

POTENTIAL USE OF GROUND PENETRATING RADAR IN HIGHWAY ROCK CUT STABILITY

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ABSTRACT

Highway rock cuts typically fail along pre-existing discontinuities, and are triggered either by seismic activity, high groundwater pressures, ice wedging, or progressive deterioration of the intact rock because of weathering. Remediation and/or damage mitigation is required for all road cuts that threaten the lives and property of the motoring public. Analysis of potential instability can range from limiting equilibrium analysis to on-site engineering judgment of an experienced specialist. Rock determined to be loose with the potential for failure must be removed or restrained in some way.

In any case, the mapping of discontinuity orientations is a requirement. Most discontinuities can be identified once the cut has been exposed. Horizontal to sub-vertical discontinuities will intersect the exposed face and can be projected back into rock mass, and an appropriate analysis can be undertaken. Vertical discontinuities however, striking parallel to the road cut cannot be seen, because they do not daylight into the cut. Ground Penetrating Radar (GPR) has the ability to detect these vertical discontinuities and can be used to identify slopes at risk, avoid failures, reduce property damage and avoid injury and lost of lives.

INTRODUCTION

Ensuring the stability of highway rock cuts, whether new or old requires an evaluation of the structure of the rock. Failure results in blocked roads, property damage, injury, and loss of life (Figure 1). Failures usually initiate and follow pre-existing discontinuities rather than break through intact rock (Figure 2). Failures are typically triggered either by seismic activity, high groundwater pressures, ice wedging, or progressive deterioration of the intact rock because of weathering.

Analysis of potential instability can range from limiting equilibrium analysis to on-site engineering judgment of an experienced specialist. Rock determined to be loose with the potential for failure must be removed or restrained in some way. Specifications for remediation methods abound in the literature (Brawner, 1994; Konya and Walter, 1991; Piteau, 1979f; Franklin and Senior, 1997; Bieniawski, 1998).

In any case, the mapping of discontinuity orientations is required before a slope stability analysis can be undertaken. Most discontinuities can be identified once the cut has been exposed. Horizontal to sub-vertical discontinuities will intersect the exposed face and can be projected back into rock mass, and an appropriate analysis can be undertaken. Vertical discontinuities paralleling the rock are however typically hidden, and can often not be identified by observation.



Figure 1. Example of a rock failures causing obstruction of a roadway.



Figure 2. The discontinuous nature of rock masses (Highway cut in Nova Scotia, Canada)

TYPES AND MECHANISMS OF FAILURES

Failures in rock cuts occur as a result of several mechanisms. Figure 3 shows raveling, undercutting, and rolling failures. These types of mechanisms are in general not conducive to predictive calculations or modeling, but rather require engineering judgment to determine whether they are likely to fail or to remain stable. Methods for analysis are described in Franklin and Maerz (1996).

Figure 4 shows examples of wedge, planar, and toppling failures. What these mechanisms have in common is that they are all conducive to predictive calculations or numerical modeling, ranging from simple limiting equilibrium analysis to sophisticated numerical modeling (Hoek and Bray, 1981; Piteau, 1979c; Piteau, 1979d; Piteau, 1979e), and a determination of their stability can be made on the basis of these algorithms.

Whichever method of analysis is used, the mapping of the discontinuities or joints in the rock is a requirement for subsequent analysis. Depending on their orientation and other characteristics, understanding the structure of the rock will help predict not only the mode of failure, but also the likelihood of failure, as well as being a strong indicator of the type of remediation that will be required.



Figure 3. Raveling, undercutting, and rolling failures along road cuts, respectively, Colorado, Highway 70.



Figure 4. Example of wedge, planar, and toppling failures along road cuts, respectively, Sudbury, Canada.

MAPPING DISCONTINUITIES

Most discontinuities can be identified by mapping once the rock cut has been exposed (Piteau, 1979a; Piteau, 1979b; Piteau 1979g). Horizontal to sub-vertical discontinuities will intersect the exposed face and can be projected back into rock mass. Vertical and near vertical discontinuities striking obliquely to the road cut will also be exposed, and can also easily be mapped.



Figure 5. Failed rock cut, Hwy 401, Brockville, Ontario, Canada, after removal of rubble. The failed material released along a sub-vertical joint, exceeded the capacity of the ditch, spilled out onto the left lane to a depth of one meter, resulting in the death of a truck driver.

