# APPLICATIONS OF GROUND PENETRATING RADAR FOR CIVIL AND STRUCTURAL ENGINEERING INVESTIGATIONS.

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## Abstract

From the largest metropolitan cities to the smallest rural towns, in recent years great emphasis has been placed on the rehabilitation of the existing infrastructure. It is becoming increasingly necessary to find effective nondestructive means to investigate the integrity of our aging roads, bridges, buildings, and industrial facilities.

Ground Penetrating Radar (GPR) has rapidly gained acceptance as an efficient tool for the detection of sub-surface features which may provide both useful information and valuable perspective for engineering evaluations and design.

## 1. Introduction

The early years of GPR concentrated on deeper probing applications such as geological strata profiling, bedrock mapping and fracture analysis, sinkhole and crevasse detection, and snow and ice measuring. More recently with the development of a higher range of antennae frequencies, more attention has turned to shallower, higher resolution investigations.

Ground Penetrating Radar surveys for pavement thickness measurement, void and cavity detection, pipe, cable and reinforcing bar detection, tunnel investigation, and concrete integrity testing have helped to provide nondestructive data critical to engineering solutions.

The acceptance and use of GPR has increased dramatically over the past five years. GPR manufacturers have provided hundreds of radar systems to geological, geotechnical, and engineering companies all over the world. New and increasingly diverse applications are putting demands on manufacturers to produce systems that can satisfy the growing range of resolution and penetration requirements.

As a member of the marketing staff and Application Engineering team at one of the most notable GPR manufacturers I have had the opportunity to be a part of some of the most unique applications of Ground Penetrating Radar in recent years. My intentions are to outline the basic principles and techniques of GPR and also offer a closer look at some of these experiences to emphasize the extensive and varied range of the GPR technology.

## 2. TECHNIQUE:

Ground Penetrating Radar is an electromagnetic sounding method of subsurface investigation which uses radio frequencies. The GPR technique utilizes high frequency impulse energy to obtain a high resolution profile of the subsurface. The system radiates repetitive short time duration electromagmetic pulses into a dielectric medium from a broad band-width antenna placed in close proximity and electromagmetically coupled to the survey surface. The equipment functions as an echo sounding system using radar pulses of only a few nanoseconds in duration and is able to detect and measure the depth of reflecting discontinuities. The radar circuitry generates a series of trigger pulses which are fed through a control cable to the antenna. The energy is transmitted into the ground or any other dielectric material until it reaches a material change or an artificially emplaced object. Then a portion of the transmitted pulses, depending on the electrical characterisitics at the interface or object, is reflected back to the surface. Reflected signals are detected by the receiving section of the antenna and fed back through the control cable to be processed by control electronics. A real time replica of the collected transects can then be displayed in line scan or wiggle plot format on a color monitor. Data may also be continuously plotted by a thermal recorder or later processed and printed on a color ink jet plotter.

The GPR survey procedure consists of towing the antenna throughout the survey area by either hand or a vehicle. One of the primary prerequisites for a successful GPR survey is the ability to transport the antenna at a stable, steady speed between reference points. A triggered pulse is sent from a marking switch built into the antenna and allows for the exact position of material interfaces or any subsurface targets or anomolies to be related precisely to fixed surface reference points. Multidirectional transects are usually collected in great detail to assure complete coverage of the area being examined. A survey wheel attachment can also be very useful for road and tunnel surveys of notable distances. Typically it is also industrious to perform reconnaissance transects to select the survey design which will produce the best results. This may also help in the selection of the most suitable antenna and provide a sufficient level of accuracy. Most radar units utilize a 12 VDC power source for field operation and a regular car battery can usually provide ample power from 6-8 hours of normal operation.

Initial interpretations of the radar data can usually be made by the operator directly in the field on the day of the survey. The interpretor's presence during the acquisition of data will help this person to understand the relation between the radar profile, the field conditions, and the survey medium. Adjustments can then be be made on the reflection amplification levels or gain, the measurment time or range, and the appropriate filters may be chosen to help to emphasize weak reflections or clean up noisy data. Post processing software is also available that employs basic seismic filters such as migration, deconvolution, and hilbert transforms to further massage difficult results.

The basic aim of the interpretation process is to identify layers shown on the profile and to calculate their thickness based on an understanding of the measuring environment. The first stage in the analysis is to identify the origins of the reflections and to discern whether the interfaces represent actual changes or interferences. The surface of the ground is the top horizantal line on the radar transect. The main features of the data are the display of high amplitude bands that extend throughout the profile at varying depths. Each of these banded lines is a reflection from an interface between two materials with different dielectric properties. Underground objects such as pipes, cables, or storage containers, and reinforcing bars in concrete structures, due to their geometric shape and the radiating angle of the transmitted pulses, produce a peak shaped signature or "inverted hyperbola" that indicates the position of these targets. Voids and cavities can be displayed in a number of different ways depending on their shape and size, and more particularly if they are filled with air or water. Prior experience in data interpretation is most certainly the best attribute for deducing successful results but one should never underestimate the importance of ground truth correlation in any GPR survey (See Fig. 1 & 2).

