On the Use of Ground Penetrating Radar to Detect Rebar Corrosion in Concrete Structures

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Outline

1. Objective.

2. GPR Barrier Rail Inspections – Old and New.

3. Laboratory measurements using a concrete “phantom”: Effect of rebar orientation and metal loss on GPR signals.

4. Summary
Objective

- The goal of this project is to develop a bridge inspection technique that will increase safety while reducing overall costs.
- The inspection technique is aimed at identifying the unsafe condition where corrosion has thinned the reinforcing steel that attaches the side barrier rail to the bridge deck to the point where it can no longer withstand the necessary impact.
- By quantifying corrosion, the test will enable reinforcement of only those barrier rails that are no longer safe.
Inspection Basics – Raw GPR Data

Horz. Line Scan of Wall

4 feet

FW+DC

Vert. Rebar

6 inches

10 nanoseconds

1600 MHz

Wave length in concrete ~ 2.5 inches
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Field Trial at a Local Highway Bridge

Assumptions: (1) Corrosive thinning will reduce the amplitude of the rebar signal. (2) Larger signal reduction if antenna is closer to the thinned region.
Field Trial at a Local Highway Bridge

Scan Distance, X (feet)

Time (nanoseconds)

Antenna on roadbed

(Antenna closer to thinned region)

Antenna elevated

(Antenna further from thinned region)
Field Trial at a Local Highway Bridge

File 10 “On Deck”

File 14 “Above Deck”
A dozen “thinned rebar” candidates were identified.

These have unexpectedly low amplitude relative to signal arrival time (rebar depth in concrete).
New Data Collected June 2017

- Three new sets of data
- Removal of the top layer of the road bed exposing the cold joint of the barrier rail
- New analysis with SAFT
New Data Collected June 2017

Above Deck

On Deck

On Cold Joint
New Data Collected June 2017 — SAFT Processed

Above Deck

On Deck

On Cold Joint
New Data Collected June 2017 — SAFT Processed
Combined Data – Rebar Response

Comparison of Rebar Signal (East End)

Response

Rebar

File 10 On Deck
File 14 Above Deck
File 5 Cold Joint
File 7 On Deck
File 9 Above Deck
Combined Data—SAFT Processed

Rebar Response (East End)

- File 10 On Deck
- File 14 Above Deck
- File 5 Cold Joint
- File 7 On Deck
- File 9 Above Deck
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Factors Affecting Peak GPR Echo From Rebar

Last year we began an investigation of each factor using rebar in air.
Antenna suspended from ceiling.

Wooden side supports being used for tilted-rebar measurements.

All measurements use standard $\frac{1}{2}$-inch rebar.

Lab Setups for Earlier Rebar-in-Air Measurements

Styrofoam table being used for rebar-gap measurements.
Lab Setups for Rebar-in-Concrete-Phantom

- **Antenna**
- **2” concrete block**
- **2” moist sand**
- **2” concrete block**
- **Metal plate**
- **Moisture content is 5.4% by weight**
- **Rebar which can slide thru holes in wooden frame**
- **Wooden frame**
- **Before sand is added**
- **After sand & top block added**
GPR Measurements in Air: Setups Used Last Year

- **Depth**: Antenna depth varies.
- **Length**: Antenna length varies.
- **Rotation**: Antenna rotation varies.
- **Tilt**: Antenna tilt varies.
- **Metal loss length**: Metal loss length varies.
- **Metal loss location**: Metal loss location varies.
- **New “phantom” data**: X into page.

X into page
For all measurements:

Use either 1.6 GHz or 2.6 GHz antenna.
Measure GPR signal from rebar target + support structure.
Measure GPR signal from support structure with rebar removed (background).
Subtract to get GPR signal from rebar target alone.
Measurement #1: Effect of varying the rebar rotation angle $\theta$ with a fixed separation between the rebar and antenna

Rebar centered below antenna at 3-inch depth in concrete phantom

Rebar length = 48”

Angle $\theta$ varies from $0^\circ$ to +/-25$^\circ$ ($\theta = 0^\circ$ when rebar is perp. to antenna scan direction X)

In bridge walls, any rotation angle is expected to be small (< 10$^\circ$).

Even the 25$^\circ$ tilt at left only lowers rebar response by 15%
Measurement #1: Effect of varying the rebar rotation angle $\theta$ with a fixed separation between the rebar and antenna.

**Rebar in Concrete Phantom**

**Comparison to Rebar in Air**

- **Peak-to-Peak Rebar Response**
  - 2.6 GHz
  - 1.6 GHz in air

- **As measured**
- **BKG subtracted**
Measurement #2: Simulates a 4-foot long rebar section having a 1” gap. The gap location varies w.r.t. the antenna center.

Rebar centered below antenna at fixed Z = 3” in “concrete”

Distance C between center of gap and center of antenna varies from 0 to 8 inches.

Background subtraction has been used.

GPR signal stable in time and shape. Large variation in amplitude seen when gap is centered under antenna.
Measurement #2: Simulates a 4-foot long rebar section having a 1” gap. The gap location varies w.r.t. the antenna center.

Normalized w.r.t. offset = 7” (Gap far from antenna center).

Results shown for two antennas (1.6 and 2.6 GHz)

Min rebar signal seen when offset is zero.
Measurement #2: Simulates a 4-foot long rebar section having a 1” gap. The gap location varies w.r.t. the antenna center.

Comparing earlier measurements in air to new measurements in concrete.

Antenna-to-rebar distance is 23.4” in air, 3” in concrete.

For in-air data offset scale is three times larger. In-air offset extends to 19”.
Measurement #3: Simulates a 4-foot long rebar section having a thinned region. Region location varies w.r.t. the antenna center.

Rebar centered below antenna at fixed $Z = 3$" in “concrete”

Thinned region is 1” long, 50% diameter loss. Distance $C$ between centers of region and antenna varies from 0 to 7 inches.

GPR signals stable in time and shape. Modest variations in amplitude seen.

Minimum rebar signal seen when offset = $C = 1$ inch
Measurement #3: Simulates a 4-foot long rebar section having a thinned region. Region location varies w.r.t. the antenna center. Normalized w.r.t. offset = 7” (i.e., thinning far from antenna center).

Results shown for two antennas (1.6 and 2.6 GHz)

Min rebar signal seen when offset is between 1 and 2 inches.
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- We have embarked on Phase II of a project investigating the use of GPR to detect and quantify rebar thinning.
- This will combine laboratory measurements and measurements on a local bridge.
- Lab measurements indicate that GPR signal amplitude is sensitive to material loss of rebar due to corrosion. But care must be taken to compensate for effects due to rebar depth and orientation.
- Bridge measurements were made June 2017.