Assessment of Crack Depth in Reinforced Concrete Bridge Elements by Ultrasonic Methods

GDOT 11-07

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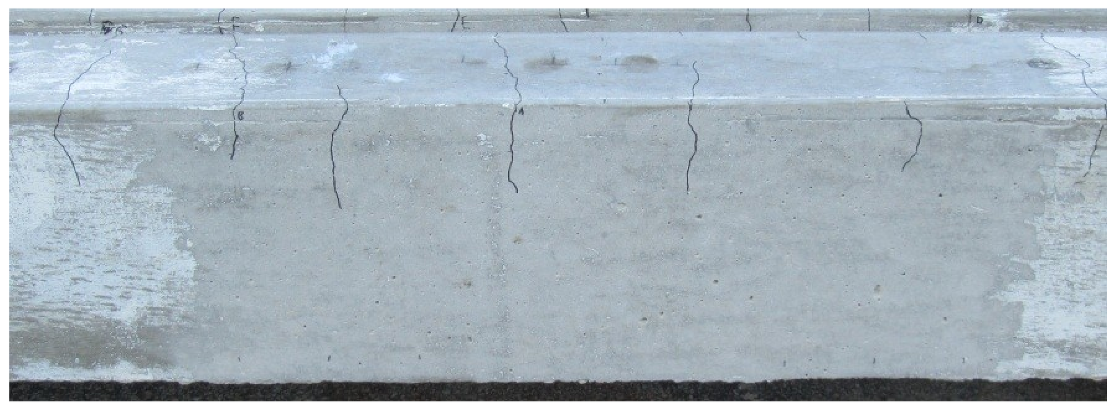
Objective

- The objective of this research is to develop ultrasonic methods to assess and measure through-cover cracks in reinforced concrete bridge pile caps.
- More sophisticated evaluation techniques could lead to a significant reduction in maintenance costs and increased safety, and thus should be investigated.
- The diffuse ultrasonic technique has shown high potential for crack depth measurement [1] in laboratory setups while its applicability to a field structure has not been demonstrated.



Technical Approach

- Compare two crack depth estimation methods: diffuse ultrasonic technique and impact-echo technique
- Develop finite element simulation of diffuse wave propagation in reinforced concrete bridge pile caps
- Apply both methods to a reinforced concrete beam under load
  - Build field-size concrete beams
- Assess applicability, accuracy, and limitations of each technique
- Recommend guidelines for practical uses of the diffuse ultrasonic technique

Diffuse Ultrasound in Concrete1,4

Due to the high density of scatterers in concrete, ballistic signals quickly become randomized.

The flow of energy due to ultrasonic excitation can be treated in the way analogous to heat transfer that satisfies the following governing equation:

$$\frac{\partial\langle E(x,t,f)\rangle}{\partial t} - D\Delta\langle E(x,t,f)\rangle + \sigma\langle E(x,t,f)\rangle = P(x,t,f)$$

where D(f) is the diffusion coefficient [m2/s] (the diffusion rate of the ultrasonic field) and σ(f) is the dissipation coefficient, [1/s] (the rate of loss of energy)

Which has the following solution in a 2D bounded plane:

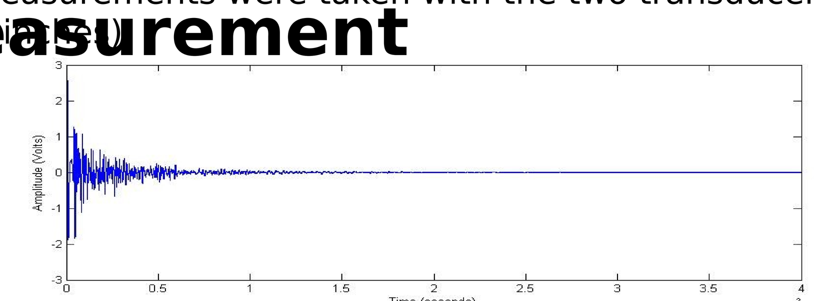
$$\langle E(x,t,f)\rangle = P_0\left\{1 + 2\sum_{n=1}^{\infty}\left(\cos(L_n x_0)\cos(L_n x)e^{-DL_n^2 t} + \cos(P_n y_0)\cos(P_n y)e^{-DP_n^2 t}\right) + 4\sum_{n=1}^{\infty}\sum_{m=1}^{\infty}\cos(L_n x_0)\cos(L_n x)\cos(P_m y_0)\cos(P_m y)e^{-D(L_n^2+P_m^2)t}\right\}e^{-\sigma t}$$

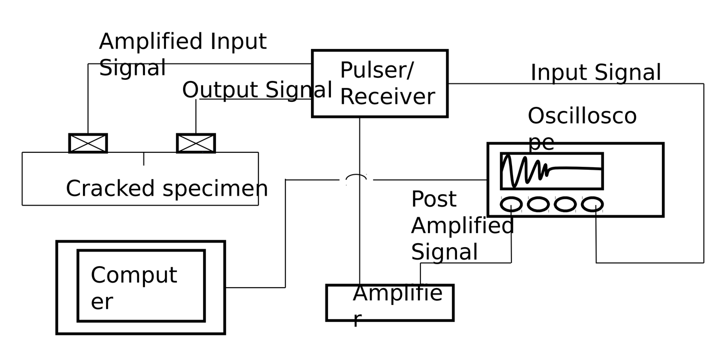
where $P_n = n\pi / p$ and $L_n = n\pi / l$ with l and p being the dimensions of the rectangular domain

