POST-EARTHQUAKE CONDITION ASSESSMENT OF RC STRUCTURES PART 2: NEAR-FIELD MICROWAVE

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Geotechnical and Bridge Seismic Design Workshop
New Madrid Seismic Zone Experience

October 28-29, 2004, Cape Girardeau, Missouri

Participants

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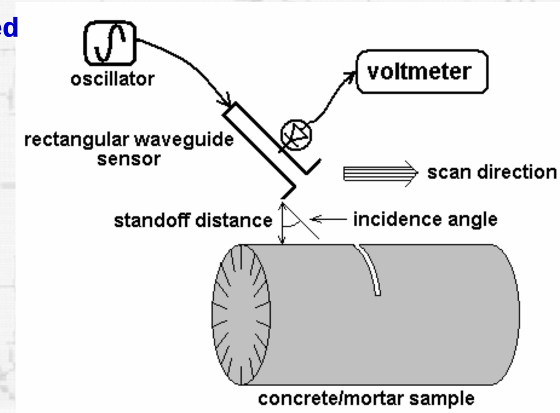
Objectives

The ultimate goal of this study is to extract crack information, width and depth, from a crack characteristic signal. This extraction process, however, is an inverse engineering problem, which is difficult to solve in practical applications. As a first step towards this endeavor, a forward model will be developed, allowing the simulation of the crack characteristic signal of a cracked concrete surface given the operating frequency, crack width, crack depth, dielectric property of the concrete, waveguide dimensions, and standoff distance. Specific objectives are

- To study how a crack characteristic signal changes with operational parameters (frequency, standoff distance, etc.) and crack sizes (width and depth) from calibration tests with a network analyzer.
- To develop a forward model with the commercial Ansoft HFSS platform.
- To develop an empirical way of constructing the crack characteristic signal

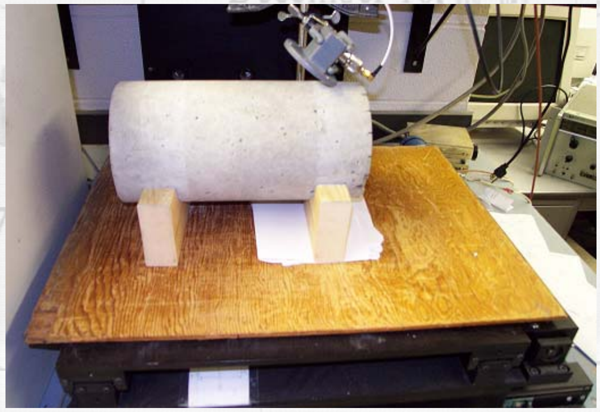
Terminology

Laboratory-Designed Microwave Reflectometer



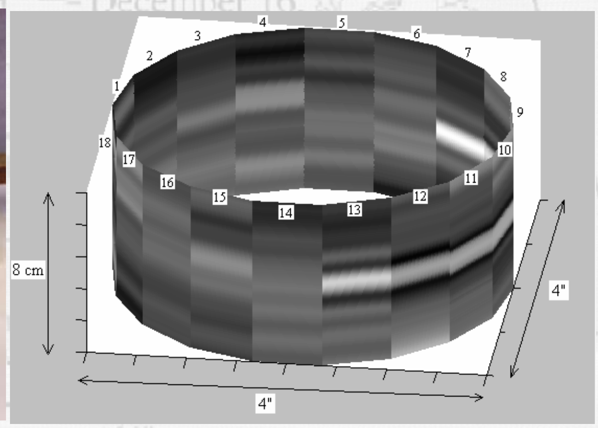
Crack characteristic signal: detector voltage plotted as a function of scanning distance, obtained when a crack is scanned over a waveguide aperture.

