LOCATING A SUBSURFACE OIL LEAK USING GROUND PENETRATING RADAR

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ABSTRACT

An underground high voltage cable, in which pressurised mineral oil is used as an insulating medium, was known to be leaking oil at one or more locations along its 2.5 kilometre length. It was impractical and even dangerous for the most part to dig along the cable route in an attempt to find the location of this leak or leaks. It was known that a significant quantity of mineral insulating oil had left the cable and entered the soil at the site of the leak.

It was decided to trial ground penetrating radar by scanning along and over the buried cable to attempt to pinpoint the site of the oil leak.

Soil dielectric properties are largely determined by the moisture content so that where moisture is displaced by oil the soil dielectric properties will change. Soil stratigraphy seen using radar is due to a large extent to the variable moisture content in the layering of the soil.

Where oil is dispersed through the soil, it will tend to displace moisture. This dielectric property change makes the area sufficiently anomalous so that it can be detected utilising ground penetrating radar.

This principle has now been successfully used on a number of occasions in New Zealand.

KEY WORDS

Insulating Oil, Dielectric coefficient variation, Moisture content, Soil stratigraphy.

PROJECT

The problem we were confronted with was that an underground high voltage cable, approximately 2.5 kilometres long, in which pressurised mineral oil is used as an electrical insulating medium was known to be leaking. The exact route of the cable was well documented and the ground cover varied from one to around 1.8 metres. The mineral oil is normally maintained and monitored at a constant pressure of 4.5 bar., There is a slight variation with temperature however generally the pressure remains reasonably constant under normal operating conditions.

In this case it had been discovered that the cable was leaking when the pressure continually declined over an extended period of several months. There are pressure vessels, each containing 200 litres of oil, connected to the cable at each end of the cable run. These vessels are used as expansion chambers and have pressure and temperature monitors fitted. It became necessary eventually, due to this leak, to top up these pressure vessels with around 160 litres of replacement oil. The complete cable including pressure vessels at each end contains a total of around 1200 litres of mineral insulating oil. It was therefore a known fact that a significant amount of oil had infiltrated into the surrounding soil at the point of the leak.

It was presumed, therefore, that at the point the oil was leaking from the cable an extensive plume of oil contaminated soil would form around the leak location. The shape and extent of this plume would of course be influenced by local conditions and could form on one or both sides of the cable.

Hypothesis.

It was reasoned that this oil entering the soil would tend to displace the natural water content in the soil. It was this change in the soil conditions brought about by the oil that we would use as our radar target to locate the source of the leak.

The variable moisture content of soil is the major contributing factor to dielectric variation. This is easier to understand when the dielectric permittivity of water is compared to that of average soil. The dielectric coefficient of most damp soils normally varies between 15 and 25, and that of most dry geological materials between 5 and 10, whereas the dielectric coefficient of water is around 80. The water content has thus a significant effect on the dielectric properties of soil. Subtle changes in water content of the soil caused by layering create strong radar reflections. As a result radar can be an effective tool when used to identify soil stratigraphy.

Typical soil dielectric coefficient variation with water content can be seen in Chart No 1 below.

