Use of a Ground-Coupled Monostatic antenna for Determining Deterioration of Concrete Structures

Doria L. Kutrubes
Radar Solutions International
51 Riverview Avenue, Waltham, MA 02453-3819
radar@world.std.com

ABSTRACT

A 1.5 GHz ground-coupled antenna was used with a digital ground penetrating radar system to evaluate the amount of deterioration within an aboveground concrete holding tank. Because of the corrosiveness of the solution held within and the structural design of the 72 year-old tank, deterioration could manifest itself by delamination and/or by surface cracking. On the GPR record, potential areas of deterioration appear as zones of attenuation. Delamination is most likely to occur at the inner wall where the tile and concrete meet, but can also occur at either the bottom or top rebar schedules within the concrete. Surface cracking can indicate both a surficial stress problems, caused by the elliptical shape of the structure, as well as more severe voiding/delamination problem. Over 50 vertical profiles were conducted on the 17-foot high walls using GPR to more accurately assess the deterioration associated with failure of the structure's integrity.

Attenuation, measured as dB loss relative to the transmitted pulse when the antenna is coupled to the concrete surface, was mapped and contoured for the tile/concrete boundary and the upper rebar schedule. Deterioration at the concrete surface was achieved by calculating the real concrete dielectric permittivity (i.e. dielectric "constant") from the reflection coefficient of the surface reflector when the antenna was mounted on a 12" thick foam block. Attenuation and dielectric information were then compared with visual observations of the data to determine the overall deterioration of the structure. Overall, the curved walls revealed more deterioration, over 25%, while the straight sections of wall had about 10 to 14% deterioration.

INTRODUCTION

A 1920's vintage concrete holding tank exhibited deterioration, as evidenced by cracking and splaying. The aboveground tank (AST) consists of two rounded vertical walls at the north and south, and two straight vertical walls along the west and north sides. The vertical walls are 17 feet high (about 5.2 m). The west and east walls are approximately 72 feet (21.9 m) in length, while the outside perimeters of the south and north walls are approximately 40 feet (12.2 m). The AST is situated such that the east wall is built directly into the east side of the building, making it inaccessible to any geophysical methods, while the top of the AST is built directly into the second floor slab.

The AST consists of heavily-reinforced concrete walls that are 17 inches (43.2 cm) in thickness at west and east walls and 10 inches (25.4 cm) at the south and north walls. A two-inch ceramic tile is glued to the interior concrete walls. A corrosive liquid, having a pH of 5.6 and used in the pulp-milling process, enters at the base of the south and north walls, where the liquid is swirled

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around by two large turbines. The majority of observed concrete deterioration is located along the curved south and north walls, towards the base.

PROCEDURE

Typically, bistatic or air-coupled horn antennas are used to determine GPR signal velocities and dielectric permittivity values. For this survey, because of the inability to use a horn antenna on a vertical wall, A GSSI SIR System 2 digital radar instrument, with a 1.5 gigahertz (GHz) ground-coupled antenna, was used instead. GPR data were collected twice along vertical lines at accessible parts of the AST walls: once with the 1.5 GHz antenna coupled directly to the wall, and once with a 12-inch foam block coupled to the wall on which the 1.5 GHz antenna was attached. Data collected with the first set-up provided attenuation and rebar depth information, while data from the foam block test provided dielectric constant data.

GPR data were collected continuously along accessible survey lines and displayed on a color monitor. GPR data were also simultaneously recorded on hard drive for post-survey processing. When implemented with the survey wheel, radar scans are triggered on distance, and therefore the horizontal scale is consistent throughout the survey. Data were collected approximately every centimeter.

Figure 1: Data being acquired along South Wall using the 1.5 GHz radar antenna

Data were evaluated using different approaches to help assess the overall integrity of the AST. First, data were evaluated qualitatively, looking at GPR records for areas of voids and delaminations, and comparing them with observed cracks in the walls.

Next, the amplitude of reflection and attenuation were measured along each survey line as an indication of corrosion along (and delamination of) the rebar from the concrete, and deterioration of the concrete. Typically, corroded rebar (i.e. rust) has a lower dielectric than good iron or steel, producing a weaker reflection on the radar record. Also, concrete deteriorated by a conductive solution will attenuate GPR signal, and, as a result, the bottom of the concrete may not be visible. RSI used several software packages to evaluate data, including a proprietary processing package developed by RSI for this job, to measure amplitude and attenuation values. Attenuation data, as measured in dB loss of amplitude relative the transmitted wave, are contoured and presented below.