Microwave Images: Experimental Setup (Previous study)



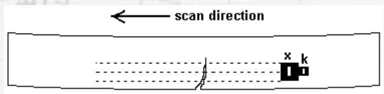
Operating frequency – 10.5 GHz (X-band: 8.2 – 12.4 GHz)
– 7.5 GHz (J-band: 5.85 – 8.2 GHz)

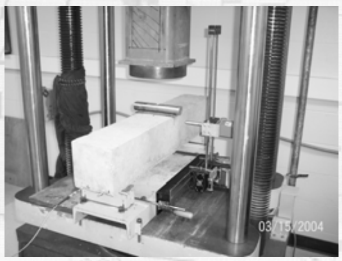
Microwave Images at X-band (pre-cracked cylinder)

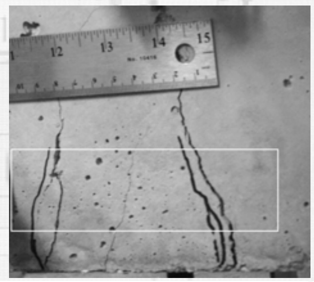


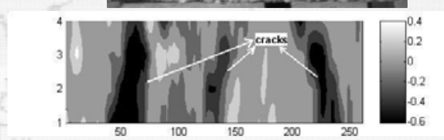
Microwave Images at X-Band (Cyclic stress induced cracks)

Schematic of testing procedure.









4 lines with 125 mm of scan length (2 data points/mm shown) with static variation removed.

Summary of Previous Study with Microwave Images at X-Band

Influences of

- Operating frequency
- Standoff distance
- Incidence angle
- Water content/moisture presence
- Polarization of waveguide sensor

on crack characteristic signals were investigated with microwave images.

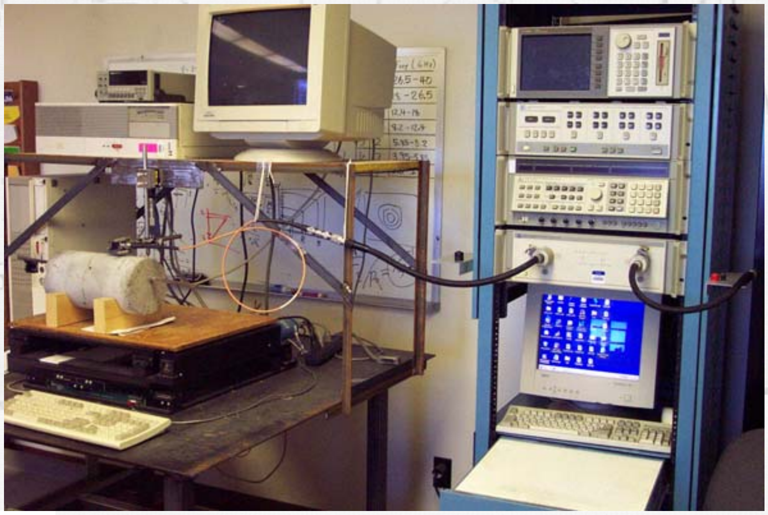
Disadvantage:

Unable to identify the depth of a crack and approximate for crack width estimation.

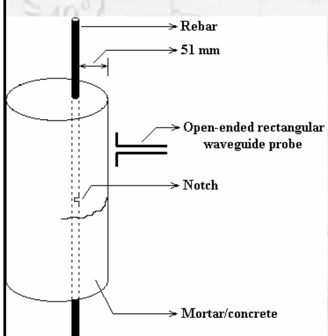
Next step:

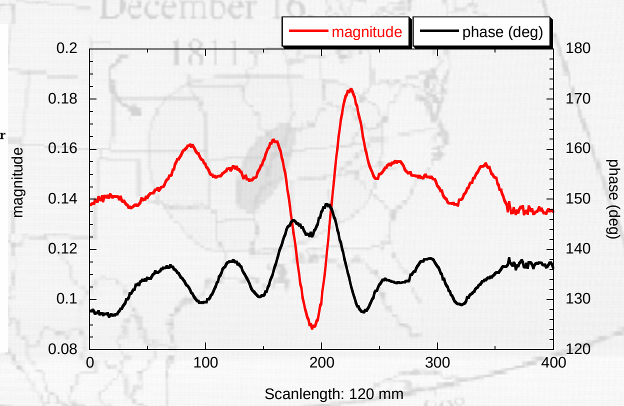
Measure both the magnitude and phase of a crack characteristic signal with a Vector Network Analyzer (VNA)

Experimental Setup Employing VNA



Magnitude and Phase of a Crack Characteristic Signal (CCS)





