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# Investigation of the soil before using trenchless techniques

ITU-T Recommendation L.39

(Formerly CCITT Recommendation)

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## Summary

This Recommendation describes the main techniques that allow an investigation of the soil in order to get information about the position of buried objects and the nature of the ground. This data is necessary to plan the execution of work using trenchless techniques and to optimize the drilling path thus avoiding the risk of damage to both the existing infrastructures and the drilling equipment; hence preventing drilling failures due to obstacles or ground characteristics.

This Recommendation gives advice on general requirements of the three different phases in which the investigation work can be divided: preliminary operations, an on-site survey and the output of utility maps.



## Source

ITU-T Recommendation L.39 was prepared by ITU-T Study Group 6 (1997-2000) and approved under the WTSC Resolution 1 procedure on 12 May 2000.

## FOREWORD

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## CONTENTS

**ITU-T Recommendation L.39**

# Investigation of the soil before using trenchless techniques

## 1 Scope

This Recommendation:

- describes the preliminary operations that are required before performing a direct on-site investigation;
- describes the main techniques and methods that can be used to make soil investigation and gives advice on some operational procedures;
- gives advice on how to produce the final map of the investigated area.

## 2 Preliminary operations

Right from the first design phase, it is essential to acquire all the available information about the existing utilities and the nature of the ground on site. This information is of the following kind:

- statutory/administrative;
- technological (e.g. presence of utilities or obstacles);
- geolithological, hydrogeological and geotechnical.

The following action is recommended:

- to consult the available existing documentation of any work carried out in the area (e.g.: laying of utilities);
- to collect all the administrative details regarding permits, monitoring, testing of existing utilities;
- to contact the technical offices of Local Authorities in order to obtain geological and geotechnical reports on work carried out in the area;
- to collect from local arts councils or museums archaeological and historical information relevant to the working site;
- to contact the contracting Companies which had previously worked on site in order to get more precise information, especially in the case of potentially dangerous utilities (e.g. gas mains) or those of public importance (e.g. hospital power and telephone lines).

## 3 On-site survey

In order to minimize the risk of mistakes due to the use of out-of-date maps or to the possible differences between "planning" and "executive" drawings, a direct on-site investigation has to be performed.

The available techniques to perform buried object detection and soil investigation are described.

## 3.1 Buried object detection

### 3.1.1 Ground Penetrating Radar (GPR)

In addition to its normal use for locating objects in air, radar can also detect discontinuities below ground. A planar antenna transmits an electromagnetic wave into the ground and the back-scattered radiation is received by another antenna and then processed, to extract the information relevant to buried objects. Usually any discontinuity of the electromagnetic properties of the soil (dielectric constant and conductivity) is detected. Objects can be classified according to their geometry: planar surfaces, long and thin objects (cables and pipes), local objects.

Wideband time-domain impulse radar systems are available commercially and are usually offered with a range of antennas to suit the desired probing range.

The extent of ground penetration is limited by the attenuation of the signal: the penetration increases at longer wavelengths, but resolution is higher at shorter wavelengths, so the choice of frequency is usually a compromise between the two. The investigation depth is also strictly related to the nature of the ground: GPR works best in dry granular soils and may not be able to see far through waterlogged or dense clay.

For average environmental conditions, medium frequency antennas (400-600 MHz) to reach an investigation depth up to 2 metres and low frequency antennas (100-200 MHz) to reach investigation depths up to 3 metres will be used.

Most antenna have relatively small footprints which means that rapid and wide-area surveying can only be achieved with multichannel radar systems. These systems use more than one antenna, mounted on a fixed scheme, which allows the acquisition of a large amount of data in a relatively short time, and so makes easier the final interpretation of the probing results.

Particularly in urban areas, it is recommended to use a multichannel radar system, mounting an array of antennas, to improve the probability of detection of underground utilities and reduce the overall investigation time.

In order to achieve a correct interpretation of the radar data a calibration procedure should be performed. As manual on-site calibration may cause information distorsion, it is recommended to collect non calibrated data on-site and process it later using the automatic calibration algorithms. In this way on-site calibration error is avoided, and the subsequent automatic calibration procedure can be repeated in the case of unsatisfactory results.

The acquisition system of modern GPR equipment includes a PC connected with the antennas both of which are mounted on a trolley that allows easy manoeuvring. The operator has an immediate view of the acquired data in the field, which can be helpful for the final interpretation of the results.

A focal point among the field operations is represented by the establishment of a reference system in the local environment to which the radar data should accurately refer in order to produce precise maps of the buried utilities.