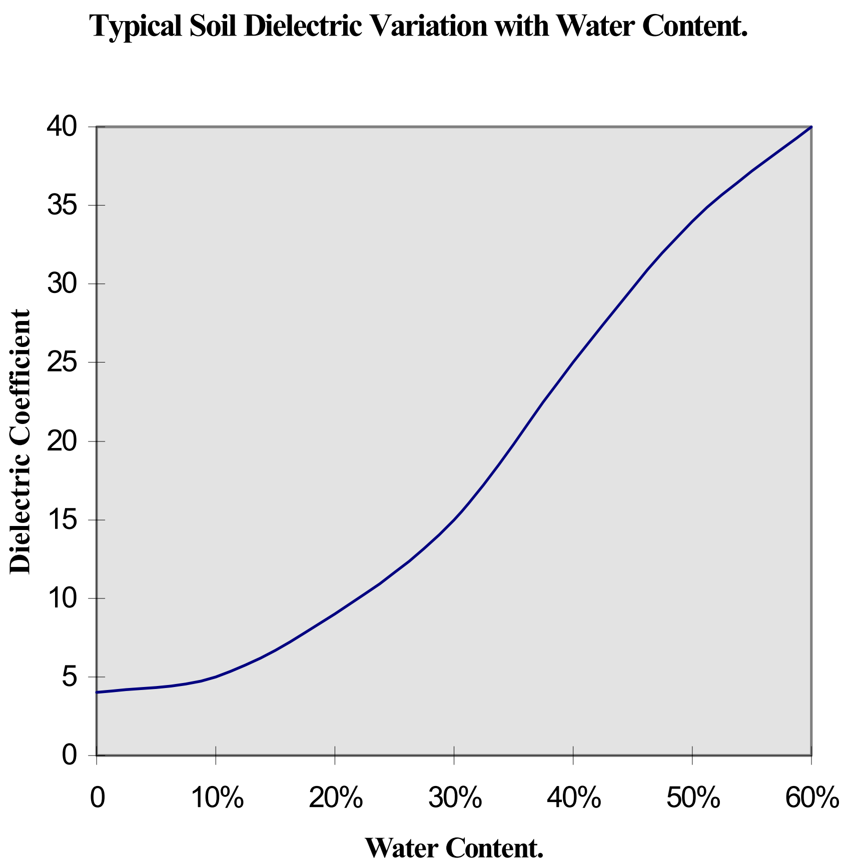
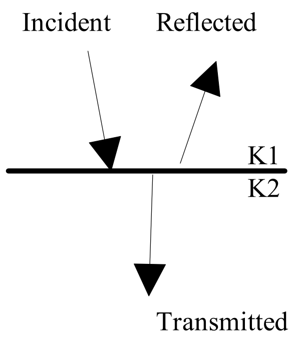


Chart No 1

The strength of the reflection seen by ground penetrating radar is directly related to the absolute difference between the dielectric properties, referred to here as K1 and K2, of the materials under consideration. The Reflection Coefficient is most often used to give a value to the expected reflection strength. The Reflection Coefficient is quantified by the difference between the square roots of the dielectric coefficient divided by the sum of the square roots of the dielectric coefficient as shown below.

Factors Affecting Strength of Reflection



$$\text{Reflected } R = \frac{\sqrt{K1} - \sqrt{K2}}{\sqrt{K1} + \sqrt{K2}}$$

The effect of moisture in the soil is to increase the values of the dielectric coefficients and consequently the difference between K1 and K2. The result is thus a stronger reflection and in this case allowing the soil stratigraphy to be seen. Chart 2. Below shows the rapid change in reflectivity as the difference in dielectric coefficients K1 and K2 is increased.

Reflection Coefficient variation with K2/K1 Differences.

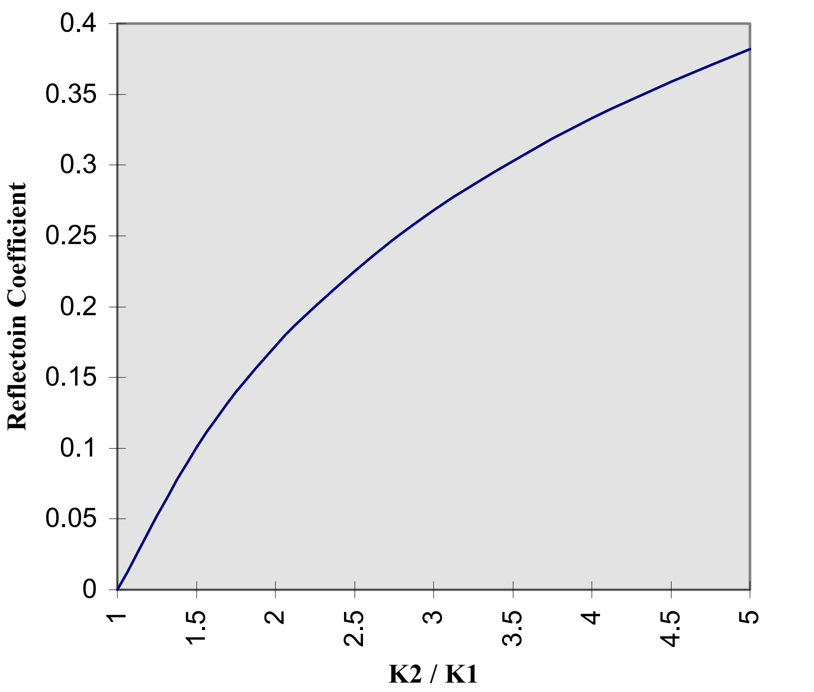


Chart No 2

Ground Penetrating Radar Application

The local soil, consists of predominantly pumice and river sand material with small amounts of other types such as loam and gravels. The dielectric coefficient of the local soil conditions was established by carrying out a radar scan over an underground service of which the depth was known. This gave a signal velocity of 0.07metres/ nano-second or a relative dielectric coefficient of 20. The first task was to establish the highest radar centre frequency that could be used which would give penetration and good data resolution to a depth of at least 2 metres.

