United States Department of Agriculture

Natural Resources Conservation Service

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Subject: Soils -- Geophysical Assistance

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To: Margo L. Wallace
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Purpose:
Ground-penetrating radar was used to profile the interior of a concrete dam, which is located along the Norwalk River just north of the village of Wilton, Connecticut. The structure is being demolished and engineers wish to know if the concrete dam contains rebar which would affect the costs of demolition.

Participants:
Eric Anderson, Engineering Draftsman, USDA-NRCS, Tolland, CT
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Activities:
All field activities were completed on 18 September 2006.

Summary:
The site offered challenges to ground-penetrating radar. Field procedures were adjusted to conditions at the dam site, but depth of penetration and the positional accuracy of the antenna were considered unacceptable. Compared to the 200 MHz antenna, the 400 MHz antenna provided a better balance of profiling depth and resolution. The GPR is believed to have effectively profiled the upper 1 to 1.5 meter of the concrete structure. While high levels of background noise plagued interpretations, radar records did not reveal the presence of reinforcing bars within the upper part of the structure.

It was my pleasure to work in Connecticut and to be of assistance to your staff.

With kind regards,

James A. Doolittle
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cc:
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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (Salem, New Hampshire).[1] Daniels (2004) discusses the use and operation of GPR. The SIR System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. The 400 and 200 MHz antennas were used in this investigation.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, and range gain adjustments.

Survey Procedures:
The SIR System-3000 and operator were seated in a canoe and the antenna towed alongside in an inflatable raft. The canoe was tethered by a rope which was secured to trees on the opposing embankments and extended across the upstream portion of the dam. The boat and raft made multiple traverses across and perpendicular to the upstream side of the structure. For each traverse, the raft with antenna was positioned over the top of the structure and either moved along the centerline or orthogonal to the top of the structure.

Study Site:
The dam (about 41°11’57” N latitude, 73°26’3” W longitude) is located on the Norwalk River just north of the village of Wilton, Connecticut. The site is located in a city park that is off of Merwin Lane.

Results:
Concrete is a composite material formed by the addition of water to a mixture of cement, sand and coarse aggregates with the inclusion of a small quantity of air. Accordingly, a range of concrete admixtures is possible. Because concrete has unclear and site specific characteristics, the effectiveness and applicability of GPR for the investigation of concrete structures is unpredictable (Annan et al., 2002). At the time of casting, because of high moisture contents, concrete exhibits a high dielectric permittivity (E_r), which may range from 10 to 20 (signal propagation velocity (*v*) of 0.094 to 0.067 m/ns) (Daniels, 2004). When hardening is complete and the water content is lowered, the E_r of concrete ranges from 4 to 10 (*v* = 0.149 to 0.094 m/ns) (Daniels, 2004). An E_r of 6 (*v* = 0.122 m/ns) was used in this study. Uncertainties as to the nature of the concrete mixture and the pore fluid content limit the accuracy of depth estimates. As a consequence, the depth scales shown on the accompanying plots should be considered as approximations.

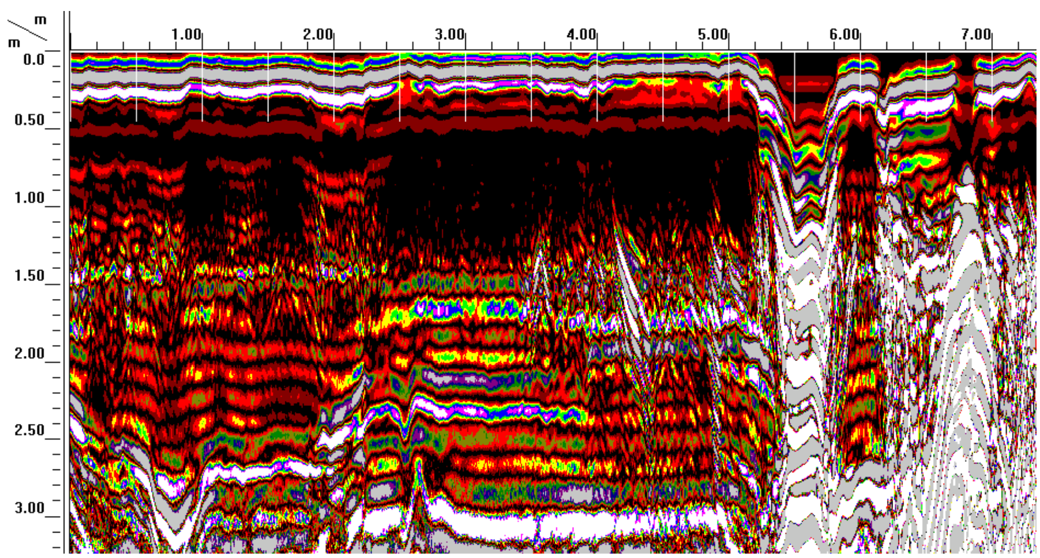

Figure 1. Radar record collected with the 400 MHz antenna along the top of the structure.

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Signal attenuation limits the maximum thickness of concrete which can be profiled with GPR. Bungey (2004) reported that a 500 MHz antenna can profile a maximum distance of about 50 cm through concrete. It was assumed that the lower frequency 400 and 200 MHz antennas used in this study would provide slightly greater penetration depths. The 400 MHz appeared to provide the best balance of penetration depth and resolution.