Finally, data collected with the antenna coupled to the 12-inch foam block were used to help determine an approximate concrete dielectric value at the surface of each wall. Concrete dielectric measurements were obtained to help assess the amount of deterioration of concrete at the surface of the wall. Prior to data collection, foam block calibrations were done by placing a metal plate directly against the bottom of the foam block. The travel time of the radar (EM) waves through the foam block and the amplitude of reflection from the metal plate were measured. This calibration helped establish the dielectric constant of the foam block, and the maximum amplitude of reflection. Foam-test data collected along the walls were then normalized relative to the metal plate reflector, and the dielectric constant of the concrete calculated from the known foam dielectric constant and measured amplitude of reflection of the surface reflector.

RESULTS

GPR signal penetration was generally good along North and South Walls, penetrating the full thickness of the concrete wall. GPR signal penetration was only fair along the West Wall, with the deeper rebar schedule and the bottom of the concrete only being visible intermittently. The lack of deep rebar and bottom reflections along the West Wall is attributed to the thickness of the and to the high density of #8 transverse rebar within the wall.

GPR data showed that the majority of concrete deterioration and corrosion of rebar occurred along the curved south and north walls. Attenuation and dielectric information were then compared with visual observations of the data to determine the overall deterioration of the structure. Overall, the curved walls revealed more deterioration, over 25%, while the straight sections of the west wall had about 10 to 14% deterioration. For purposes of brevity and space, only results from the north wall will be presented.

Figure 2: Cracking and staining observed on north wall of AST

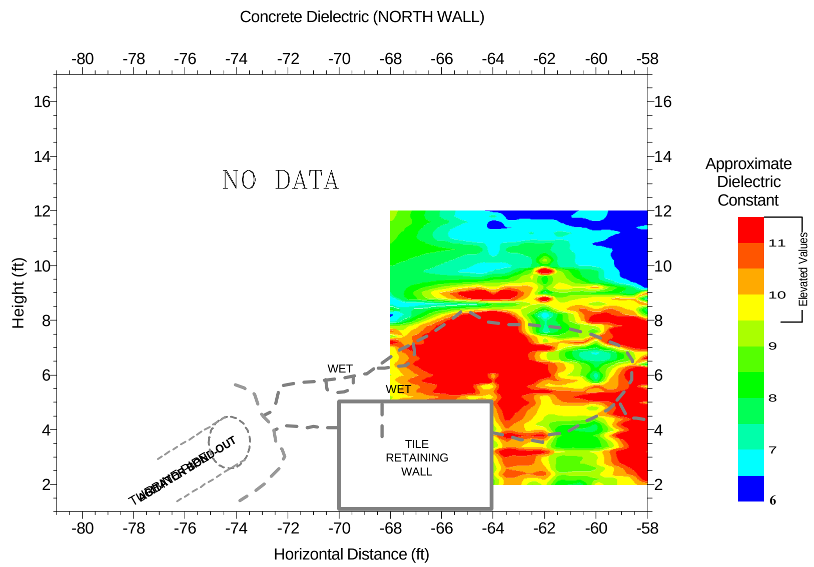

Figure 3: Approximate dielectric constant (real permittivity) measurements along accessible sections of the north wall. Note the correlation of high dielectric values with staining on the wall.

Calculated dielectric constant values of the concrete are presented on Figure 3. Upon comparing Figures 2 and 3, GPR data, not surprisingly, indicate a strong correlation between the amount of staining and moisture at the concrete surface and elevated dielectric constant values. Some elevated dielectric values are also attributed to deteriorated concrete and grouting. High dielectric values were also observed immediately above cracked areas, such as between Lines 67N and 63N, around 9 feet in elevation, and from 61N through 58N between 7 and 8 feet, and may indicate that deterioration has not yet manifested itself by surface cracking or slaying.

Figures 4 and 5 show deterioration at the rebar schedule and at the base of the concrete, as manifested by GPR signal attenuation. Numerous GPR anomalies consistent with delamination above (Figure 4) and below (Figure 5) the rebar schedule were observed along North Wall survey lines. The majority of GPR anomalies were observed between Lines 58N and 77N, although pipes, stairs, and other aboveground obstacles prevented full GPR coverage and created artifacts in the data. Also note that artifacts in the data may also be created by the unevenly spaced rebar (Figure 4). Some of the anomalous GPR readings could also be attributed to grouting, which conducted between Lines 58N through 72N.