It is therefore necessary to define in the survey area a reference line (zero line) preferably in correspondence with an existing one (e.g. a wall, the edge of a pavement, etc.), which represents one of the two axes of the local coordinate system, and an origin of the axes (zero point).

In this way by performing survey along lines at a known distance from the axes, all the GPR profiles with the relevant position of each detected object can be automatically referred to the local co-ordinate system.

In order to determine the position of the GPR profiles with respect to the local coordinate system, a survey wheel directly connected to the GPR trolley shall be used.

#### 3.1.2 Cable and pipe locators

Most locators work by detecting the electromagnetic signals generated around "live" cables and can operate at various frequencies to suit electricity and telecommunication lines. A metallic pipe locators can be used as a simple metal detector, but it is better to use it in conjunction with a transmitter which induces a signal in the pipe, that can be picked up by a receiver.

Systems are available which can trace the path of cast iron and other metallic pipes at depths up to 10 m.

The location of non-metallic pipes is more difficult and it can be performed only if it is possible to rod or to pull a small transmitter through the pipeline while following the signal with a receiver on the surface. To trace non-metallic live gas or water pipes, the locators shall be used in conjunction with a standard transmitter attached to a connector block on the tail of a semi-rigid coated wire inserted into the pipe.

### 3.2 Soil investigation

A geological investigation, because of its extent and thus expense, should contain available bibliographical knowledge of the area and also information taken from an on-site investigation.

The techniques used to perform the investigation can be divided into two classes: direct and geophysical methods.

Direct investigation techniques consist mainly in boring and excavation methods and mechanical soundings. All of these methods are based on direct observation of soil samples or on the result of mechanical tests, thus giving reliable responses about the nature of the soil in the areas close to the investigated points.

In geophysical explorations some physical parameters, such as electrical resistance, magnetism or wave propagation velocity can be measured by sensing devices to interpret the characteristics of the ground. They perform a non-disruptive investigation and some of them also allow a continuous investigation of large areas.

Such geophysical explorations supply information for bedrock profiling, define the limits of granular soil areas and large organic deposits. They yield a general definition of subsurface conditions including the depth of the ground water.

However, there are limitations to the information obtained by these methods and they should not be expected to give reliable or useful results for all subsurface conditions.

To reach a convenient compromise between the time and cost of investigation, the reliability of the results obtained and the impact on the working-site, as a general rule, the following items shall be taken into account:

- to perform mechanical soundings or to collect samples of the soil by boring at a limited number of points along the investigated line and to extrapolate the data using the continuous acquisition results obtained by the use of an appropriate method;
- to ensure the optimum utilization of such investigational techniques, geologists or technicians experienced in both soils and geophysical theories should be consulted to determine the applicability of geophysical procedures to the area under investigation.

### 3.2.1 Direct investigation methods

Soundings generally have the advantage of speed and low cost when compared to borings. To obtain more information several soundings can be used as substitutions for a single boring. In addition, soundings can be used to obtain additional information between borings at minimal cost once it has been ascertained that conditions vary in between the borings. Soundings are particularly useful when performed to obtain information on stratification that normally would not be available until additional borings were performed in a later stage of exploration.

Excavations that are large enough to permit the entrance of one or more persons represent one of the most valuable and dependable means of exploration, since they permit detailed examination of the subsurface materials in situ.

The following action is recommended:

- to use soundings in the mapping of soil strata during the early stages of explorations when the number of borings that can be drilled is normally limited;
- to integrate the results obtained by soundings with other data in order to avoid misleading results caused by the presence of local obstacles (gravel, boulders, roots, etc.);
- to limit the use of excavation methods to the digging of pits necessary for the use of trenchless techniques, in order to reduce obstruction to traffic and pedestrians on site.

### 3.2.2 Geophysical methods

#### 3.2.2.1 Electrical resistivity method

Two types of resistivity surveys are used for subsurface explorations, namely, horizontal electric sounding and vertical electric sounding.

Horizontal electric sounding is performed by maintaining constant electrode spacing as the electrodes are moved across an area and a resistivity measurement is made for each new location of the electrodes. Data from a series of such traverses across an area may be presented in the form of a series of contours of equal resistivity. Horizontal electric sounding can be used to delineate an area of permeable soil deposits, to locate fault planes, and to locate steep contact surfaces between different materials.

Vertical electric soundings are made by maintaining the centre of the electrode spread at a given location and taking a series of resistivity readings as the electrode space is increased. As the spacing is increased, the depth of material that effects the resistivity increases, and changes in material are reflected in the resistivity values obtained. Vertical electric sounding is used to estimate the depth to bedrock, sand and gravel, or water-bearing strata and to estimate the thickness of strata.