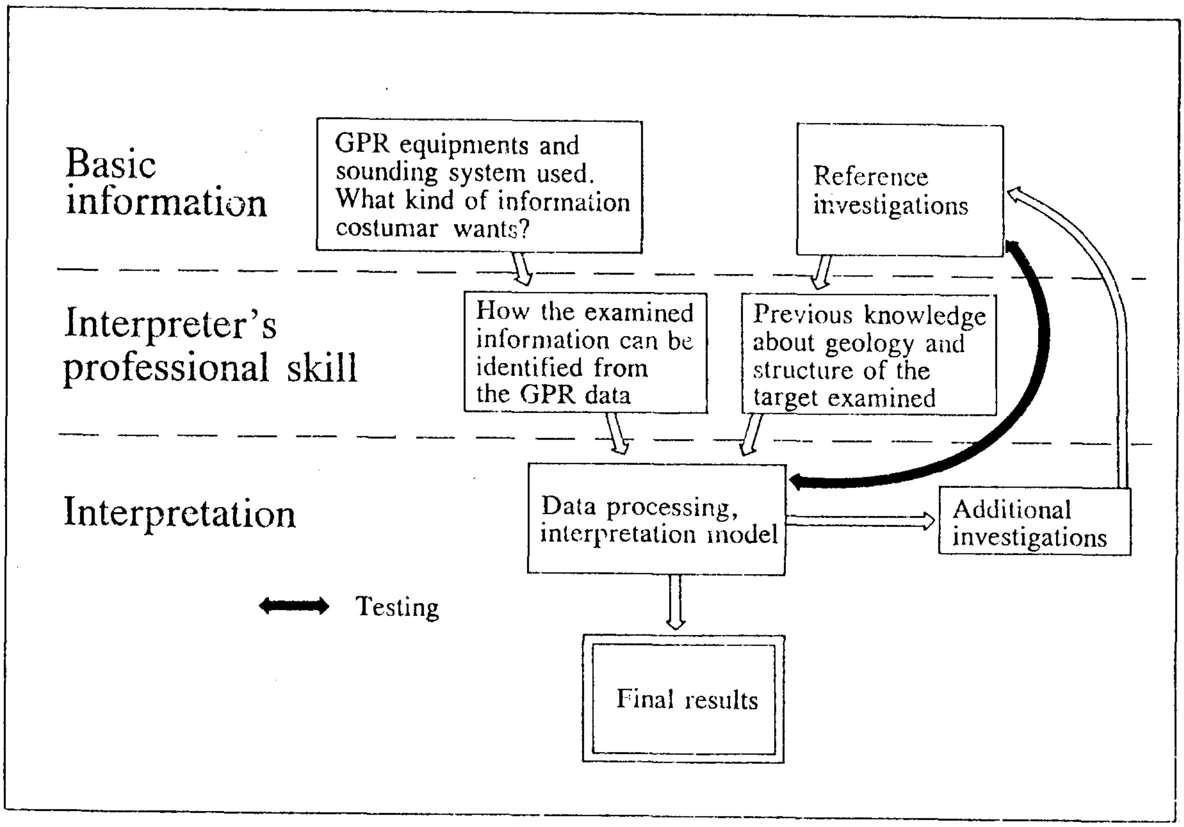
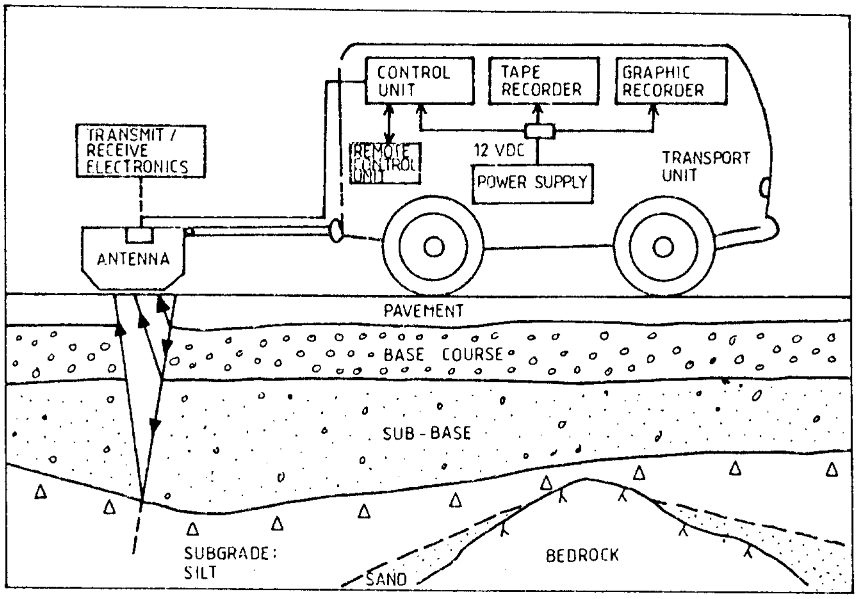


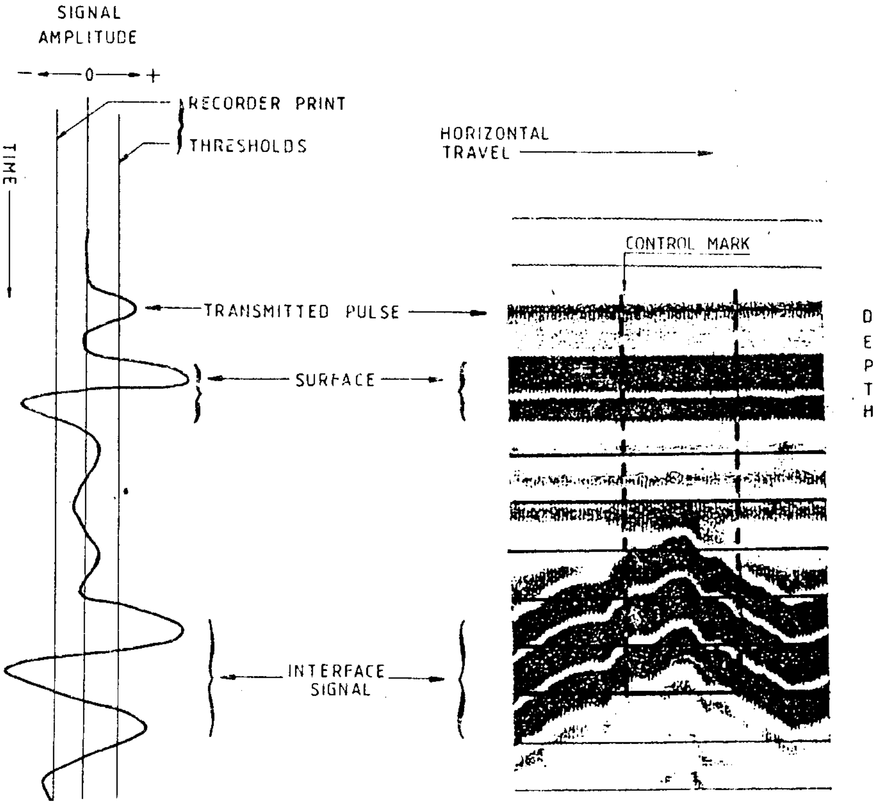
Fig 1. *. Interpretation process of ground penetrating radar soundings.*