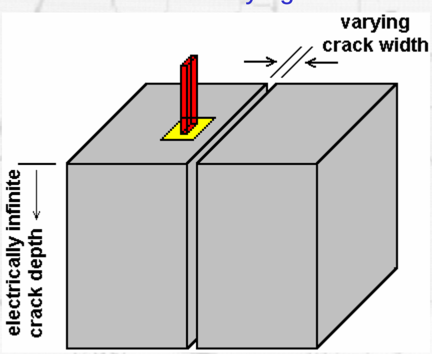
(Reflection co-efficient of X-band open-ended waveguide for a surface-breaking crack generated in mortar sample by externally loading the rebar)

Modeling of Probe Response to a Crack

- Why Electromagnetic Modeling?
  - Optimization of Measurement Parameters
  - Characterization of Crack Dimensions
- Forward Model: To simulate CCS given the
  - standoff distance,
  - operating frequency,
  - crack dimensions and
  - waveguide dimensions.
- Conduct measurements to record the magnitude and phase of CCS as a function of these parameters.

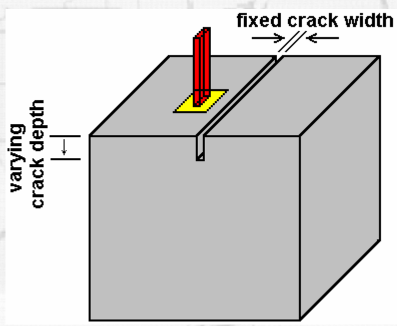
Specimens for Calibrated Measurements

Arrangement 1:
Cracks of Varying Width



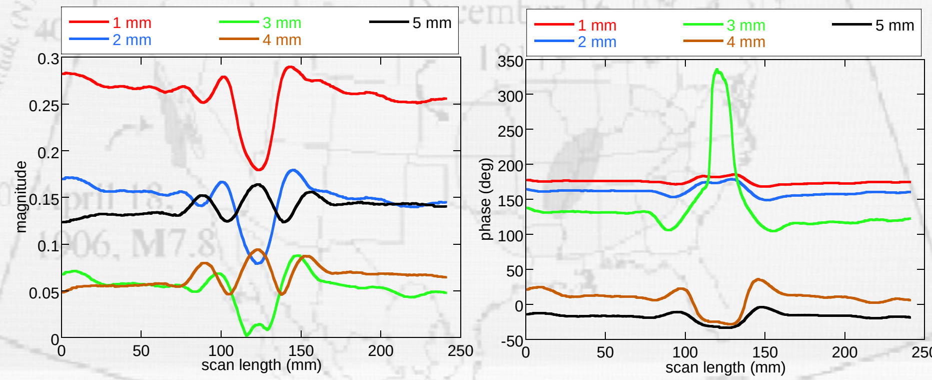
Two mortar cubes used to simulate cracks with varying crack width.

Arrangement 2:
Cracks of Varying Depth



Cement-past cube with a notch cut using hacksaw to generate a crack of varying depth.

Influence of Standoff Distance



Magnitude and phase of reflection coefficient for a 2 mm-wide crack on day 13 at different standoff distances (Arrangement 1).

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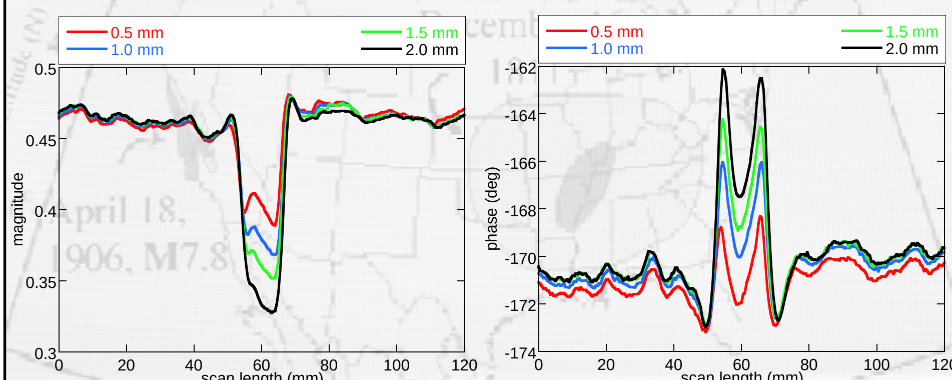
Influence of Crack Width



Magnitude and phase of reflection coefficient for different crack widths at a standoff distance of 0.05 mm (Arrangement 1).