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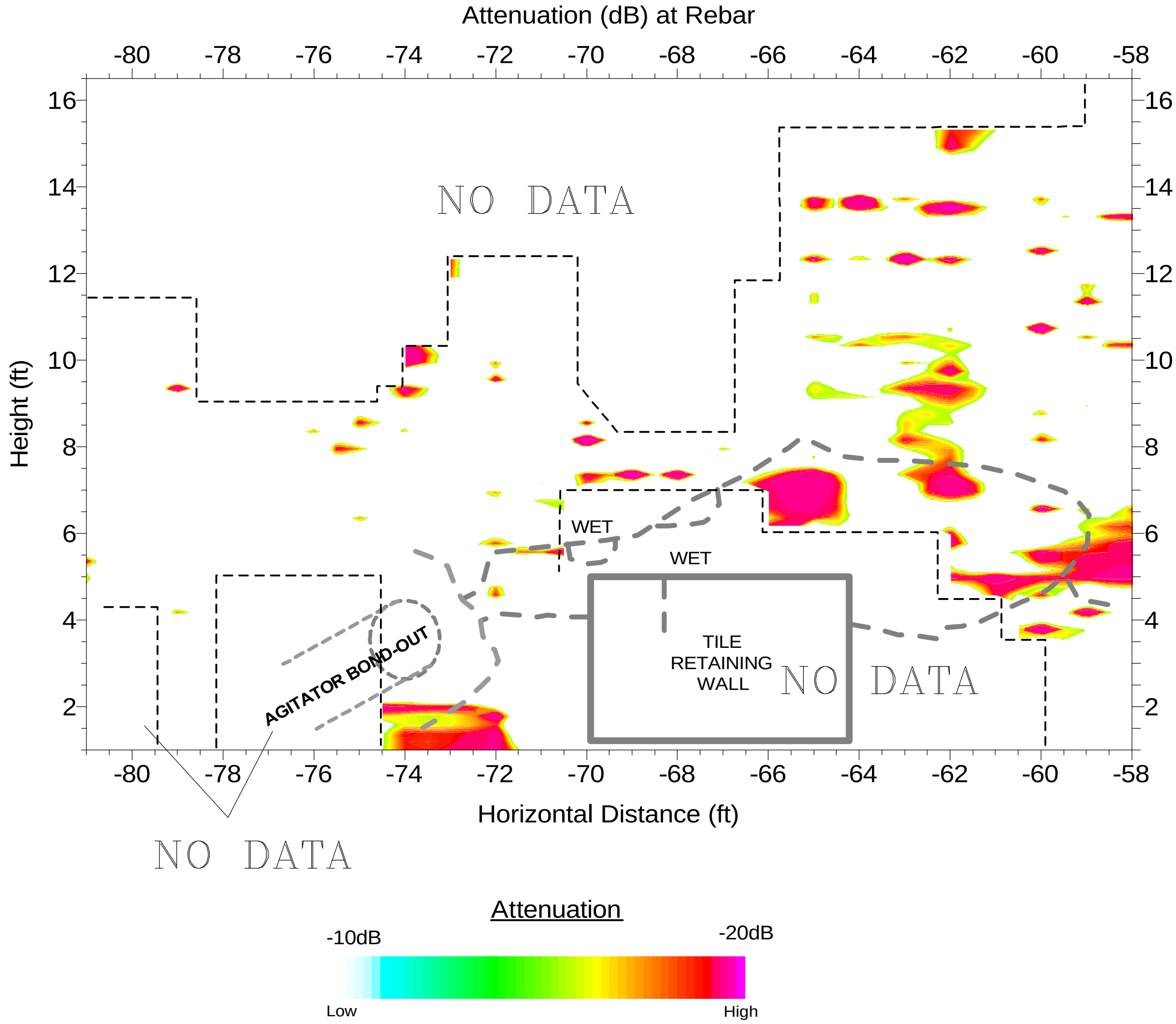

Figure 4: Deteriorated concrete, as measured at the rebar schedule. Note that some artifacts may have been generated in the data from the irregularly spaced

Figure 5 maps the attenuation at the concrete bottom. Nominally, the amount of calculated deterioration at the bottom of concrete is about the same as at the rebar. Some of the attenuation, however, is attributed to grout, which was injected in to the concrete near the junction of the west wall. Nevertheless, deterioration throughout the concrete wall is more significant between Lines 58N and 66N, although significant areas of deterioration were also observed above the retaining wall, from 68N to 70N and near the agitator bond out. It should also be noted that rebar was not observed in proximity of the agitator bond out, which may be the reason deterioration is more significant there.

