Non-destructive Evaluation of FRP-Concrete Structures using Microwave Techniques

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Background

Fiber-reinforced plastic (FRP) composite jacketing systems have emerged as an alternative to traditional construction, strengthening, and repair of reinforced concrete structures. Escalating deployment of this new technology is expected, especially in seismically active regions. Assessment of the degree of damage in structural members that are confined in FRP jackets becomes problematic as the concrete core conditions cannot be fully revealed until physical removal of the jacketing system, unless the member has already been subjected to extensive damage. Based on previous studies, a concrete column may appear safe without showing any sign of substantial damage on the jacket, while the concrete core might have undergone severe cracking or crumbling [1]. Currently, several non-destructive evaluation (NDE) techniques for assessing FRP-confined concrete structures have been under development. In spite of these efforts, there is no currently available technology capable of characterizing the various forms of FRP-bonded concrete damages that is ready for real-time, large-scale damage detection on site. A reliable imaging technology is in pressing need to complement the rapidly growing deployment of FRP jacketing in concrete columns and bridge piers.

Objective

The objective of the 1.541 Class Project is to establish the most current understanding of NDE imaging techniques to visualize and quantify damages on FRP-confined reinforced concrete members using wideband radar. According to previous research, microwave radar technology presents several advantages other methods [3,6]. Additionally, new imaging techniques have been recently developed to better capture the electromagnetic wave propagation phenomena [2]. Numerous research tasks such as determining electromagnetic properties of materials, numerical simulations, and physical radar measurements need to be carried out in order to develop effective radar imaging methods. As a result, this class project will only focus in the area of assessment of electromagnetic properties for concrete and FRP composite materials. The project will consist of an extensive literature review covering the developments in this particular area of NDE using microwave techniques, the study of the underlying physical principles of electromagnetic properties of concrete and FRP materials, and an analysis of today's research efforts in this particular area.

Literature Review

The first step in the developing effective radar imaging techniques is the determination of the electromagnetic properties of the investigated media. These properties become key parameters for understanding the results of both numerical simulations and physical radar measurements. Several studies have been carried to capture the variation of the properties as functions of radar frequency, moisture levels, and material density. For the purposes of this progress report, three studies will be presented, which portray the advances in dielectric property measurements of concrete and FRP composites.

Early work in electromagnetic property assessment focused in measuring the dielectric properties of concrete, mortar, and aggregates using the open-ended coaxial probe method [6]. Being concrete a dielectric material, its electromagnetic properties can be characterized essentially by the complex permittivity [4]:

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

where the first term is related to the dielectric constant and the second term to the loss factor. For the case of concrete, the dielectric constant is associated with the reduction of velocity and wavelength of the transmitted waves, which in turn increases detectability. The loss factor is associated with changes in penetration depth of waves in the concrete medium. The open-ended coaxial probe consists of a network analyzer, and measuring probe, and a computer for data acquisition. The method is based on the principle of measuring the reflection of waves from the material along with knowledge of its physical dimensions (refer to Figure 1). Rhim [6] established a clear understanding of the relations between these parameters and radar frequency, moisture conditions, and penetration depths. Based on his experimental work, mathematical expressions were obtained to describe the variation of the permittivity parameters with changing radar frequencies. It was also proven that moisture content significantly affects the permittivity parameters for concrete. Additionally, a clear tradeoff between radar detectability and wave penetration depth was identified for concrete.

In 1996, dielectric properties of low-density fiberglass composites were studied at microwave frequencies [6]. The main goal of the research project was to relate that information to the state of cure of the resin binder content. A waveguide method was used to study the dielectric properties of fresh and cured resin (used in the production of low-density fiberglass composite materials) in an extensive frequency range. The same method was used to determine the dielectric properties of fiberglass materials containing several curing levels of resin binder. However, the results were similar for all curing levels. Consequently, another method referred to as open-ended rectangular waveguide was used. This technique allowed for non-contact inspection. The results of the experimentation showed that dielectric property measurements served as effective tools for determining the state of cure in liquid resin binders. After optimizing the radar operating frequency and the standoff distance (related to the open-ended rectangular waveguide method), a microwave NDE imaging approach was developed to effectively distinguish among fiberglass at different levels of resin binder.

