TriDurLE

National Center for Transportation Infrastructure Durability & Life-Extension

UTC Project Information – National UTC TriDurLE	
Project Title	Poro-Elastic modeling and measurement of rebar corrosion and crack formation using high frequency ultrasonics.
University	Florida Atlantic University.
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Funding Source(s) and Amount Provided (by each agency or organization)	TriDurLE: $48,710 FAU (in-kind cost share): $48,710
Total Project Cost	$97,420 (including cost share)
Agency ID or Contract Number	
Start and End Dates	September 1, 2021 to August 31, 2022 (tentative)
Brief Description of Research Project	The goal of this project is to demonstrate the ability to detect early appearance of cracks in reinforced concrete due to rebar corrosion, using ultrasonic nondestructive acoustic testing with no direct contact between the sensor and the concrete block, in conjunction with a poro-elastic ultrasound propagation model. The objectives are threefold: (1) Identify the proper measurement configuration and predict the performance, using the modeling of the ultrasound propagation in the reinforced concrete; (2) Perform a series of targeted measurements using the proper ultrasonic transducers on a set of existing reinforced concrete samples placed in partial or complete immersion; (3) Evaluate the degree of corrosion within the reinforced concrete with confidence levels according to the poro-elastic model, and correlate the results with those obtained (separately from this proposal) using traditional non-invasive techniques (e.g. corrosion current and corrosion potential measurements). The proposed poro-elastic model ties the physical properties of the porous medium (such as porosity, mean grain diameter, mass density, bulk modulus, shear modulus) to the sound propagation through the porous medium. It can also handle gradual changes of the physical characteristics of the medium and produce a synthetic response to a broadband acoustic impulse. This technique is very relevant in the material observed around the corroding bar.

	This research would be the foundation for a more detailed acoustic analysis of rebar corrosion detection in reinforced concrete pilings/columns out in the field.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	To date, the following tasks have been completed: • Development and testing of the poro-elastic model for the reinforced concrete samples. The model details are quite extensive and will be presented in the yearly report. In addition, the PI is preparing a manuscript for submission to the Journal of Infrastructure Preservation and Resilience. • Ultrasonic data collection on a limited number of reinforced concrete samples. The concrete block sample was submerged in salt water in a small tank. An Olympus Panametrics V389 (Panametrics, 2010), operated at 500 [kHz] and connected to an HP8112A high-frequency impulse generator and a Tektronix DPO3014, was placed at 12 [cm] above the concrete surface, to avoid near-field acoustic interferences (Figure 1). A sample of experimental results is shown in Figure 3. The transducer was carefully placed on top of the corroded rebar and moved along the axis of the rebar in increments of 0.5 [cm]. The initial position was at 2.5 [cm] off the edge of the concrete block. The last position was at 9.5 [cm] off the edge of the concrete block. At every position, ten acoustic signatures were recorded. In order to reduce the electric and thermal noise contained in the high-frequency measurements, an acoustic signature averaged across the ten measurements was computed. • Processing of simulated data sets and comparison between simulated and measured data were completed. Figure 2 shows an example of measured vs. simulated acoustic signatures, using the parameters listed in Table I. The table coefficients were obtained from concrete sample information provided by Dr. Presuel Moreno and from literature. The results clearly indicate that model and measurements match closely. • A graduate student was hired and trained, completed two semesters of research and produced a Directed Independent Study Report. • Discussion with Olympus was initiated for an industry partnership, in the likely form of a free loan or donation of an ultrasonic acquisition unit and contact transducers.

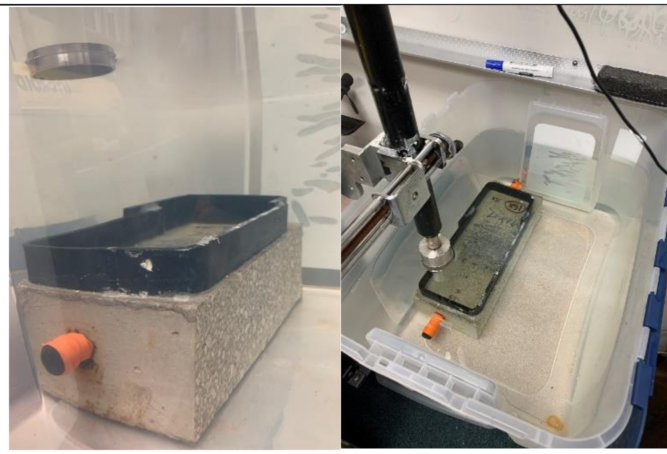

Figure 1. Ultrasonic testing of the reinforced concrete sample fully immersed in salt water. Left: side-view. Right: Top view.