The following action is therefore recommended:

- to use horizontal electric sounding to provide information concerning lateral variations in subsurface materials;
- to use vertical electric sounding to provide information on the variation of subsurface materials with depth.

A recently acquired technology applies the electrical resistivity method using electric arrays composed of tens or hundreds of electrodes spaced sometimes less than 1 metre apart and arranged along profiles or on surfaces. The arrays provide electric images of the soil, both along 2-D sections and also at planes at various depths to provide 3-D images. The physical principle is based on the measurement of the electrical resistivity in direct or pulsed current using quadripoles or dipoles whose geometric spacing increase for increasing depth.

To improve the performance of the resistivity measurement, it is necessary:

- to use alternating current with very low frequency, in order to eliminate the effects of polarisation and to allow greater depths to be reached;
- to use the multiple cover of the measurement points to enhance the signal/noise ratio;
- to use scientific and commercial software programs which allow good treatment of raw data.

The main drawbacks of the method are:

- the need to implant a large number of electrodes in the soil;
- the large number of operators required for rapid operation in the field.

Due to these reasons this method is preferably to be used in countryside areas, limiting its use in urban and sub-urban areas.

Moreover, to obtain reliable data, as a general rule, electrical resistivity methods in conjunction with borings shall be used.

#### 3.2.2.2 Electromagnetic systems

These systems rely on measuring the induced voltage generated between the electrodes of a multi-probe system when an inducing current is injected into the ground.

As inductive methods are applied, these systems do not need grounded electrodes, so that several kilometres of surveying profiles per day can be performed. Where a quick response is needed, these methods shall be used to create maps or profiles in which variations in electrical resistivity are attributed to lithological variations, water contents, etc., both vertically and horizontally.

#### 3.2.2.3 High resolution shallow-reflection seismic

Seismic reflection exploration is a technique used to detect underground continuous stratum boundaries. Seismic waves are generated artificially above ground and the reflected waves, generated by changes in acoustic impedance (e.g. stratum boundaries), are measured by multiple geophones placed on the ground and finally processed.

Seismic reflection exploration is a technique developed in resource exploration fields such as oil and coal and it allows soil investigation up to thousand metre depths. In order to perform soil investigation at shallow depth (up to 10 m) before using trenchless techniques, special equipment and data processing techniques are required. Moreover, especially in the urban environment, it is necessary to reduce the overall dimensions of the equipment, to reduce on-site obstruction to traffic.

It is recommended:

- to use longitudinal waves (instead of transverse waves), which are more effective in shallow depth exploration, because they travel through soil slower than transverse waves. In this way, at the same frequency they have a shorter wavelength and the reflected signals have consequently better resolution;

- to use a seismic source machine capable of generating repeatedly stable longitudinal waves.

Moreover, in urban environment a geophone array, mounted on a metallic base which can be moved simultaneously, should be used, to avoid the insertion of the geophones into the ground and to reduce the working time.

#### 3.2.2.4 Ground Penetrating Radar

In addition to its use for locating discontinuities in the ground, GPR can also detect ground characteristics. The electromagnetic soil backscatter is processed to extract the information relevant to the ground features: ground conductivity, water content and granulometry.

The ground features can be extracted by analysing the electromagnetic signature of the ground response. The efficiency increases with multifrequency and multipolarization radar.

It is therefore recommended to perform multifrequency surveys by using medium frequency antennas (400-600 MHz) and low frequency antennas (100-200 MHz), and to perform multipolarization surveys by acquiring co-polarized and cross-polarized radar data.

Both multifrequency and multipolarization data should be used in order to extract ground features; therefore all the data should be acquired simultaneously, to ensure it is relative to the same ground volume.

A multichannel radar system mounting an array of antennas shall be used, to allow multifrequency and multipolarization data to be simultaneously acquired thereby reducing the overall time.

Radar multifrequency and multipolarization surveys may allow the production of continuous profiles of the soil characteristics. The calibration of such information by means of core samples improves the quality of the results.

It is therefore recommended:

- to calibrate radar data by means of core samples, thus improving the reliability of the results of the survey.

#### 3.2.2.5 Ground water investigation

Ground water investigations are of two types, those used to determine groundwater levels and springs and those used to determine the permeability of the subsurface materials. The former includes measurements to determine the elevation of the groundwater surface (water table) and its variation with the season of the year, the location of water tables, the location of aquifers and the presence of artesian springs. Water levels may be measured in existing wells, in boreholes, and in specially installed observation wells.