Current Work

Some of the most recent work in the area of determining dielectric properties for FRP composites is in progress at MIT. The Infrastructure Science and Technology Group (IST) at the Civil Engineering Department have performed extensive studies in the area of FRP retrofitting of concrete structures. One of the latest projects is currently underway, which is looking into developing effective radar NDE techniques for visualizing the condition of concrete core in FRP wrapped columns. The author of this class project is leading these research efforts. The measurement of dielectric properties of FRP materials has become an even more difficult task due to the variety of composites used in industrial applications. Typical FRP composites used in the field range from fabric sheets to plates of both glass and carbon-based materials. The mentioned variety of materials and geometries present a challenge when trying to assess their dielectric properties. With the collaboration of Lincoln Laboratory at MIT, the measurement of such properties will be performed using a new approach compared to previous work in this area. In this case, radar technology will be used to study the wave propagation phenomena thought FRP laminate sample. Looking at readings related to microwave power reflected and transmitted, appropriate algorithms will be developed to backfigure the dielectric constant and the loss factor for different FRP samples. The study will involve both experimental measurements and numerical predictions based on electromagnetic wave theory. The study aims at the determination of dielectric properties of FRP composite materials as functions of radar frequency, moisture condition, and sample thickness.

Conclusion

The objective of this class project is to review the most current understanding of NDE radar imaging techniques used to visualize and quantify damages on FRP-confined reinforced concrete members using wideband radar. For the purposes of this project, the focus will be narrowed down to the study of measurement techniques of dielectric properties of FRP composite materials, which is a key component in the development of effective NDE imaging techniques. This progress reports was outlined some of the previous work done in the field as well as some of the most current research efforts. Several tasks need to be carried out for the completion of this class project such as a more detailed explanation of the several techniques, their applications and results.

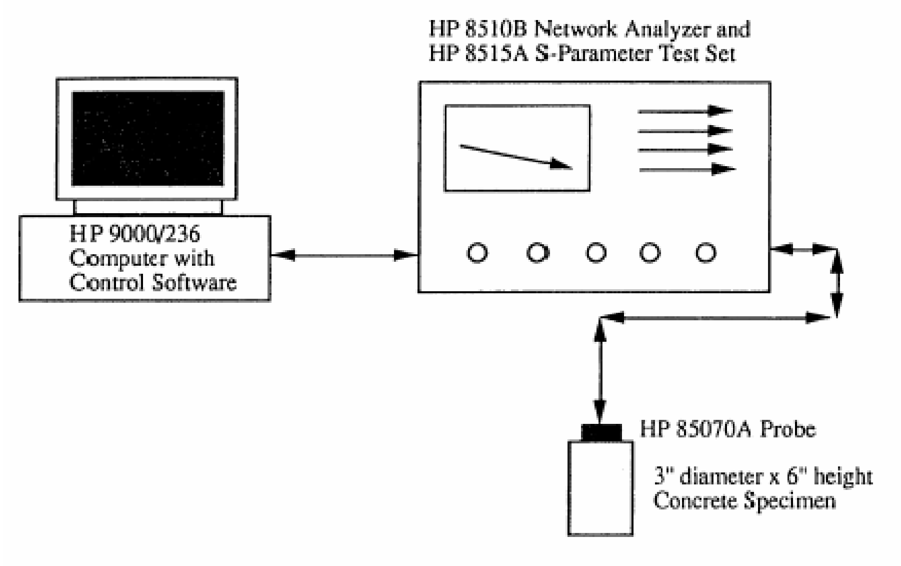

Figure 1. A Block Diagram of Dielectric Constant Measurements using the Probe Method

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