The higher the frequency the more detail available and hence increased chance of identifying areas of change in the soil strata. More detail is available from high frequency radar reflections due mainly to the shorter wavelength.
After some preliminary trials it was found that a radar centre frequency of 400 MHz yielded the most suitable results. At this frequency penetration to 3 metres could be achieved and soil strata lines could be clearly identified on the radar data.

Methodology

A GSSI SIR-2 unit with a model 5103 400 MHz antenna was used to carry out this survey. The time interval or range was set at 60 nano- seconds giving effective penetration to just over 2.0 metres. Data collection was controlled by a GSSI survey wheel set to give 55 scans/ metre. This ensures that sufficient data was captured in order to give good resolution of soil strata variations.

The method employed was to use radar antenna to scan parallel to and alongside the cable route. Scans were taken along lines 1 to 1.5 metres either side and parallel to the cable, for the whole length of the cable.

Results

The radar data showed good soil stratigraphy detail along the route. In the area of the oil leak however the soil stratigraphy became immediately invisible. Radar reflection in this vicinity was distinctly different. (Refer Figure 1). This indicated that the effect of the soil is to minimise the soil dielectric property variations and make the soil appear homogeneous while not significantly affecting the attenuation of the radar frequency impulses. A definite rounded plume could be easily identified where soil strata lines could no longer be seen by radar. This proved to be the area where the natural soil moisture had been displaced by the leaking oil. The plume extended on either side of the cable for around 10 metres. The top of the plume can be clearly seen starting at around 0.8 metre depth on the radar data. It is evident on the radar data that normal soil stratigraphy reflections can be seen all around the plume, including underneath the contaminated volume.

The leak had evidently been caused by damage to the cable at some previous date by unknown contractors working in the area.

This method using ground penetrating radar to trace oil leaks has also since been successfully used to locate a marine heavy fuel oil pipeline leak. This pipeline runs between inland fuel oil storage tanks and a shipping port.

Radar Computer Printout. Showing Effect of Oil Plume

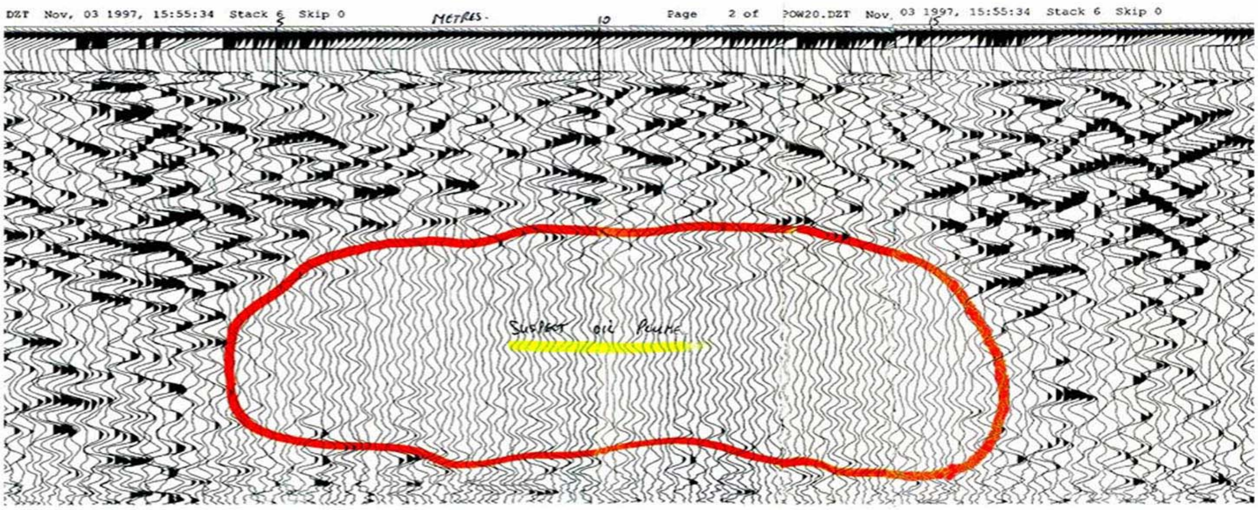


Figure 1

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