Vertical discontinuities, however, striking parallel to the road cut cannot be seen, because they do not daylight into the cut. Although these should daylight above the road cut, they are typically obscured by a layer of soil, and are not visible unless a significant effort is made to remove the soil and clean the top of the rock. As this is a costly and environmentally unfriendly undertaking, the removal of overburden above the cut is rarely attempted. Consequently, when vertical discontinuities occur parallel to a rock cut they are typically not identified, and cannot therefore be incorporated into the analysis.

Vertical discontinuities contribute to a significant proportion of rock cut failures precisely because they are so difficult to detect. Figure 5 shows a cut where failure along one such discontinuity, in this case sub-parallel to the road cut, caused the death of a truck driver.

Ground Penetrating Radar (GPR) has the ability to detect vertical discontinuities that are parallel to the rock cut, and hidden from view.

GROUND PENETRATING RADAR

Ground penetrating radar is a quick, non-destructive testing method that has the ability to locate discontinuities to a depth of several 10's of feet. Young (1998) used GPR to find horizontal fractures in limestone. Toshioka et al. (1995) mapped cracks in vertical rock faces in tuff also using GPR. Stevens et al. used GPR to map fracture zones in granite. Grandjean and Gourry (1996) mapped fracture zones in the floor of a quarry.

A series of field trials were set up to evaluate the effectiveness of ground penetrating radar for the purposes of identifying hidden discontinuities. This paper presents the results of these trials.

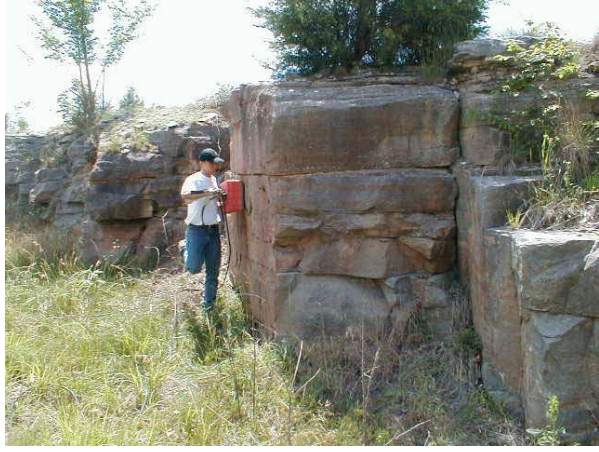


Figure 6. Obliquely striking vertical joints in sandstone of the Roubidoux Formation.



Figure 7. SIR10B ground penetrating radar system, showing a 400 MHz. antenna.

FIELD TRIALS

INTRODUCTION

In order to do a preliminary investigation into the ability of GPR to detect vertical fractures, road cuts of Missouri Roubidoux sandstone were used. Individual outcrops were selected where vertical joints in the rock mass were clearly observable and their aperture and depth (defined as the horizontal distance into the rock) were observable and measurable (Figure 6). The joints were in general parallel to each other, but in places sub-parallel because of large-scale waviness.

SETUP

A Geophysical Survey Systems Inc. SIR10B ground penetrating radar unit was used to make the measurements (Figure 7). Three antennas were employed. 400 MHz, 900 MHz, and 1500 MHz (The higher the frequency the greater the resolution, the lower the frequency, the greater the depth of penetration).

In this study, preliminary results showed that only the 400 MHz antenna penetrated deeply enough into the rock to clearly identify the fractures. Consequently only the 400 MHz antenna data was recorded and analyzed.

Survey lines were run multiple times horizontally across the rock cut for distances between 6 and 12 feet. The data sampling rate was set at 50 scans per second, using an 800 MHz low pass filter and a 100 MHz high pass filter.

The software used to analyze the GPR field data was the program Radan (Geophysical Survey Systems Inc.). A dielectric constant of 6 was used for the internal calculations.

GPR RESULTS

Figures 8 and 9 show that GPR is able to find the open structure at a depth of about 7'. The two or three weaker reflections at shallower depth may be joints that are fully closed or blast induced fractures. Figures 10 and 11 show a somewhat weaker signature from joints that appear to be closed, or have a very small aperture.

Figure 13 reveals a stronger signature for a joint with a much larger aperture. The two or three weaker reflections at shallower depth are indicative of the smaller shallower joints seen in Figure 12.



Figure 8. Site 1 with a 2" soil filled vertical joint, 7' deep into the rock.