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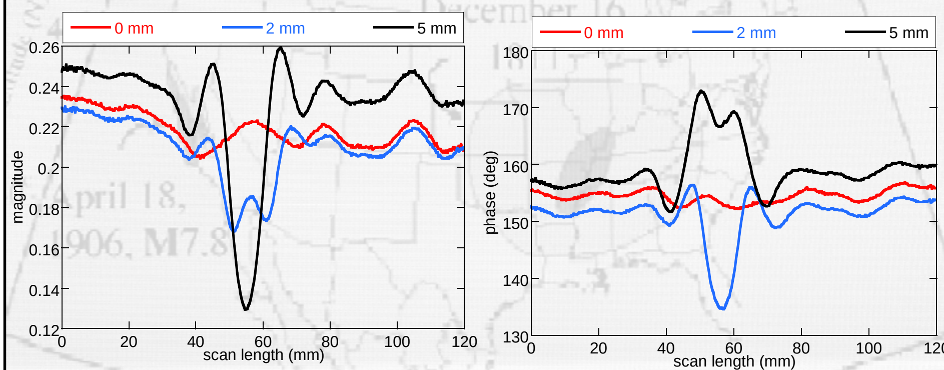
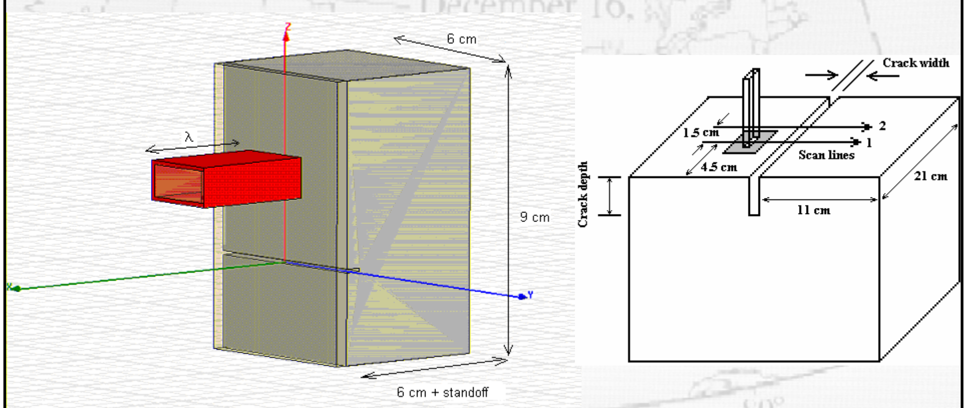
Influence of Crack Depth



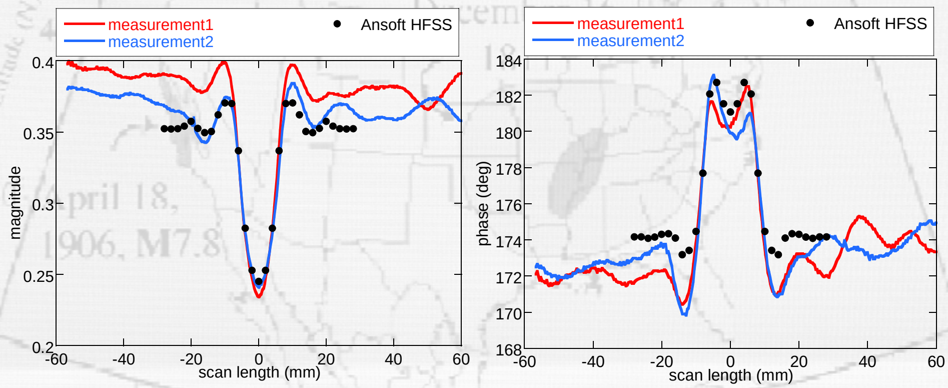
Magnitude and phase of reflection coefficient of a 1.14-mm wide crack for different crack widths at a standoff distance of 2.0 mm (Arrangement 2 @10 GHz).