## Fig 2. PRINCIPLES OF THE GROUND PENETRATING RADAR SYSTEM

I MEASURING EQUIPMENT



II EXAMPLE OF RADAR DATA



a) SKETCH OF A SINGLE ESP PULSE AND REFLECTIONS AS SEEN BY THE RECEIVER

b) EXAMPLE OF PROFILE INFORMATION AS DISPLAYED BY THE ESP GRAPHIC RECORDER

## 3. ROADS, BRIDGES, RAILROADS AND TUNNELS

As the transportation network throughout the world expands, there is an ever widening escalation of severe settling, faulting, and cracking within the system. Impulse Radar has proven to be a very quick method of identifying where problems exist both in the surface materials as well as the subsurface. Cavities and voids that develop below a road surface or behind a tunnel wall can be located and presented on a plan view of the inspected areas. Factors responsible for void development can also be ascertained in some instances from radar profiles. Motorway thickness measurements and depth and spacing information of reinforcement steel verify specified construction requirements.

The radar technique has also been employed to routinely inspect and evaluate the conditions of railroad ballast, sub-ballast, and sub-grade. Railbed Radar data has produced evidence to confirm the intrusion of water and ballast contamination. Profile data has also revealed information regarding various strata layers and the transition between incongruous subgrade materials. Signature records from railroad ties may also be interpreted to determine their general condition and indicate deterioration, softness, or rotting.

The high cost of airliners and airline equipment has caused many airport authorities to focus their attention of the conditions of their aging runway systems. Again, Impulse Radar has proved useful in detecting subsurface features valuable in assessing repair and rehabilitation procedures. Voids and cavities below airport runways can cause safety hazards and serious consequences. Salt damange may also promote pavement deterioration. Regular inspection using Impulse Radar can acquire information rapidly and nondestructively before problems occur.

## 4. DAMS, LOCKS, AND BULKHEADS

The forces of nature should never be underestimated. Through the years as man has attempted to harness her power, later her course, and hold back her might, he has constructed many mighty barriers. The years do, however, take their toll on these structures and it becomes necessary to verify their stability. Traditional methods to determine voids or faults would be to drill closely spaced borings along the areas of suspect. Drilling enough holes to locate problem areas can be very time comsuming and quite expensive. Voids, cavities, and areas of unconfined weakening can effectively be located with the aid of Impulse Radar. Multiple Radar transects can produce a full view picture to expose underground features and map the location, depth, and extent of anomolous areas.

Typical methods to alleviate the problems of cavities have been to grout or mudjack the void areas. Impulse Radar surveys can help to direct this process by selecting the optimum position for grout holes, and data can also be helpful in calculating the necessary amount of grout material. Post-grouting surveys can provide confirmation that all void areas have been satisfactorily filled.

## 5. BUILDINGS AND STRUCTURES

To meet the needs of an ever growing population, the construction industry has been required to build bigger, taller, and stronger. Concrete, steel, and an array of other building materials have been meshed to provide the framework for these superstructures. Impulse Radar is being used throughout the industry to reduce construction and maintenance costs. Drilling effort can be accomplished more efficiently by accurately locating reinforcing steel. Worker safety is greatly increased by locating high voltage cables, electrical ducts, and conduit. Excavation operations produce no surprises when Radar profiles precisely locate underground metallic or non-metallic pipes and buried storage containers. Quick and accurate job cost estimations are imperative for the conscientious contractor.

Poor job site quality control and documentation can also be substantiated by Impulse Radar to verify that beams and reinforcing steel were emplaced as required. The hefty expense of repairing a post-tensioned cable can be avoided by accurate location within an elevated concrete slab. Renovations are accomplished more efficiently and rehabilitation work is made easier with accurate subsurface information provided by Impulse Radar.

## 6. CONCLUSION

As it would be with almost any geophysical or geotechnical instrument, the limitations of Ground Penetrating Radar must also be discussed. Many independent site variables can work to effect the resulting information. It is imperative that Radar operators have a strong working knowledge of system mechanics, signal enhancement capabilities, and most importantly, sound experience in interpretive data analysis. It is also very worth noting that most often a combination of investigative tools and techniques produces the most comprehensive conclusions. As far as future radar technology is concerned, advances are likely to involve software for various image indentification programs. Target and pattern recognition neural networks will allow for quicker more efficient interpretation and dedicated design of GPR systems will offer endless possibilities for future applications.

## 7. Attachments:

Sample data sections
(Fig. 3 through 15)