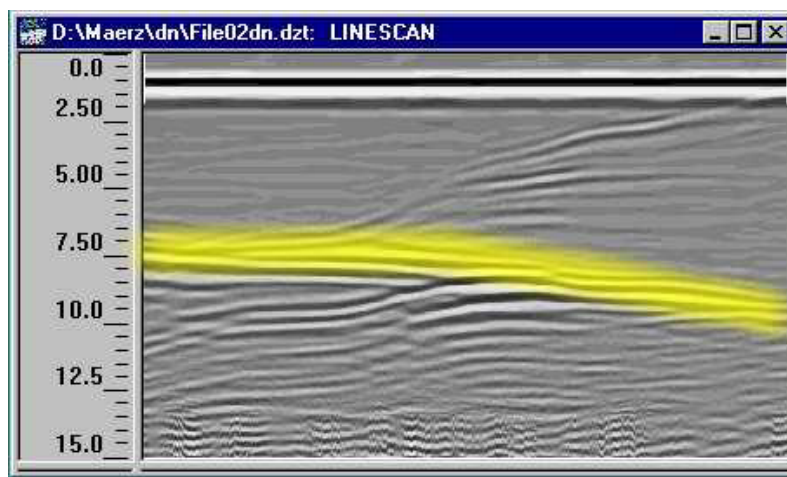


Figure 9. Site 1 survey results for 2" aperture on a vertical joint, at a depth of 7', measured by tape measure at the center of the profile (signature highlighted, scale of profile is in feet).

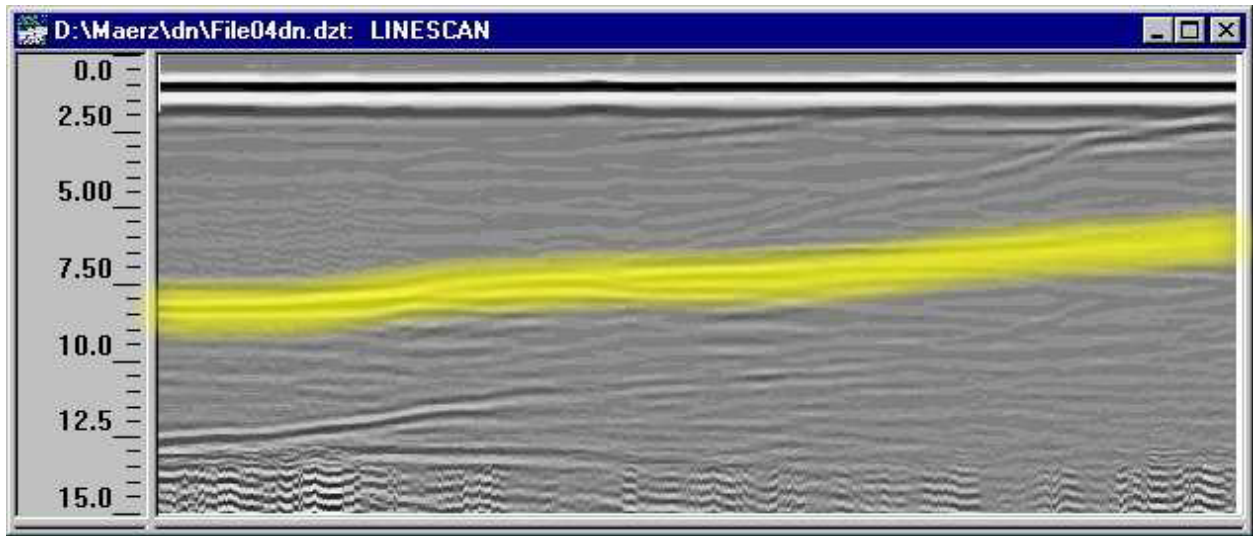


Figure 10. Site 2 survey results for <1" aperture on a vertical joint, at a depth of 7', measured by a tape measure at the center of the profile (signature highlighted, scale of profile is in feet).

