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STRUCTURAL HEALTH MONITORING OF REINFORCED CONCRETE STRUCTURES USING GUIDED WAVES

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ABSTRACT

Ultrasonic guided waves provide a highly efficient method for non-destructive evaluation and the structural health monitoring (SHM) of solids with finite-cross-sectional dimensions (waveguides). Guided waves are widely used for the inspection of structures such as pipelines, annular tank plates, aircraft wing assemblies, composite radius fillers and wind turbines. They are also attractive for long-term structural health monitoring due to their ability to provide long-range and feature-rich through-structure information from a single transducer location. The use of guided waves in reinforced concrete structures is limited to the monitoring of setting and curing of concrete due to the heterogeneous nature of concrete and its high acoustic impedance which is comparable to the steel reinforcement bars. This leads to a significantly high energy leakage into the embedding concrete making it impossible to use guided waves for the inspection of reinforced concrete structures. Corrosion resistant epoxy coatings on reinforcement coatings are widely used for structure exposed to harsh environmental conditions such as high temperatures, humidity, water, acids, solvents, salts and other chemicals. In this work, the attenuation of the L (0,1) guided waves modes propagating along a 20 mm diameter mild steel is monitored using finite element simulation for a fusion bonded epoxy (FBE)rebar and for plain rebar both embedded in an infinite concrete medium. The attenuation in the epoxy coated rebar is shown to be substantially reduced compared to the plain rebar embedded in concrete. This reduction in guided wave attenuation can make it possible to use guided waves to conduct structural health monitoring of concrete structures.

Keywords: Reinforced concrete, Ultrasonic guided waves, Longitudinal waves

NOMENCLATURE

SHM	Structural Health Monitoring
L (0,1)	Fundamental longitudinal wave mode
FBE	Fusion Bonded Epoxy
FE =	Finite Element

1. INTRODUCTION

Reinforced concrete find application in almost every infrastructural asset, e.g. buildings, bridges, power plants, etc due to its durability [1,2]. To guarantee safe and efficient operation, these structures require regular inspection [3]. The heterogeneous nature of concrete has presented challenges over the years in transferring the various NDT technologies designed for steel testing to the inspection of concrete structures [4]. Today ultrasonic is widely used for assessment of the quality of concrete. However, bulk ultrasonic techniques are tedious and time consuming. As a result, guided ultrasonic waves that can cover long distances from a single transducer position are of much interest [5]. Whena waveguide is embedded in another material, energy leakages into the embedding material can lead to high attenuation rates especially if the acoustic impedance of the waveguide and the surrounding solid are matching [6,7]. Several guided waves studies have been conducted to study the effect of embedding medium on a waveguide [7-11]. Recent work on quantitative defect detection in composites using guided waves [14] can be exploited in order to enhance the capabilities of using guided waves for structural health monitoring of reinforced concrete structures.

2. MATERIALS AND METHODS

In this study, we investigate guided wave propagation in a coated (fusion bonded epoxy) reinforcement bar embedded in an infinite concrete medium using the longitudinal L (0,1) mode. The main aim is to develop a novel concept based on guided waves for online health monitoring of concrete structures where the reinforcements in the concrete will act as a natural set of waveguides and will be used to transmit ultrasound into the concrete. Stress and displacement continuities are imposed on the interfaces between the rebar and epoxy coating and between epoxy coating and concrete. Attenuation was predicted using the Disperse software [15] using the material properties listed in Table 1.

Table 1: Material properties of steel and concrete used for modelling in Disperse [15]

Material Property	Rebar	Concrete	Epoxy
Modulus E, (GPa)	210	29.569	3.5
Density, (kg/m3)	7932	2200	1200
Longitudinal Attenuation (db/m)	0.003	0.2	-
Shear attenuation (db/m)	0.008	0.5	-
Longitudinal velocity (m/s)	5960	4100	2610
Shear velocity (m/s)	3260	2300	1100
Poison's Ratio	0.2865	0.2703	0.33

Finite element (FE) simulations consisted of a 3 m long, 20-mm diameter epoxy coated steel bar surrounded by an infinite concrete medium. The thickness of the epoxy coating was 0.3mm. To enable comparison, the same size of rebar was modelled in with air and concrete as the embedding medium. The amplitude of the ultrasonic wave was monitored every 0.5 along the rebar. A 160 kHz hanning pulse was used as the load from one end of the rebar.

3. RESULTS AND DISCUSSION

The phase velocity, attenuation characteristics and group velocity have been plotted against frequencies in the figures 1a, 1b and 1c respectively.