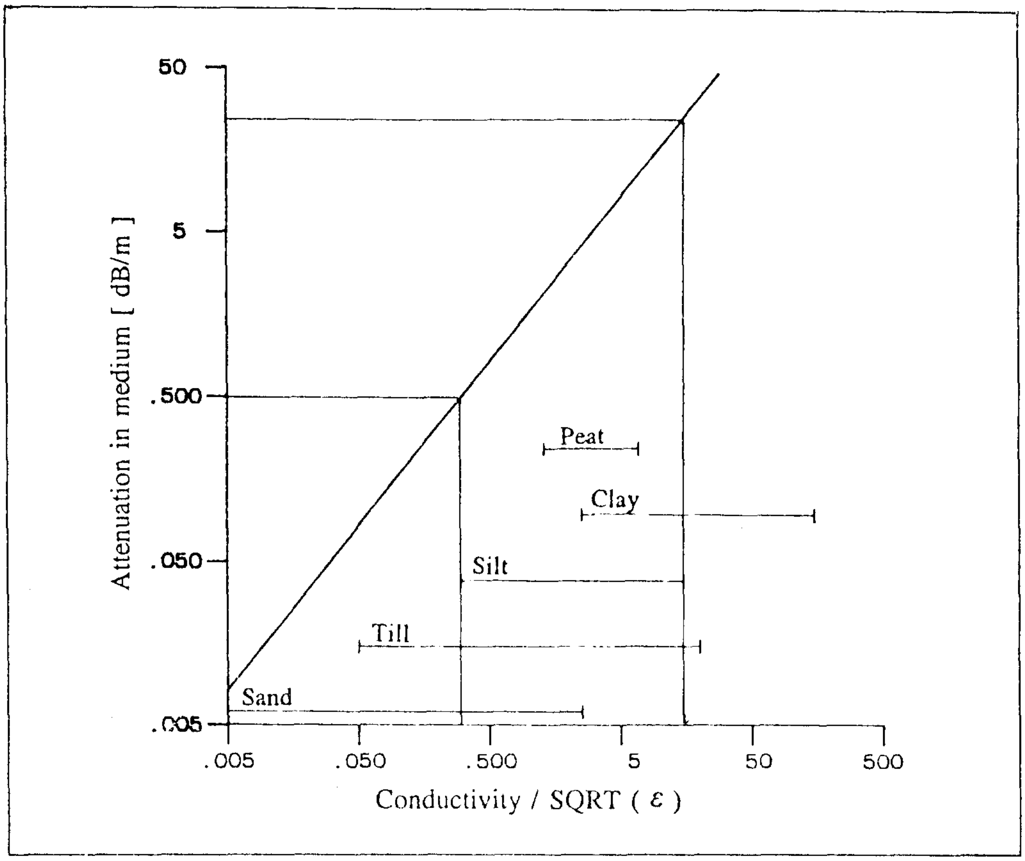


**Fig 3.** *Soil-based attenuation. The correlation between the square roots of conductivity and dielectricity is presented on the horizontal axis. When a vertical line is drawn from each soil type to the gradient line, attenuation in medium can be obtained from the intersection of the two lines.*

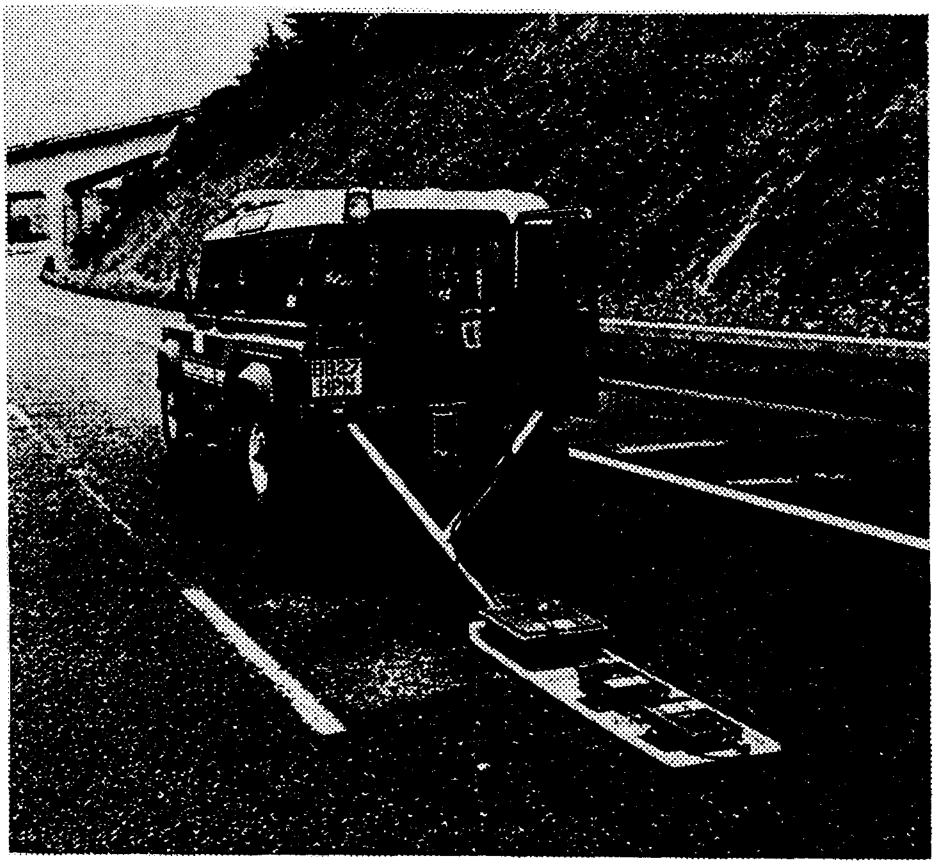


Fig. 4 - Ground Penetration Radar ( GPR ) under surveying for asphalt pavement's continuous profiles.

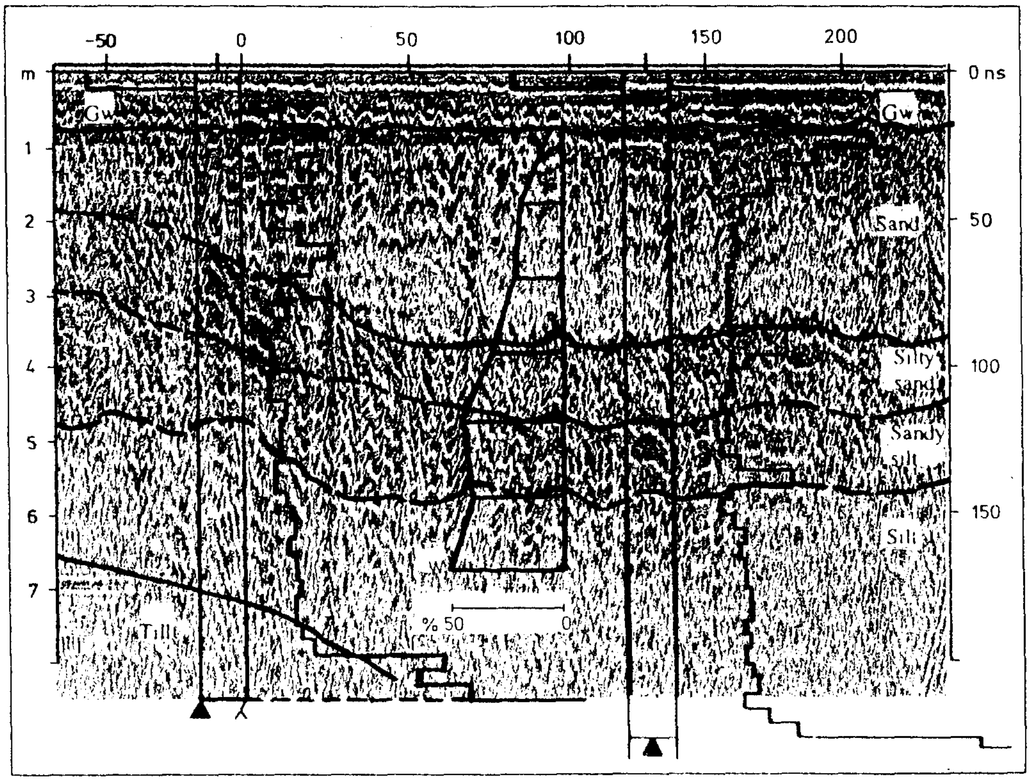


Fig 5. *Use of ground penetrating radar in subgrade investigations for the design of a motorway between Kemi and Tornio at Laurila. In addition to an interpretation, the profile also includes weight penetration test data including moisutre contents. Depth scale corrected. 100 MHz antenna.*