An investigation to determine the depth of the water table should be performed, especially if it is possible to estimate, from existing documentation or previous soundings, that a proposed drilling path could be deeper than the water table.

## 4 Output of utility maps

One of the principle aspects of the soil investigations for the detection of underground utilities is the production of maps that can be easily used by operators performing installation or maintenance work on site.

The final report shall provide details of specific soil characteristics as required by the customer.

The final map, showing the position of the detected utilities, should be drawn with respect to the same coordinate system adopted in the field, so that it is easy to correlate the map with the local environment.

It is also necessary to indicate on the map all potentially dangerous utilities (e.g. gas mains) or those of public importance (e.g. hospital power and telephone lines).

The post-processing software of some of the modern GPR systems provides a link with a CAD station to transfer directly on a digital map the information relevant to position and depth of the detected underground utilities.

When an existing digital cartography of the investigated area is available, the information relevant to the position of the detected utilities should be integrated with the existing cartography by directly updating it.

This is extremely important especially in urban environments, where the subsoil is sometimes congested by the presence of many different utilities.

Sometimes, due to obstacles or traffic conditions, one or more portions of the site cannot be investigated. In order to avoid risks, the end user of the utility map should be made aware of this lack of information.

Therefore it is necessary to show the areas not investigated on the map of the surveyed area. It is possible to do this by extracting the information directly from radar data when the GPR is directly linked to the CAD station.

APPENDIX I

## Available investigation methods

### I.1 Boring methods

A boring may be defined as any vertical, inclined, or horizontal hole drilled in the ground for the primary purpose of obtaining samples of the overburden or rock materials present, and thereby permitting the determination of the stratigraphy and/or the engineering properties of those materials. In addition, the hole may be utilized for the in situ determination of such engineering properties, such as permeability and shear strength, the determination of lateral earth pressure, the observation of fluctuations in the groundwater level, the determination of pore water pressures by means of piezometers inserted in the holes and the measurement of deformations by the installation of devices such as extensometers.

The procedure used to make exploratory borings may be divided into two basic operations:

1) advancing the hole to the depth at which samples are to be obtained; and

2) sampling of the soil or rock.

The variability of materials encountered and the need of samples for various purposes have resulted in the development of many different techniques and types of equipment. Methods for advancing the hole are classified according to the manner in which materials are removed. Among the techniques commonly employed are displacement, continuous sampling, augering, wash boring, percussion drilling rotary drilling, and hammer drilling. The techniques for soil sampling are classified, in general, by the mechanical configuration of the sampler and/or the name of its developer. The sampler in common use include spiral, bucket, and hollow-stem augers, solid and split-tube drive samplers, the Shelby tube core barrel sampler, single- and double-tube rock core barrels with diamond or carbide insert bits, shot core drills and others.

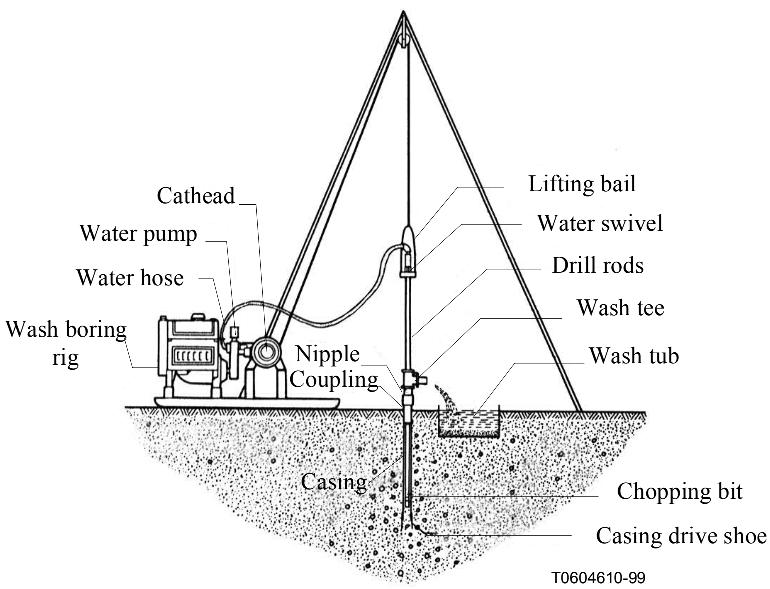



**Figure I.I/L.39 – Schematic of boring method (Wash boring)**

The machinery used to advance the hole and take samples (see Figure I.1), commonly referred to as a drill rig, in general consists of a motor, a water pump or air compressor, a winch and a tripod, four-legged frame mast or derrick. A motor provides power to operate a hammer to drive casing and to operate a winch to raise or lower the drilling and sampling equipment. This also provides rotary motion to turn augers or coring equipment and provides downward pressure to push samplers into the ground. A water pump or air compressor provides water or air under pressure for the removal of cuttings from the drill hole and for the cooling of rotary bits. A winch can be used to raise or lower drilling tools and casing.