Figure 1 is a radar record that was collected with the 400 MHz antenna as it was moved along the center line and across the top of the concrete structure. In Figure 1, all scales are in meters. The depth scale is based on a propagation velocity of 0.122 m/ns. The horizontal scale has been approximated and is inaccurate.

The radar wave transmitted through concrete diverges at a wide angle. As the radar's wave front propagates downward in a conical form, the cross-sectional or footprint area measured by the antenna increases with increasing depth. Reflections occurring below a depth of about 1.5 m are considered background noise (mostly parallel, horizontal bands) and reflections from the sidewalls of the structure. For the first 5 meters (horizontal distance), the upper part of the radar record is virtually free of subsurface reflectors. If present, reinforcing bars would produce high amplitude reflections that would mask deeper features. These features are not present in the upper 1 m of the radar record shown in Figure 1.

The antenna is arranged with the electric fields of the transmitter and receiver antennas aligned in parallel with each other and parallel with the surface. The antenna is towed along the surface in a traverse direction that is perpendicular to the electric field direction. In this arrangement, if an antenna is pulled across a buried metallic rebar, the rebar will appear on the radar record as a hyperbolically shaped (the shape is the result of the antenna pattern and geometry of the traverse motion) reflector. If the antenna is pulled parallel to the rebar, the rebar either does not appear or appears as a continuous linear reflector (if rebar is located directly below the aperture of the antenna. Other than the reflection and reverberations from the surface pulse, no high amplitude (white colored) linear or hyperbolic patterns occur in the upper part of the radar record between the 0 and 5 m distance marks shown in Figure 1.

In Figure 1, between the 5 and 6 meter distance marks, a lower-lying sill, through which water from the reservoir was flowing over the dam, was crossed with the antenna. This feature produced a distinct pattern (within the upper 50 cm) and noticeable high-amplitude (white colored) reverberations (generally below a depth of about 1 m). In Figure 1, at the 6.3 and 6.8 m distance marks, spacings that are believed to separate concrete slabs were crossed with the antenna. Metallic objects were observed within these features and are believed responsible for the conspicuous high-amplitude reflections. As these features were crossed orthogonally with the antenna, they produce hyperbolic patterns.

Figure 2 is a radar record that was collected with the 400 MHz antenna as it was moved away from the top of the concrete structure in an orthogonal direction. In Figure 2, all scales are in meters. The depth scale is based on a propagation velocity of 0.122 m/ns (through concrete). The contact of the structure and the mineral soil boundary with the overlying water column is clearly evident on this record. Water has a high E_r (80) and radar pulses travel through this medium at a very low propagation velocity (0.033 m/ns). This results in a more restricted depth of penetration through the water and a reduced depth scale than is shown on the left-hand margin of this record.

In Figure 2, the horizontal scale has been approximated and is inaccurate. Within the concrete structure, reflections below an approximated depth of 1 to 1.5 m are considered background noise (mostly parallel, horizontal bands) and reflections from the sidewalls of the structure. Within the concrete structure, the upper meter of the radar record is virtually free of subsurface reflectors. It is inferred that the upper part of the concrete structure contains no reinforcing bars. It is unlikely that the radar effectively profiled the concrete below a depth of 1.5 m. The gain settings used to profile the concrete structure were too high for the bottom sediments of the reservoir. The dissimilar layers of bottom sediments produce reflectors with conspicuously high amplitudes and noticeably clipped signals in the lower right-hand corner of Figure 2.

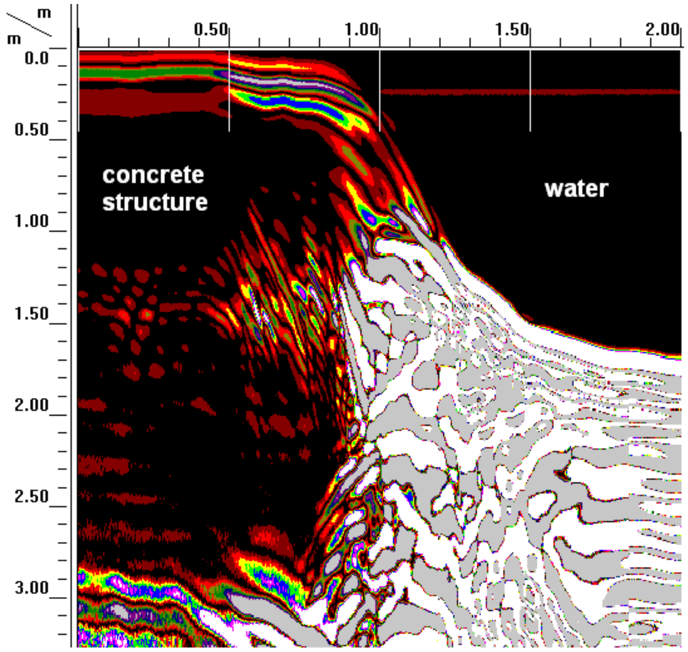

Figure 3. Radar record collected with a 400 MHz antenna orthogonal to the top of the structure.

References:

Annan, A. P., S. W. Cosway, and T. De Souza, 2002. IN: Koppenjan, S. K., and L. Hua (editors). Ninth International Conference on Ground-Penetrating Radar. Proceedings of SPIE Volume 4158. 30 April to 2 May 2002. Santa Barbara, CA. 359-364 pp.

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