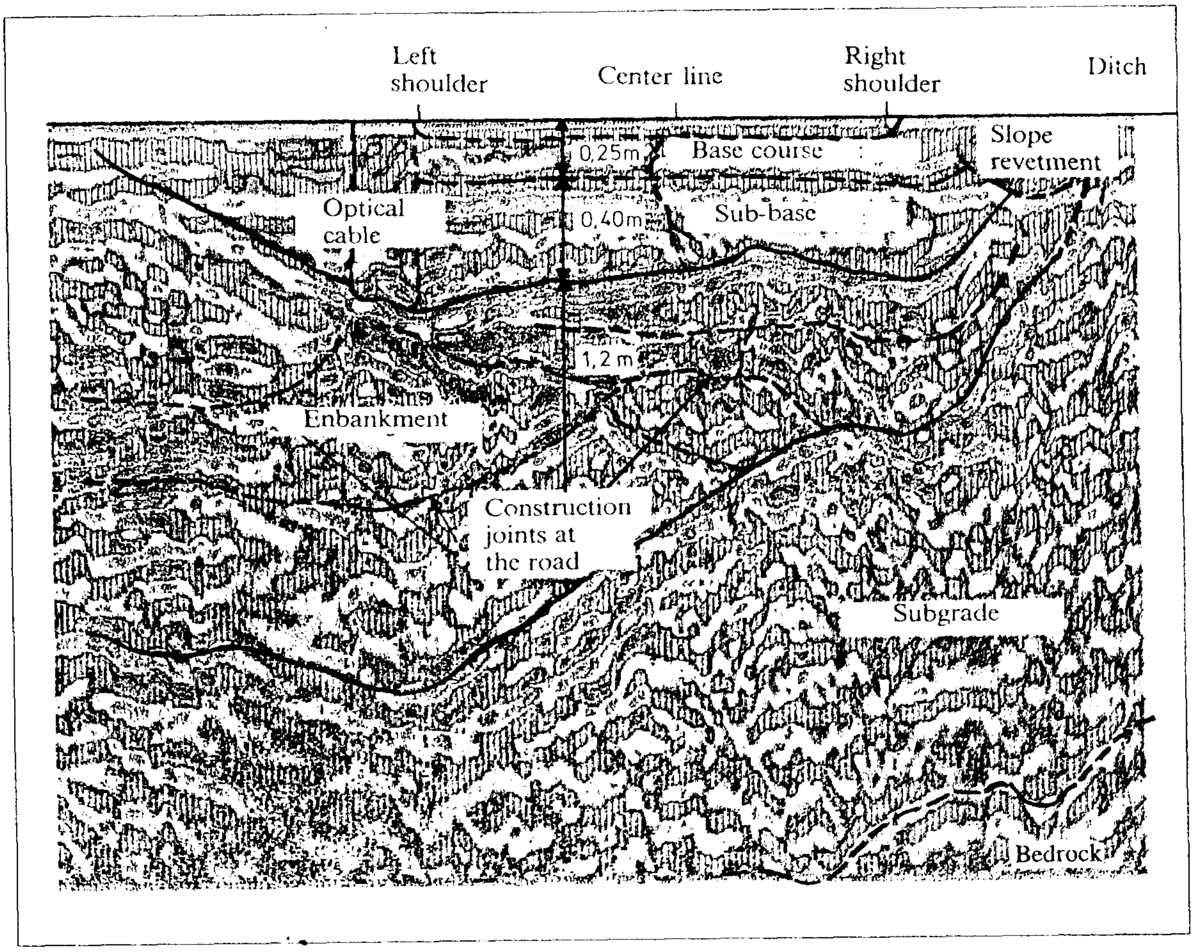


Fig 6.. *Cross-section of a road constructed on a laterally gradient slope, Highway 83 at Ritavalkea, Pello. Structural courses, road embankment and subgrade can be interpreted from the profile. Construction joints of the road, and the ditch excavated on the left-hand shoulder for optical cables can also be seen on the profile. 500 MHz antenna, measurement time (range) 55 ns.*