The unit selected will depend on the availability of specific rigs, the location of the work, the materials to be penetrated, the type of sampling, the size and depth of the hole, and the method of penetration.

## I.2 Soundings and probings

The terms sounding and probing are used synonymously to represent the method of exploration in which a rod is made to penetrate overburden deposits by means of dynamic or static loading and a continuous or semi-continuous record of the resistance to penetration is obtained. The penetration resistance is used to delineate changes in materials, to correlate the resistance to penetration with various soil properties.

In its simplest form the apparatus used to make soundings consists of a conical point attached to a steel rod, which is referred to as a cone penetrometer (see Figure I.2). Soundings consist of pushing or driving the point into the ground and recording the pressure required to achieve a specified penetration or the number of blows required to drive the point with a specified hammer weight and drop.

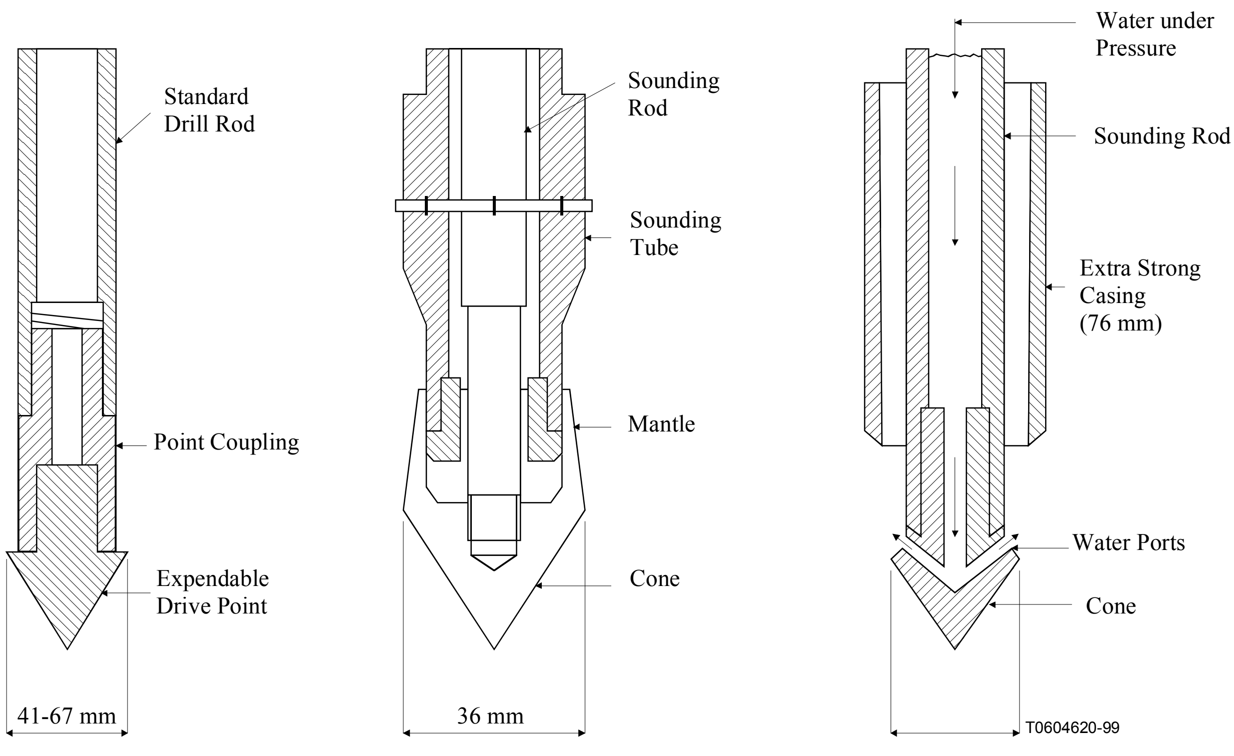



**Figure I.2/L.39 – Examples of cone penetrometers**

Soundings are primarily useful in the mapping of soil strata during the early stages of explorations when the number of borings that can be drilled is normally limited. Soundings generally have the advantage of speed and low cost when compared to borings. To obtain more information several soundings can be used as substitutions for a single boring. In addition, soundings can be used to obtain additional information between borings at minimal cost once it has been ascertained that soil conditions, in between the borings, are variable. Soundings are particularly useful when performed to obtain information on stratification that normally would not be available until additional borings were performed in a later stage of exploration.