Numerical Simulations Using an 3D Electromagnetic Field Solver: Ansoft HFSS



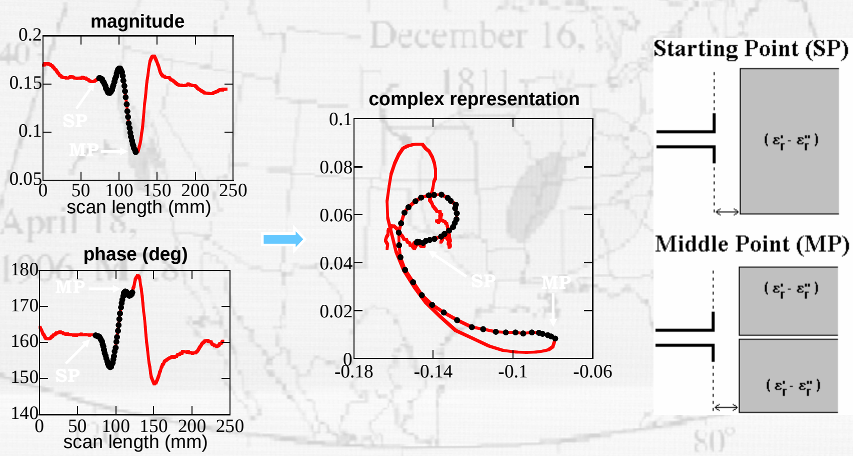
Schematic of HFSS model developed for simulating crack characteristic signals (CCS).

Results of Numerical Simulations of CCS using Ansoft HFSS



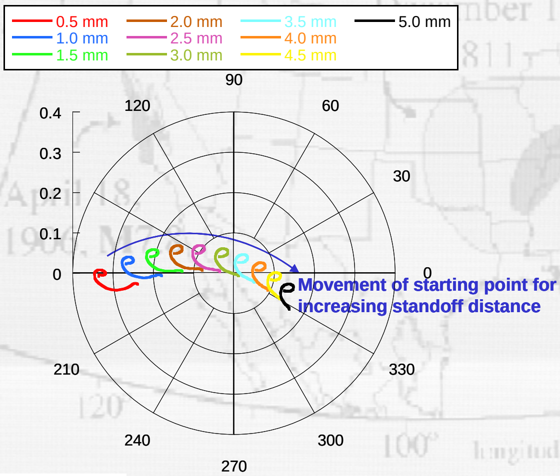
Magnitude and phase of measured and simulated crack characteristic signals for a crack of 1.14 mm wide, 5.0 mm deep, at a standoff distance of 1.0 mm and for a dielectric property of (5.96 – j1.02) at 10.0 GHz using *Arrangement 2.*

Complex Representation of CCS



Complex plane representation of reflection coefficient of 2 mm-wide crack at a standoff distance of 2.0 mm on day 13.

Complex Plane Representations: CCS as Function of Standoff Distance



2 mm-wide crack for different standoff distances (Arrangement 1 @ 10 GHz)

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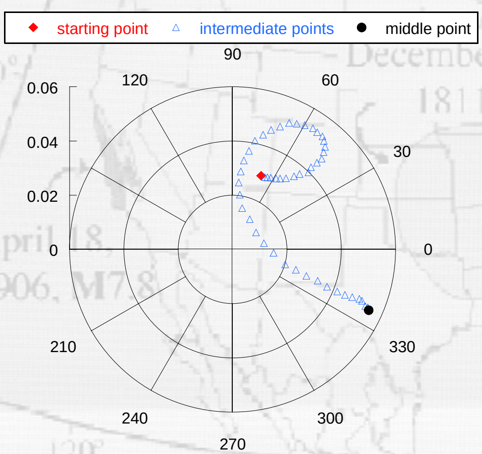
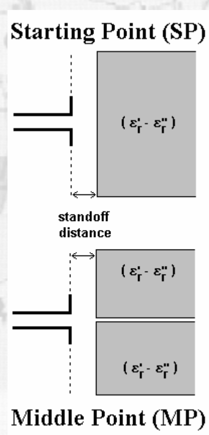
Modeling of CCS in Complex Domain