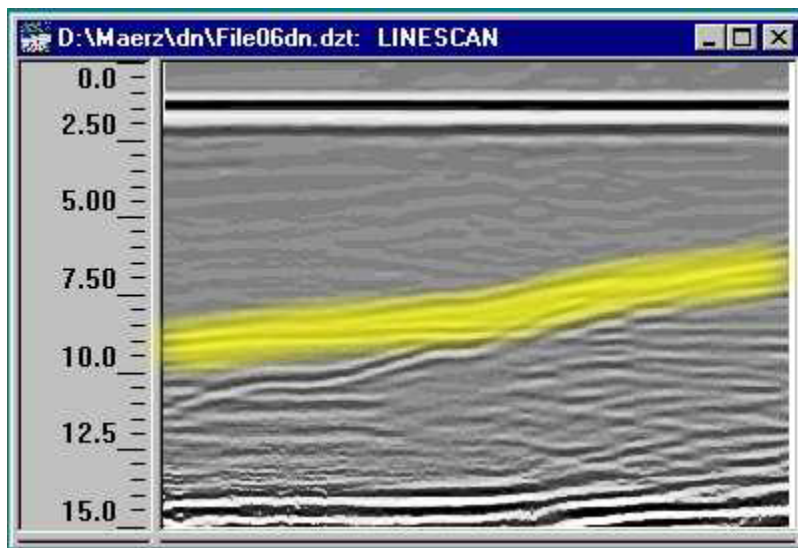


Figure 11. Site 3 survey results for <1" aperture on a vertical joint, at a depth of 5', measured by a tape measure at the right end of the profile (signature highlighted, scale of profile is in feet).



Figure 12. Site 4 with a 12" soil filled vertical joint, 10' deep into the rock'.

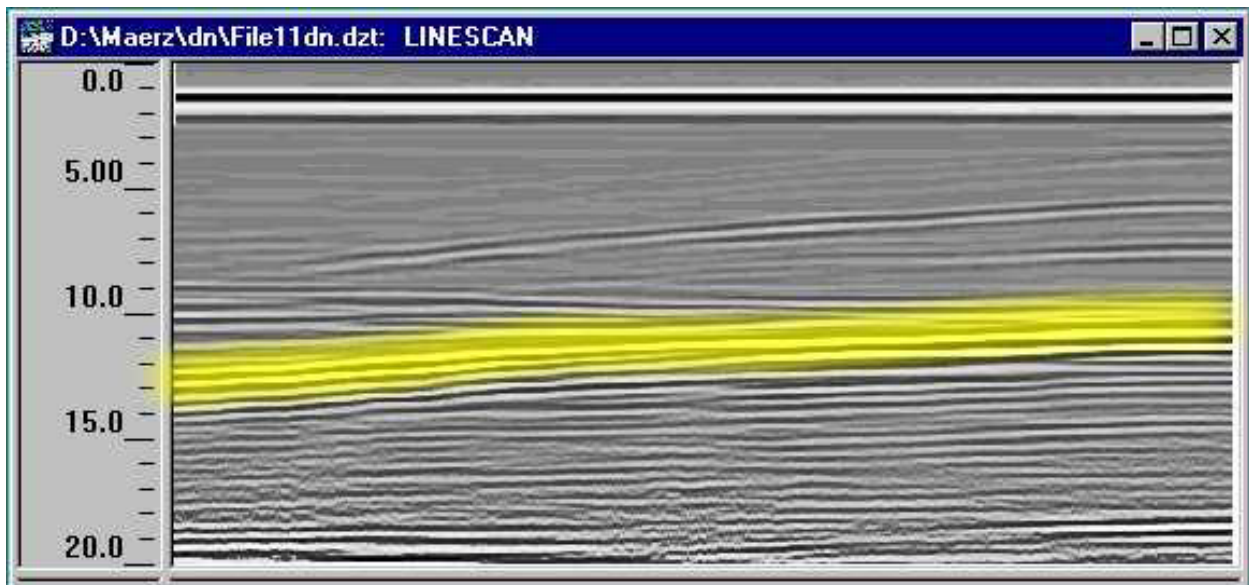


Figure 13. Site 4 survey results for 12" aperture on a vertical joint, at a depth of 10', measured by a tape measure at the right end of profile (signature highlighted, scale of profile is in feet).

SUMMARY

If an efficient procedure for screening cuts can be developed using GPR, vertical discontinuities could be identified, slopes remediated, failures reduced, and property damages and loss of life reduced.

This study showed that GPR is easy to use, and the results are relatively easy to interpret. Training of field personnel would be relatively simple, and these same personnel would be capable of interpreting their data.

GPR is also well suited for mounting on a mobile vehicle, perhaps on a boom mounted on a small truck. This would make data collection fast and efficient.

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