However either no samples or only wash samples are obtained from soundings, therefore strata cannot be definitely identified by soundings alone. In addition, the possibility of obtaining misleading results caused by the presence of gravel or erratic boulders or wood within the soil strata must be considered. Interpretation of the results obtained from soundings consequently requires considerable experience, particularly in those cases in which correlation between the penetration resistance and engineering properties of the soils is to be developed.

## I.3 Excavation methods for exploration

Excavations that are large enough to permit the entrance of one or more persons represent one of the most valuable and dependable means of exploration, since they permit detailed examination of the subsurface materials in situ. They also provide a means to obtain large-size samples of the materials encountered.

Test pits and trenches may be excavated by hand or by power equipment such as ditching machines, backhoes, bulldozers, and other types of construction excavators. Special-purpose drilling rigs such as large diameter bucket augers may also be used. One limitation placed on the use of power equipment is that it should not be used too close to locations where undisturbed samples are to be taken.

The size of the excavation will depend primarily on the space required for efficient excavation and on economic limits. Test pits normally have a cross section 1 to 3 m square or in diameter. Test trenches are usually 1 to 2 m wide and may be extended for any length required to reveal conditions along a specific line. In general, test trenches are relatively shallow, whereas test pits may be deep. However, it is common to keep even test pit depths to a minimum, owing to the expense involved.

## I.4 Geophysical explorations

### I.4.1 Seismic

Seismic methods are based on the fact that shock waves travel at different velocities through different types of materials. Since the velocity of wave propagation depends on numerous factors such as density, moisture, texture, void space, and elastic constants, the nature and stratification of subsurface materials can be determined. However, most subsurface materials are non-homogeneous and anisotropic and this makes the analysis of seismic exploration data somewhat complex.

In seismic explorations, artificial impulses are produced by blasting, vibration, mechanical or electrical perturbation, or other disturbances at ground surface or at shallow depth within a hole. These artificial shocks generate three types of waves, namely, compression, shear, and surface waves, in general only compression waves are observed. These are classified as direct, reflected, or refracted waves. Direct waves travel in approximately straight lines from the source of impulse to the surface. Reflected or refracted waves undergo a change in direction of propagation when they encounter a boundary separating media of different seismic velocity. Waves that are turned back when they encounter such a boundary are called reflected waves and those that undergo a change or a bending in the direction of propagation are said to be refracted. Mainly refraction and reflection seismic methods are used for subsurface profiling in engineering exploration. Of these, the refraction method is most commonly used for civil engineering purpose, since the reflection methods are limited to providing information on subsurface materials at depths greater than approximately 150 metres below ground surface.

When exploring extremely shallow soil stratum (up to ten metres) in urban areas, it is necessary to consider the problems related to the interference between the reflected waves and the surface and direct waves which increase the difficulty in processing the acquired data.

Special techniques have been developed in order to detect shallow strata boundaries, based on the reflection of longitudinal waves. Longitudinal waves have a shorter wavelength than transverse waves of the same frequency, thus allowing a better resolution. Moreover, while transverse waves are influenced by subterranean water and exhibit a smaller speed contrast in stratum below the subterranean water surface, longitudinal waves are unaffected by water table.

Seismic sources which generate longitudinal waves generally use the plank hitting method. This method consists of placing a weight on a plank and then manually applying striking force on one side of it, to generate longitudinal waves from the resulting frictional force. However, since people must strike the plank directly, this method requires large amount of labour and it is unable to produce repeatedly stable waves. In addition, the sound generated by hitting the plank can be quite noisy, making this method unsuitable for being used in urban areas.

Seismic sources machines designed to be used in urban environment have been recently developed. These sources generate longitudinal waves by lifting a hammer with an air cylinder and then letting the hammer fall freely to hit the plank. The principle is the same as the general plank hitting method, but allows repeated strikes of the same energy. This seismic source can generate longitudinal waves capable of exploring up to depths of about 15 metres.

Measurement was formerly performed by inserting pins with geophones attached, directly into the ground, but it was possible just in bare place such as mountainous places and plains. Locations where pins can be inserted in paved urban areas are limited, so that new systems were developed. Aluminium bases which can easily be installed on the ground surface and easily moved were designed: the weight of the base produces frictional force with the ground surface, allowing underground vibration to be received.