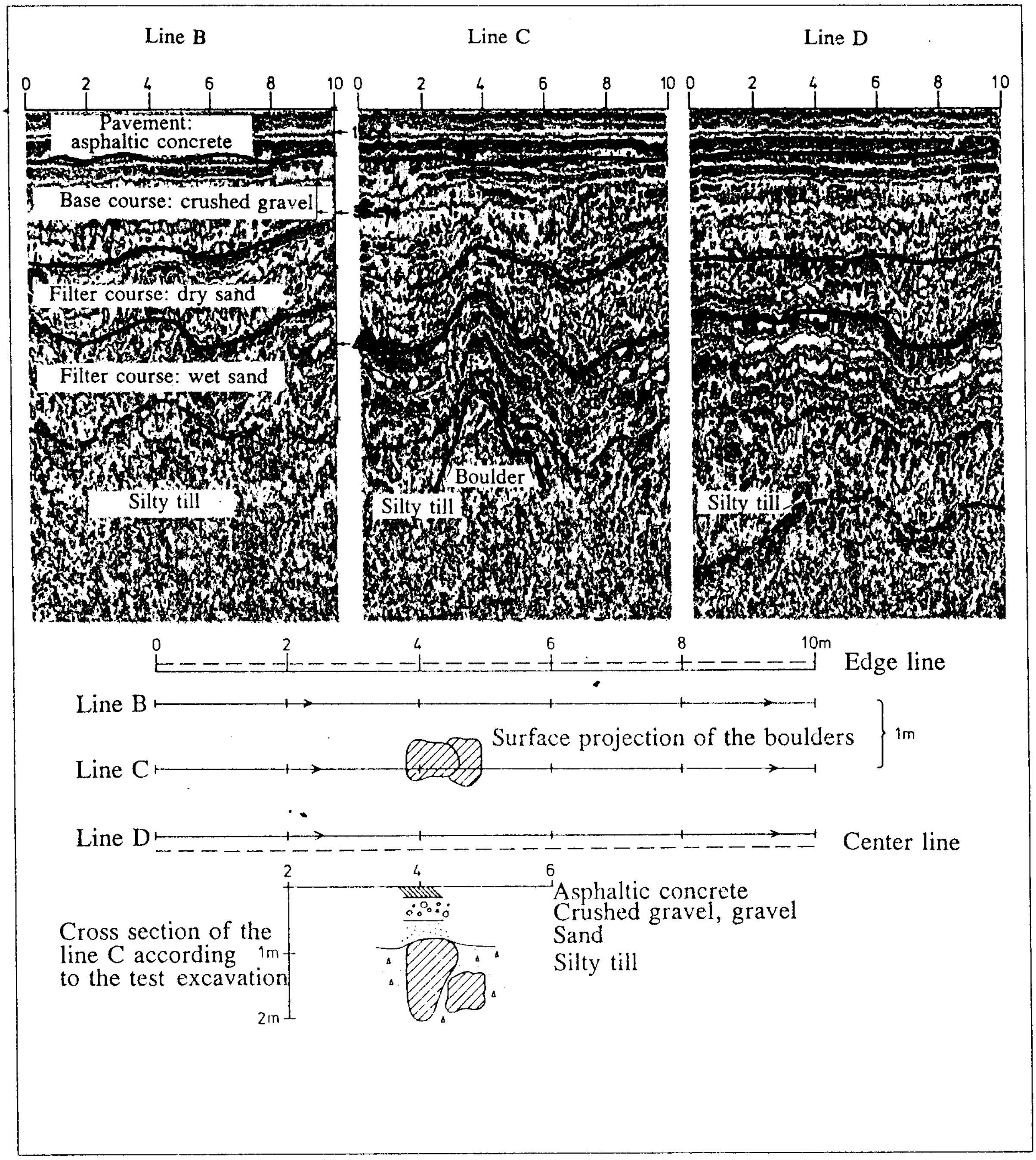


Fig 7. *Road damage assessment on Highway 83 at Aittamaa, Pello. Structural courses and frost-elevated boulders causing road damage are shown on the parallel radar images. Identification of the boulders requires the antenna to be located directly above them. Transect B shows only a few signs of the boulders. The pronounced reflection in the lower part of the structural courses is due to the considerable moisture difference between the materials. The mutual locations of the sounding profiles and the cross-section of transect C at the site of damage as determined by opening up the road are shown in the lower part of the figure. 900 MHz antenna, measurement time (range) 30 ns.*

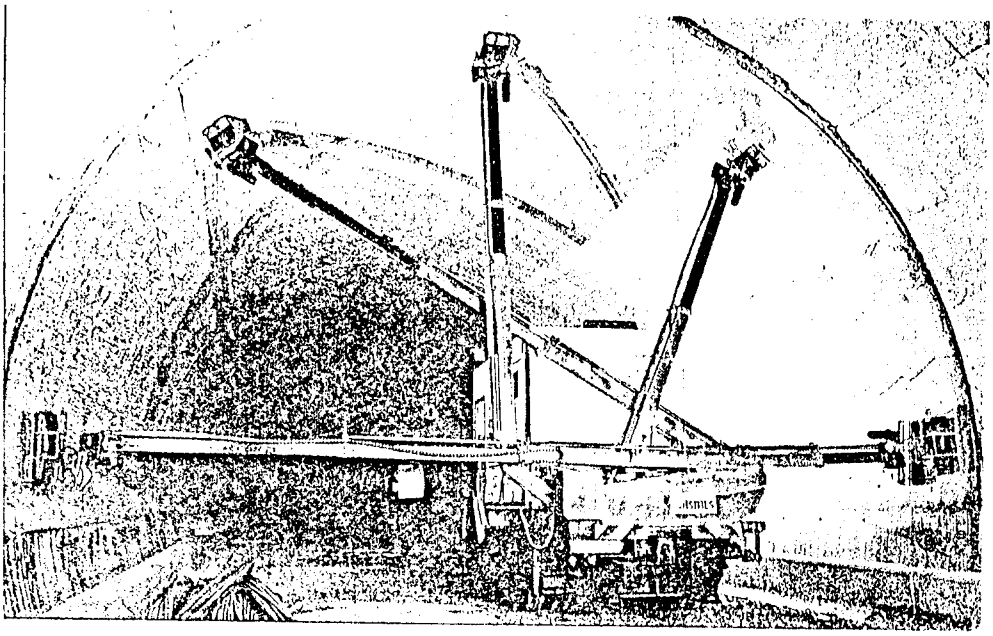


Fig 8. - Mechanical Survey Rig for tunnel investigations by Ground Penetration Radar ( GPR ).

Fig 9. - Discovery of ancient EGYPTIAN funeral boat using Ground Penetration Radar ( GRP )