Measured crack characteristic signal of a 2.0 mm-wide crack at a standoff of 3.5 mm on day 13 comprising of starting point, intermediate points and middle point

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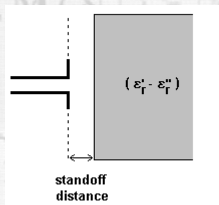
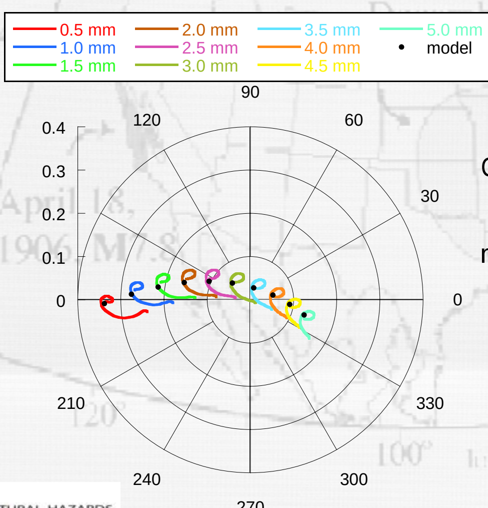
Computing Starting Point

- This can be accomplished by using a custom-built electromagnetic model ("nlayer") available from previous studies for determining the reflection coefficient at the aperture of an open-ended rectangular waveguide radiating into a stratified media given the dielectric properties and thickness of each layer.



Schematic showing the inputs given to "nlayer" code for computing the starting point

Computing Starting Point: Using N-layer code



Comparison of starting points computed from "nlayer" and those obtained from the measured crack characteristic signals at different standoff distances for a 2.0 mm-wide crack in mortar (4.11-j0.56) at 10.0 GHz.

Difficulty in Computing Middle Point

- It is difficult to develop an electromagnetic model to accurately determine the middle point. The difficulty arises mainly because of:
  - the complex near-field interaction of probe field properties with discontinuities (presence of a crack in this case) in a dielectric material,
  - flange effect of the waveguide,
  - edge effect of the crack, etc.,

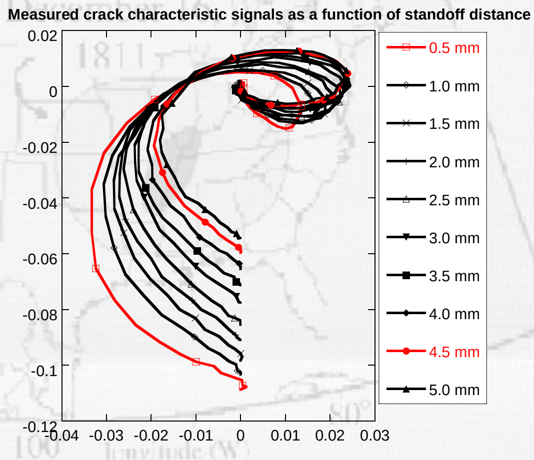
  to compute the middle point with reasonable accuracy.

Alternative to Compute Middle Point

- Use an 3D electromagnetic field solver (previously developed Ansoft HFSS model)
- This model takes approximately one hour to compute this single point.
- Simulating an entire crack characteristic signal is time consuming and hence only the middle point is computed using Ansoft HFSS for the overall empirical model.

Computing Intermediate Points

- The shape of the crack characteristic signal between the starting point and the middle point is dependant on standoff distance and crack dimensions.
- The shape of measured crack characteristic signals as a function of only one parameter (e.g. standoff distance) can be used to generate templates for a given value of that parameter.



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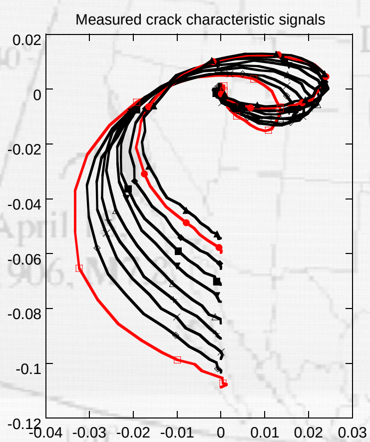
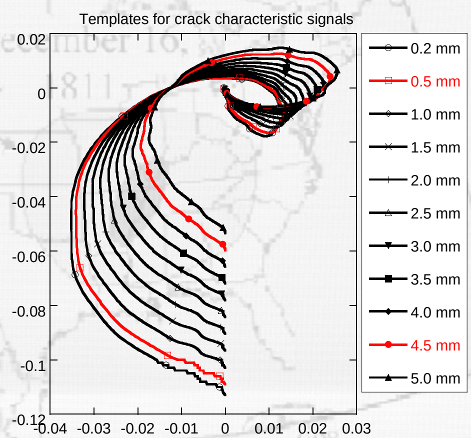
Computing Intermediate Points by Generating Templates