The seismic methods can be used in surface, down hole, or cross hole modes. In the down hole system, the transmitter and the receiver are mounted on the same probe separated vertically by a known distance. In the cross hole mode, the receiver is placed in one borehole while the transmitter is placed in another hole which could be acoustically "seen" from the receiver hole.

In addition to subsurface profiling, seismic methods can also be used to determine engineering properties of soil and rock, computing in situ the velocity of compression waves, and sometimes of shear waves.

### I.4.2 Electrical resistivity method

The electrical resistivity method of subsurface exploration is based on the fact that different materials offer different resistance to the passage of an electric current. Thus, by the determination of vertical and lateral variations in this resistance it is possible to infer the stratification and lateral extent of subsurface deposits. In this method, the resistance to passage of the current is determined by measurement of the specific resistance of the materials, which is defined as the resistance in ohms between opposite faces of a unit cube of materials (see Figure I.3). In soils, the resistivity of the particles is high; similarly the resistivity of groundwater, if pure, is high. Therefore, if there is to be a passage of current through a soil mass it will be almost exclusively through electrolytic action due to the presence of dissolved salts in the groundwater. Consequently, the resistivity of a soil is primarily dependent on the moisture content and the concentration of these dissolved salts. It is also influenced to varying degrees by the void ratio, particle size, stratification and temperature. In rocks other than mineralized deposits, the resistivity similarly depends primarily on the moisture content and the concentration of dissolved salts in the groundwater. It is also affected by porosity, dip and strike, soundness and temperature.

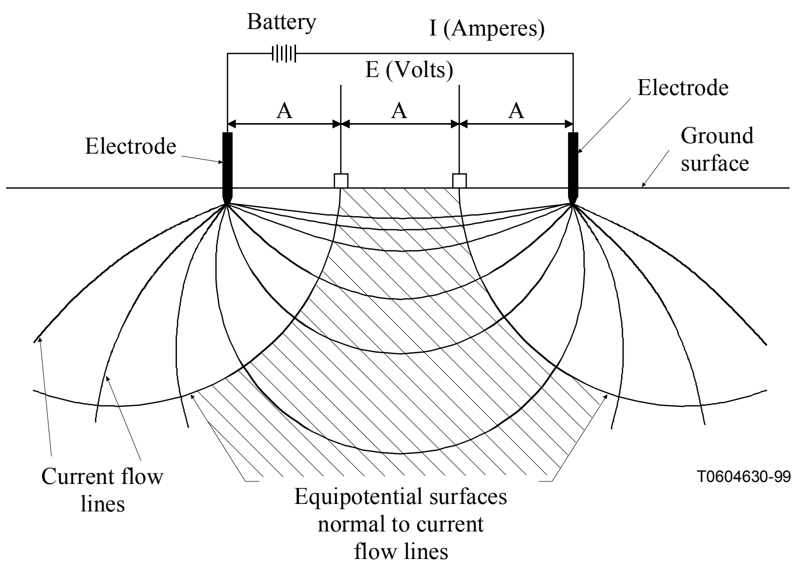



**Figure I.3/L.39 – Electrical resistivity method**

The electrical resistivity method must be used in conjunction with borings if reliable data are to be obtained. In general, it is not as accurate or reliable as the seismic method. However, it is a faster and more economical means of exploration. The required equipment had a low initial cost and is completely portable.

### I.4.3 Ground Penetrating Radar

Explorations of subsurface conditions by means of impulse radar systems, referred to as ground penetrating radar (GPR), or, as an alternative, electromagnetic subsurface profiling (ESP) or subsurface interface radar (SIR), have been successfully used in the field of civil engineering. These methods have been used for many purposes, among which are the continuous profiling of strata between borings, the profiling of the surface of bedrock and the groundwater table, the detection of voids in soil and rock, the detection of voids within and below pavements, the location of utilities and buried objects, the detection of holes in clay liners, and the location of reinforcing bars in pavements. As with other geophysical exploration methods, it is necessary to have borings for correlation and calibration when the technique is used to delineate subsurface conditions. And these methods require the help of a specialist to interpret the geophysical data into engineering terms.

These methods consist of the radiation of repetitive electromagnetic impulses into the ground from the surface and the recording of the travel time of the pulses reflected from the ground surface and from discontinuities in the subsurface profile. The travel time of the reflected pulses is used to determine the depth to the discontinuities and to delineate these discontinuities. Reflection of the radar signals is caused by differences in the conductivity of the materials through which the signal passes and the relative dielectric constants of the materials penetrated.