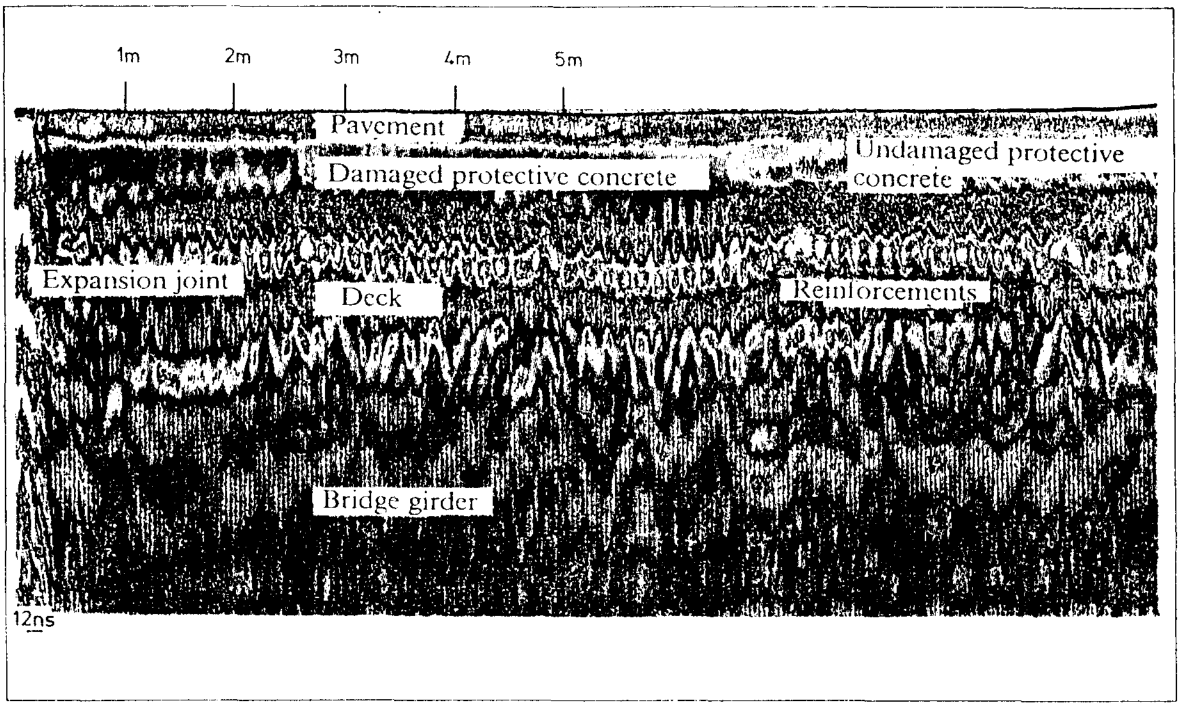


Fig 10. *Examination of concrete bridge deck damage at Patoniva, Utsjoki. The damage in the protective concrete under the pavement can be perceived from the radar profile. 1000 MHz antenna, measurement time (range) 12 ns.*

Fig 11.- Portable, hand held,Ground Penetration Radar ( GPR ) for structural survey under a reinforced concrete bridge.

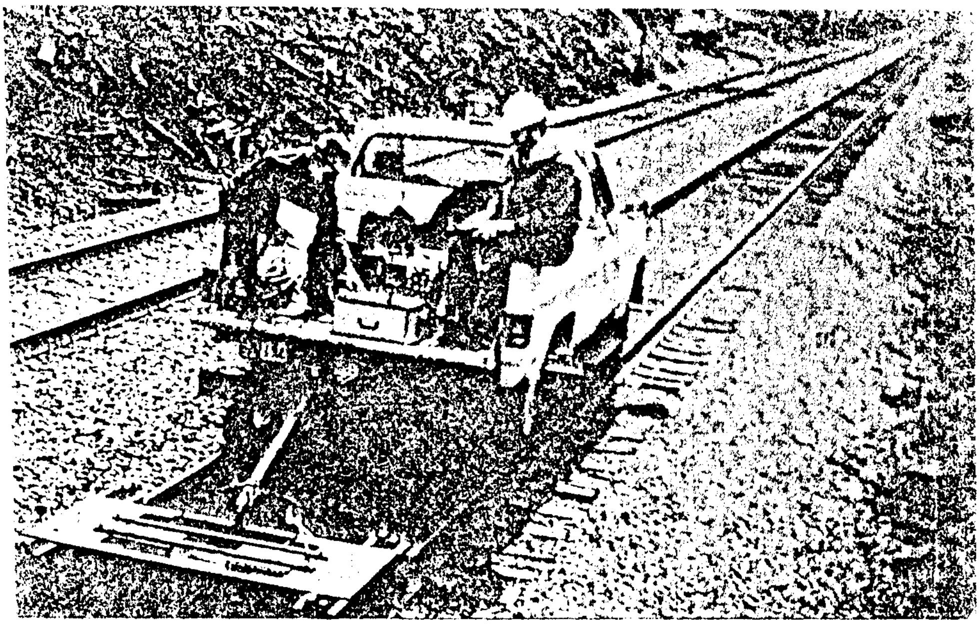


Fig 12.- Profiling ballast and sub-bed conditions on rail road tracks by Ground Penetration Radar ( GPR ).

