a possible solution.

GROUND PENETRATING RADAR

In addition to its normal use for locating objects in air, radar can also detect discontinuities below ground. The extent of ground penetration is limited by attenuation of the signal: it increases at longer wavelengths, but resolution is higher at shorter wavelengths, so the choice of the best frequency is usually a compromise between the two. Ground penetrating radar (GPR) works best in dry, granular soils, and may not be able to see far through waterlogged ground or dense clays. It can reveal changes in soil strata, highway construction layers, buried pipes and cables, voids, leakage and hard inclusions.

The equipment is normally packaged in the form of a box or sledge which is pulled slowly over the surface of the ground, rather like a lawn-mower without wheels. There is usually an integral liquid crystal display (LCD), together with some method of storing data for downloading to a computer. Systems have also been built to operate within a pipe, with the aim of finding voids in the surrounding ground or zones of leakage.

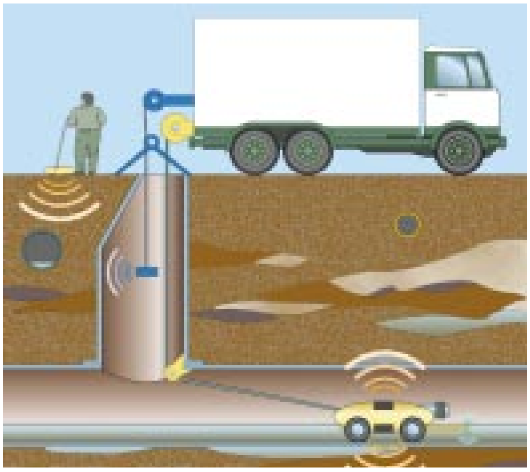

Diagram courtesy of Subterra

Ground-penetrating radar may be used from the surface, or from within a chamber or pipe

The major difficulty with GPR has always been the interpretation of the output, although in recent years some manufacturers have made considerable progress in demystifying it. To the uninitiated, the raw graphical output from a GPR survey often appears complex and unfathomable. Even an expert may rely on a high degree of deduction based on experience, rather than conclusive evidence.

The output can be `cleaned up' by filtering the data and optimising sensitivity levels, and computer enhancement may then be applied to produce a graphical display which is much less daunting than the original. Some systems now claim to be user-friendly, even with more inexperienced operators. However, whilst GPR may indicate that a discontinuity exists below ground, there is often uncertainty about what the discontinuity actually is, and about its depth, due to variations in the radar velocity.

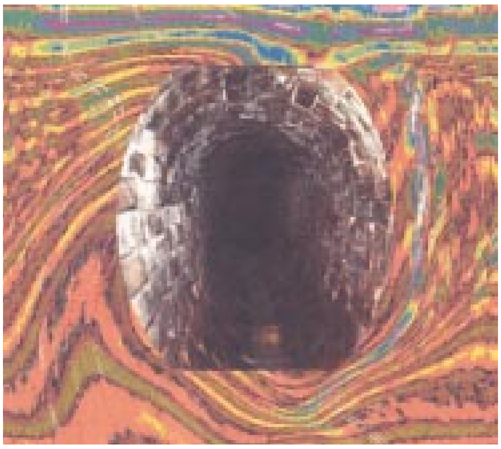

Photo courtesy of Subterra

GPR output around an existing sewer, with a photograph of the sewer superimposed

When trying to locate something which is believed to exist but whose plan position is unknown, GPR can be of considerable assistance in the right ground conditions. Further progress on GPR technology is likely in the future, and the technique will almost certainly become more widely used.

UTILITY DETECTION EQUIPMENT

Pipe and cable locators will be familiar to most people in the civil engineering industry, and are regarded as standard equipment for site investigations prior to trenching or underground construction projects. Their use has become even more essential with the advent of specialised, modern underground utilities such as fibre-optic cables, where the consequence of disruption can be severe and the cost of repairs extremely high.

Most cable locators work by detecting the electromagnetic signals generated around live cables, and can operate at various frequencies to suit electricity and telecommunications lines. Metallic pipe locators can be used as simple metal detectors, or more commonly in conjunction with a transmitter which induces in the pipe a signal that can be picked up by the receiver. Systems are available which can trace the path of cast iron and other metallic pipes at depths of up to 10 metres.

Photo courtesy of Radiodetection Ltd

Receiver and transmitter for utility detection and tracing

The location of non-metallic pipes is more difficult, and usually entails rodding or pulling a small transmitter through the pipeline, and following the signal with the receiver on the surface. Live gas or water pipes can be traced using a length of semi-rigid nylon-coated wire with a nose cone on the leading end and a connector block on the tail. A length of tracer wire is pushed directly into the pipe, through a glanding system or a service tee. A standard transmitter is attached to the connector block on the tail end of the wire, and a utility locator is then used to trace the line.

LEAK DETECTION

The detection of leaks in gravity pipelines, using `test and seal' systems, is discussed in the Localised Repair and Sealing Section. Leak detection in pressure pipes, particularly water mains, has achieved prominence in some countries during the last few years, as water resources have become scarcer and there has been increased public and political pressure for wastage to be reduced.

Many, but not all, leakage detection systems for pressure pipes use a process known as `leak noise correlation'. This involves identifying the sound of water escaping from a pipe by means of hydrophones in contact with the pipe at two locations a distance apart. Sophisticated computer software is then used to compare the data and pinpoint the location of the sound.

There are also modern equivalents of the traditional `listening sticks', using ground microphones which assist an experienced operator to locate the source of water leakage. Ground penetrating radar (GPR) may also be used to detect areas of leakage, operating either from the surface or from within a pipe.

SUMMARY

- Thorough surveys and site investigations are essential to the success and efficiency of trenchless installation and repair techniques. The survey results also help to determine the most appropriate system. Any conventional site investigation method can be used in conjunction with trenchless technology.
- CCTV is the most common technique for inspecting gravity pipelines, and its use in pressure pipes is increasing. Many types of CCTV system are available for pipes of all sizes and shapes, including compact systems that are easily transportable.
- The input of CCTV survey data into computerised interrogation and analysis systems facilitates planned maintenance and asset management procedures.
- Sonar can be used either on its own or in conjunction with CCTV to obtain a profile of a pipe below the water level. It can also provide quantitative information on pipe dimensions and silt levels.
- Ground penetrating radar (GPR) can detect buried objects, discontinuities and leakage, depending on the nature of the ground. The output from some systems requires expert interpretation.
- Utility detection equipment is in common use to plan an installation route and avoid expensive damage. Some locators can also be used for tracking guided bores.
- Leak detection techniques are available for both gravity and pressure pipes, and can obviate the need for expensive excavations and reinstatements to trace the source of a problem.