Templates at other standoff distances are obtained by interpolating or extrapolating the measurement signals at standoff distance of 0.5 mm and 4.5 mm

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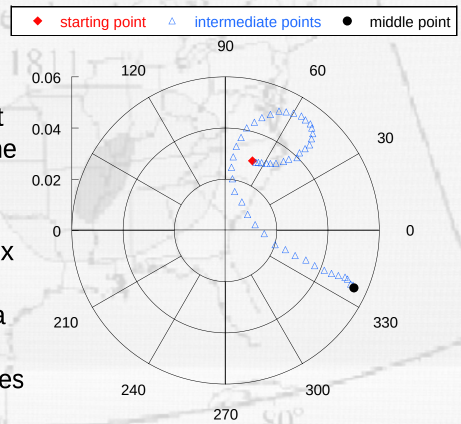
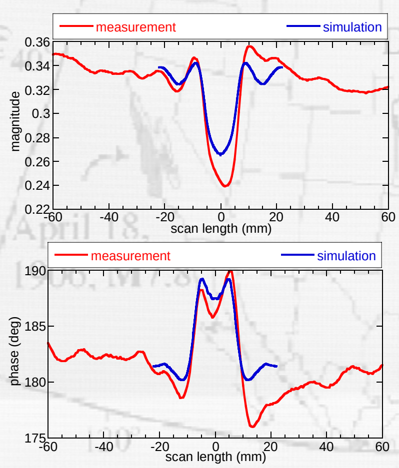
Modeling Crack Characteristic Signals

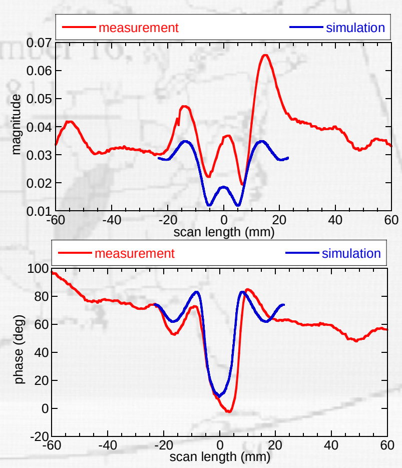
- Once the template signal is found for a given standoff distance, a scaled version of this signal is rotated and translated such that it fits in between the starting and the end points.
- Thus, the simulated crack characteristic signal in the complex domain is unwrapped to obtain magnitude and phase of CCS for a given standoff distance, crack dimensions and dielectric properties of the mortar cube.



Modeling CCS: Results



crack width of 2.0 mm
at standoff distance of 0.5 mm



crack width of 1.0 mm
at standoff distance of 3.5 mm

Conclusions

- Surface-breaking cracks can be successfully detected with open-ended rectangular waveguides.
- Influence of various measurement parameters on crack detection was discussed.
- The results of empirical modeling show that the simulated crack characteristic signals match well with the measured signals.
- The results presented here are only for infinitely deep cracks. For this empirical model to work for finite depth cracks, a database of template signals as a function of crack dimensions, operating frequency and waveguide dimensions must be created.

Future Considerations

- Generate a database of template signals (general shape of a crack characteristic signal) as a function of various parameters such as standoff distance, crack dimensions, waveguide aperture dimensions and the operating frequency.
- The model needs to be robust irrespective of the waveguide probe used and the operating frequency (test using K-band & J-band probes).
- An inverse model needs to be developed which can be used to extract information regarding crack dimensions (width and depth) from the magnitude and phase of crack characteristic signal assuming the dielectric properties of the material is known *a priori*.
- Extend this study to model interior cracks as well.