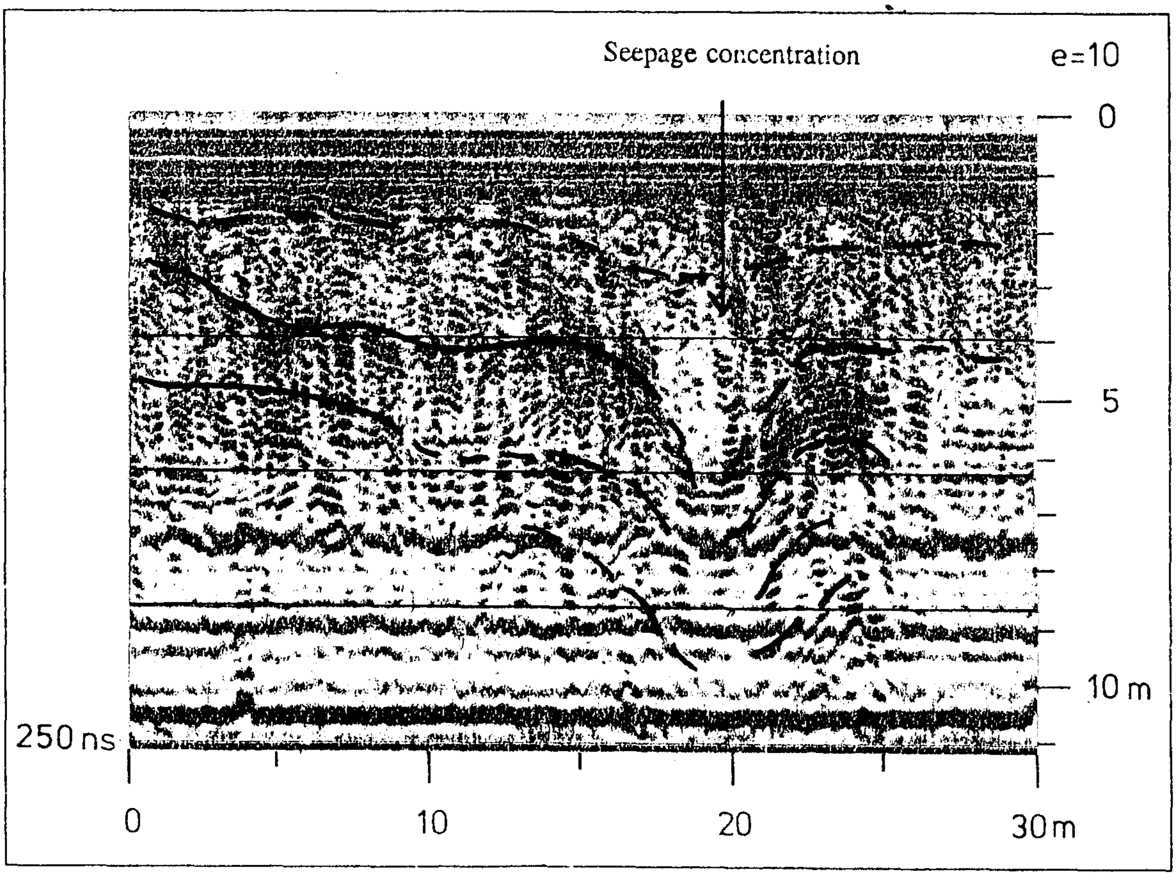


**Fig** 13. *Seepage concentration in a till dam. 120 MHz antenna.*

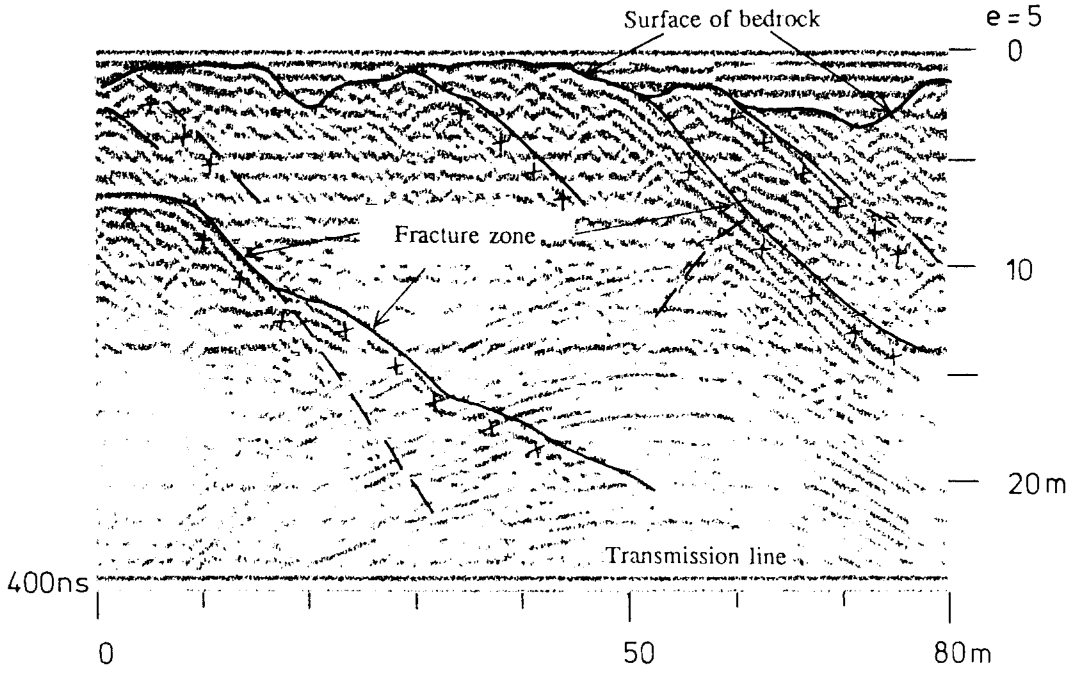


**Fig 14.** *Rock fracture zones. The figure also shows the arch-like interference caused by a power line passing above the measurement transect. 120 MHz antenna.*

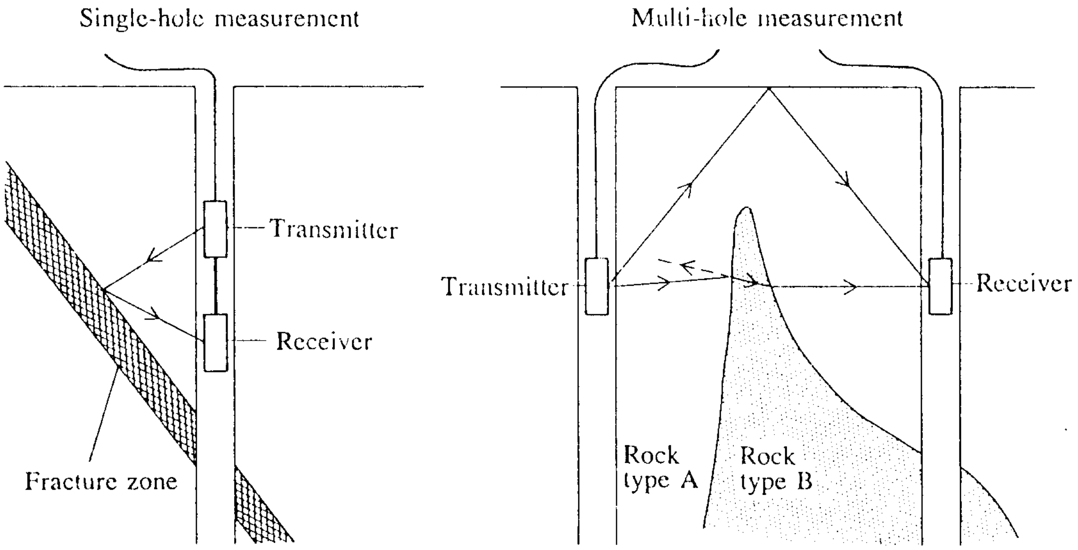


**Fig 15.** *Arrangements required for borehole radar measurements.*