The equipment used for ground penetrating radar surveys includes a radar impulse generator, low- and high-frequency antennas that are used both to transmit the applied radar signal and to receive the reflected signals, a graphic recorder or a portable computer. Antennas with high frequencies (300 to 900 MHz) produce a greater resolution of detail over a shallower depth, whereas antennas with low frequencies (80 to 120 MHz) provide greater penetration but with less resolution. Objects less than 3 cm in size can be detected to a depth of 1 m with the 900 MHz antenna and a penetration up to 20 m with a resolution of about 1 m can be obtained with the 80 to 120 MHz antennas.

The GPR signals penetrate PVC casing, oil or water, but it is significantly attenuated by steel, heavy bentonitic suspension or salt water.

New conception radar systems have been recently developed to improve the reliability of the results of the investigation and to reduce the time necessary to perform the surveying. The main features of these systems are:

- multi-antenna and multichannel array;
- powerful post-processing tools;
- direct connection with CAD (Computer Aided Design) and GIS (Geographical Information System) systems.

The "radar array" consists of several antennas operating simultaneously, and allows a significant improvement in the detection probability of utilities or other underground targets. These systems may acquire several different radar channels, which can be monostatic, bistatic, co-polarized and cross-polarized, thus allowing the array configuration to be fitted to different application requirements. Moreover the array architecture allows a three-dimensional survey of the ground to be obtained (see Figure I.4).

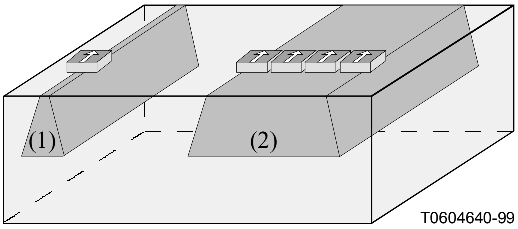



**Figure I.4/L.39 – Comparison between: (1) – 2D (single antenna) survey
(2) – 3D (array of antennas) survey**

The most common output products are:

- a group of parallel radar (vertical) sections (see Figure I.5), where targets are represented in a deformed geometry;
- planimetric radar (horizontal) view of slices of subsoil (see Figure I.6), where the real target geometry has been reconstructed.

This second type of representation, useful for a quick and synthetic view of the site, is made possible thanks to the use of an antenna array.

Some radar systems allow the information related to utilities and other buried objects to be automatically transferred into a CAD environment, producing the final map of the investigated site.

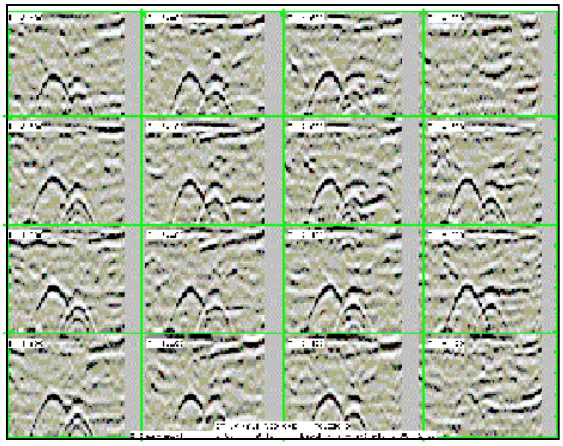
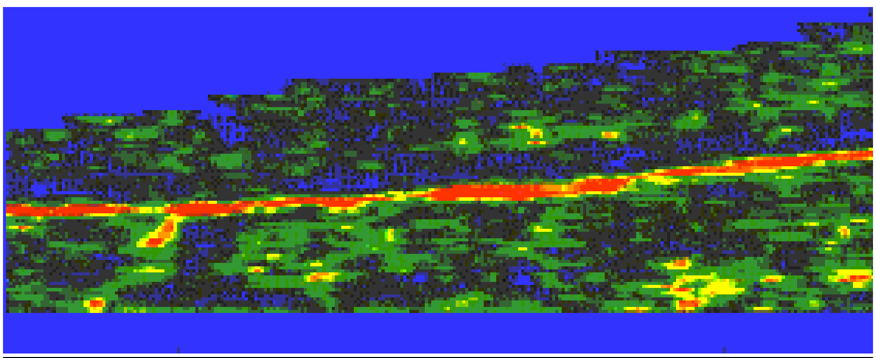



**Figure I.5/L.39 – Multiple radar section representation**




**Fi gure I.6/L.39 – Planimetric view of a pipe**

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