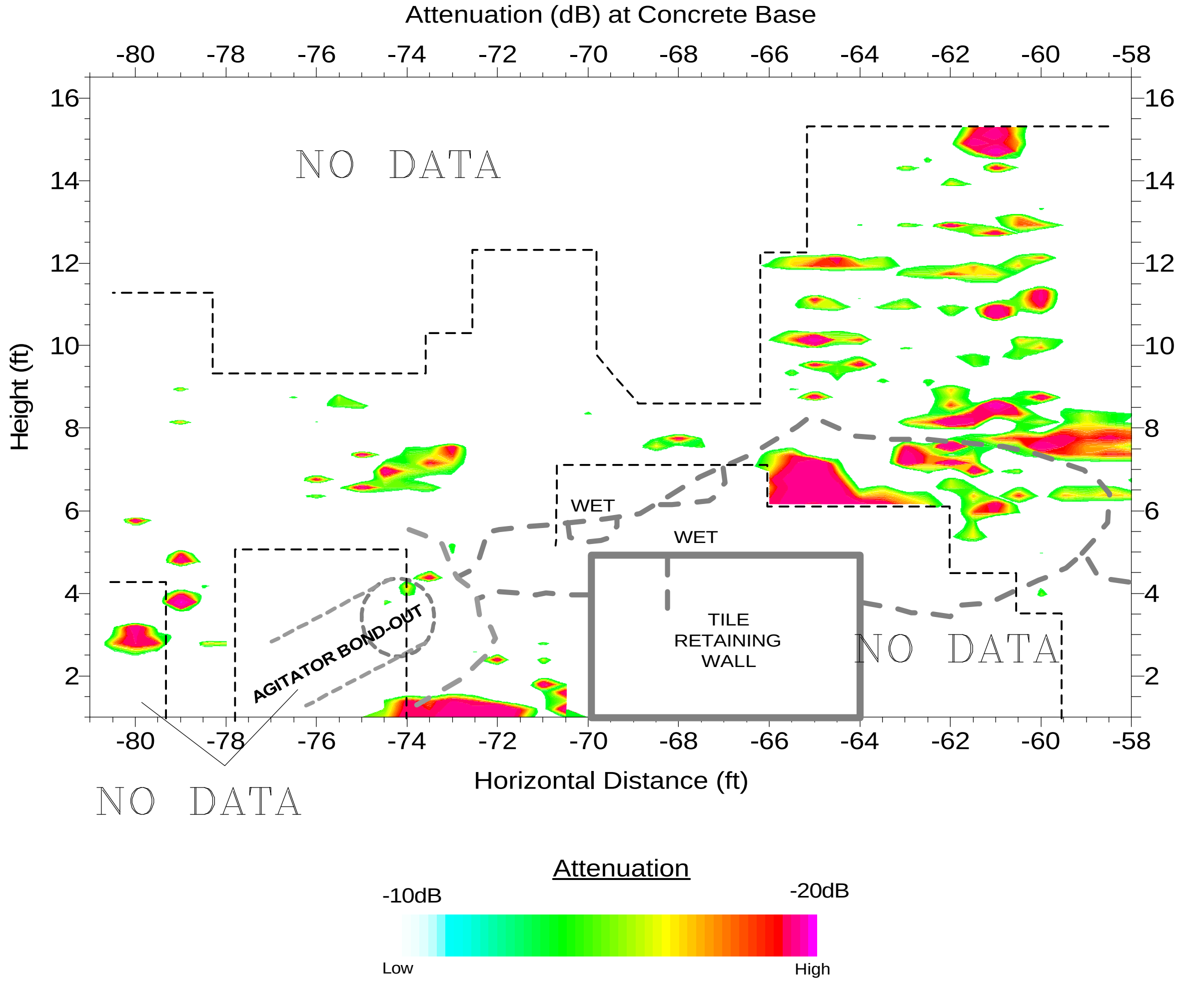

Figure 5: Concrete deterioration as determined at bottom of concrete.

CONCLUSIONS

Calculated deterioration, as quantified by measuring attenuation, has proven to be reasonably accurate and useful to engineers given the potential limitations of the method. The use of a ground-coupled antenna to measure deterioration has similar limitations as a horn antenna, specifically, concrete dielectric data can be adversely influenced by increased moisture and surface staining. The design of the concrete structure must also be considered when quantifying deterioration. Also, although a less significant problem than with the horn antennas, side reflections from nearby pipes and other metal objects can also introduce artifacts in the data. Using the ground coupled antenna also had the added disadvantage of having to obtain two sets of data, as there was insufficient signal penetration when the antenna was coupled to the foam block. However, given the difficulty of using an air-coupled antenna against a vertical wall, the trade-off between accessibility and ease of operation far out weighed the inaccuracies introduced by using a ground-coupled antenna.