Table I. Physical Properties of the Reinforced Concrete Material used in the Simulation.

Layer	Physical Property	Symbol	Value
Salt water (top layer and pore fluid)	Mass density of the fluid	ρ_f	$1026\ kg/m^3$
	Phase Speed in the Fluid	c_f	$1.5 * 10^3\ m/s$
	Bulk modulus of the Pore Fluid	K_f	$2.28 * 10^9\ Pa$
Concrete 16.6% cementite, 33.4% sand, 43.1% coarse, 6.8% water (if saturated)	Bulk modulus of the Concrete Material	K_r	$4.49 * 10^{10}\ Pa$
	Mass density of the dry concrete material	ρ_r	$2341\ kg/m^3$
	Fluid Viscosity	η	$0.001\ kg/m.s$
	Porosity	β	0.1
	Permeability	$\varkappa$	$8.0^*10^{-12}m^2$
	Pore Size Parameter	a_p	$1.3975^*10^{-5}m$
	Dry Concrete Shear Modulus	μ	$1.22 * 10^{10}Pa$
	Poisson's ratio of the Dry Concrete	v	0.27
	Mean Grain Diameter	d	$0.0002\ m$
	Shear Logarithmic Decrement	δ_s	0.12
	Bulk Logarithmic Decrement	δ_p	0.12
	Biot Added Mass Coefficient	c	1.25
Rebar	Mass density of the Rebar	ρ_b	$7800\ kg/m^3$
	Phase Speed in the Rebar	c_b	$5180\ m/s$
	Depth below the concrete surface	h	$0.022\ m$

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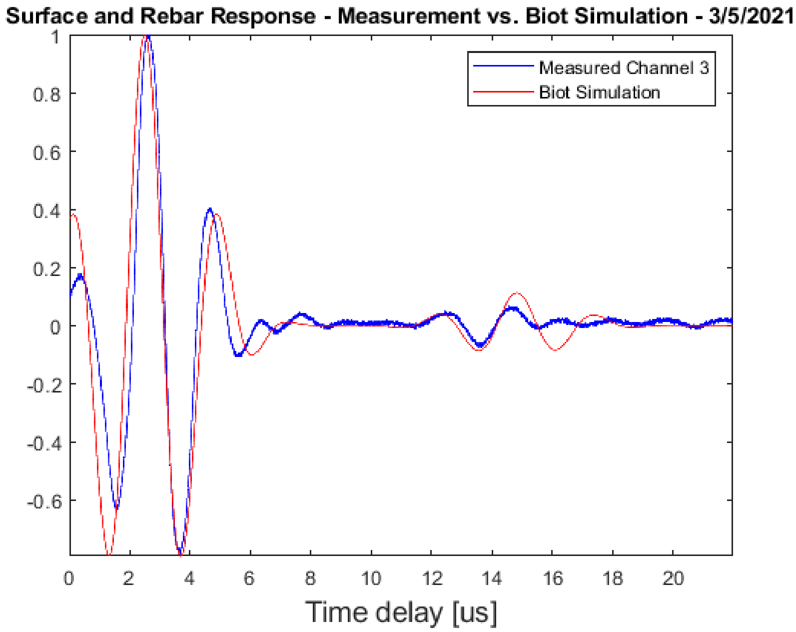

Figure 2. Comparison between measured and simulated results. In blue: concrete echo and rebar echo obtained using an average across the ten ultrasonic signatures (following careful time alignment, with the transducer placed at 2.5 [cm]. In red: Poro-elastic model simulation result for the same configuration, using the parameters listed in Table I.
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<td>Impacts/Benefits of Implementation (actual, not anticipated)</td>
<td>The results clearly indicate that ultrasonic propagation model and measurements match closely. This is an important step towards estimating the degree of corrosion and crack propagation in the rebar according to the match between ultrasonic measurements and the poro-elastic model prediction.</td>
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<td>Web links
Reports
Project website</td>
<td>www.ome.fau.edu</td>
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