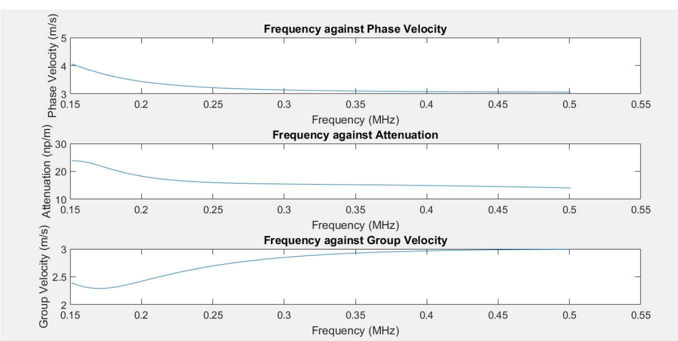

Figure 1: Dispersion curves of the zero-order guided wave modes

Figure 2a and 2b below shows a comparison of the amplitudes at a monitoring point 1 meter from the excitation point with respect to rebar in air. Figure 3 shows the attenuation levels for the coated rebar and plain rebar with distance from the point of excitation. Table 2 present signal amplitudes at various depth from the point of excitation.

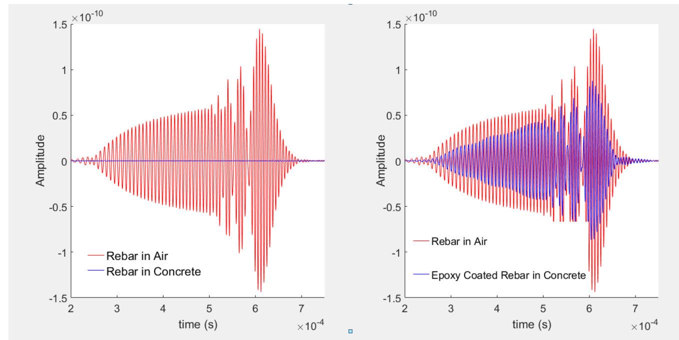

Figure 1: Signal Amplitude at 1 m from the excitation (red-signal for a rebar air situation; blue- signals for either rebar in concrete and epoxy coated rebar in concrete)

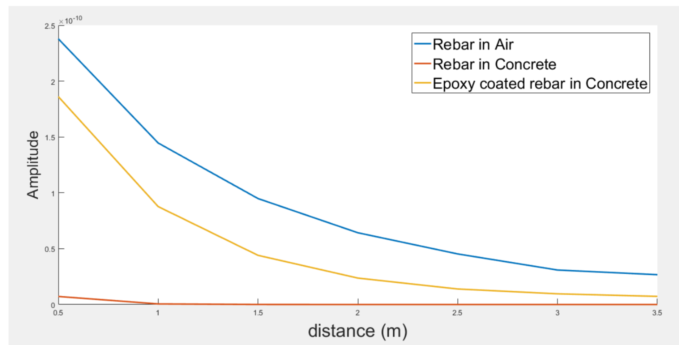

Figure 4: A plot of signal amplitudes with distance for the three modelled cases

Table 2: Signal amplitudes at various depth from the excitation

Distance	RebarConcrete	RebarEpoxyConcrete
0.5	3%	78%
1.0	0%	61%
1.5	0%	46%
2.0	0%	37%
2.5	0%	31%
3.0	0%	31%
3.5	0%	27%

From the simulation, it can be seen that more ultrasonic guided waves guided wave is able to propagate when a thin layer of epoxy layer is coated on the reinforcement bar. At 0.5 m, only 3 % of energy is transmitted in the rebar embedded in concrete. This is mainly due to high attenuation losses from leakages as the acoustic impedance is close to that of steel. When a 0.3 mm epoxy layer is introduced, 27 % per cent of the energy is detected by a monitor at a depth of 3.5 meters from the point of excitation.

It needs to be pointed out that these relative amplitudes are taken relative to the signal amplitudes for rebar in air.

4. CONCLUSION

The work shows reduced transmission loss of energy when the material of lower impedance, in this case, an epoxy layer, is used between the waveguide and the embedding medium. This can lead to increased inspection distances into a concrete medium which has high attenuation properties. The work shows the potential of development of guided waves in online structural health monitoring of reinforced concrete structures. Ultrasonic guided waves can offer an advantage over other available test methods since they can travel over a longer distance a single transducer position. Experimental validation of waveguide concepts generated by simulation is in progress, and if successful, it will have the potential of online monitoring large reinforced concrete infrastructures from just a few locations.

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