High frequency excitation → High resolution → Diffuse ultrasound can detect smaller sized defects such as distributed microcracks or shallow cracks (< 8 in)

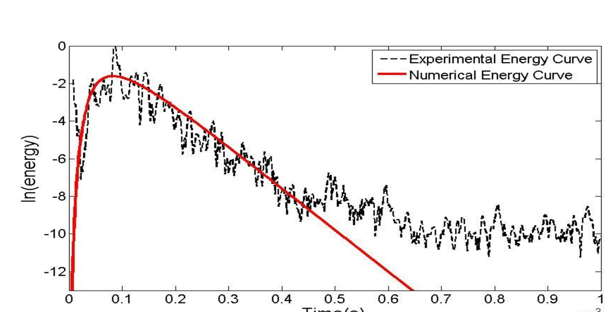
Diffusion Ultrasonic Measurement

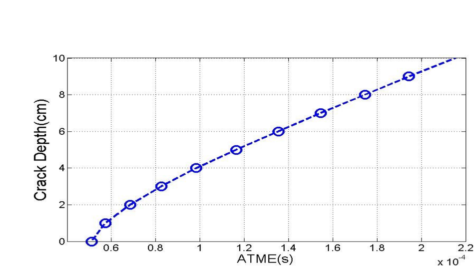
1) Measurements were taken with the two transducers separated by 6 cm





2) Ultrasonic signals were taken at an uncracked portion of the beam and then the dissipation and diffusivity values for the undamaged concrete using the 2D bounded solution.
3) The transducers were then placed on both sides of the crack and measurements were taken to find the arrival time of maximum energy (ATME).
4) An ANSYS heat transfer FE simulation, developed in Task 3, was run using dissipation and diffusivity values of the uncracked portion of the beam and a master curve - a crack depth vs ATME was obtained.





1Numerical and experimental study of crack depth measurement in concrete using diffuse ultrasound. M.Seher et al, Journal of Nondestructive Evaluation (2013).
2Determining the depth of surface-opening cracks using impact-generated stress waves and time-of-flight techniques. M. Sansalone, J.-M. Lin, W.B. Streett. ACI Materials Journal (1998).
3Use of stress waves for determining the depth of surface-opening cracks in concrete structures. Y. Lin, W.-C. Su, ACI Materials Journal (1996).
4Ultrasound diffusion for crack depth determination in concrete, S.K. Ramamoorthy, Y. Kane, and J. A. Turner, *JASA* (2003).

Impact Echo2,3

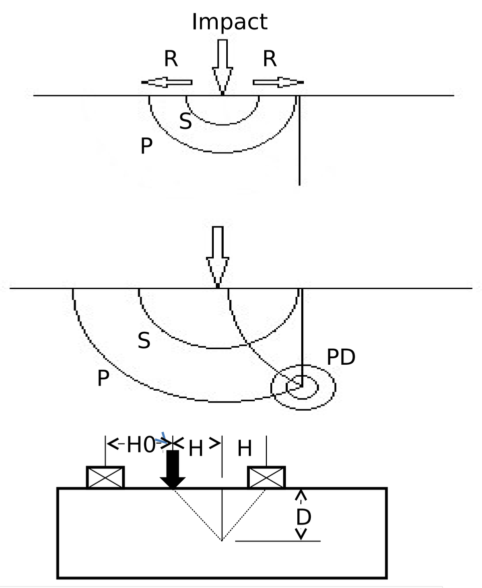
Upon impact, spherical longitudinal and shear waves that emanate through the material and Rayleigh waves that emanate radially on the surface are generated.

Low frequency excitation → Low resolution

When the longitudinal wave strikes the crack tip, the crack tip then acts as a new source for pressure and shear waves.

Knowing the time it takes for the diffracted wave to arrive at the receiver, and the speed of the longitudinal wave, it is possible to calculate the distance that the wave has traveled.

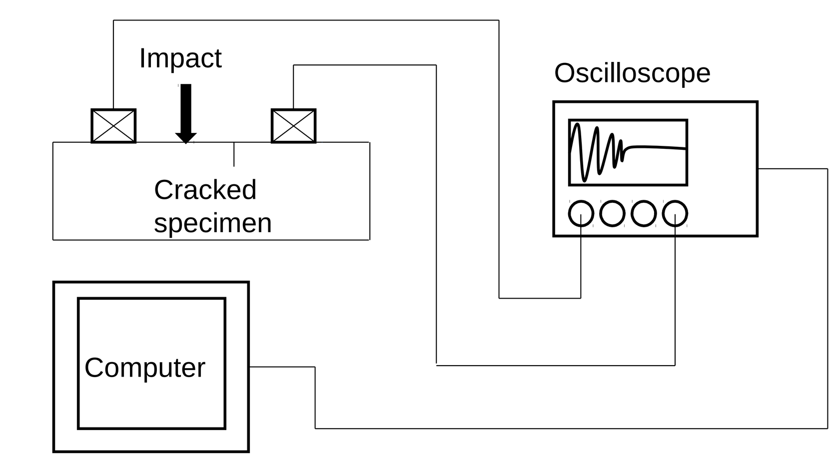
Once distance is known, calculating the crack depth becomes a simple geometry problem.



$$D = \sqrt{\left(\frac{C_P \times \Delta t}{2}\right)^2 - H^2}$$

Impact Echo Measurement

1) Transient elastic waves are introduced to the specimen via a commercially available impact echo impactor. The measurement setup is shown to the right.



2) The starting times of each signal are identified through a computer algorithm to eliminate user bias.

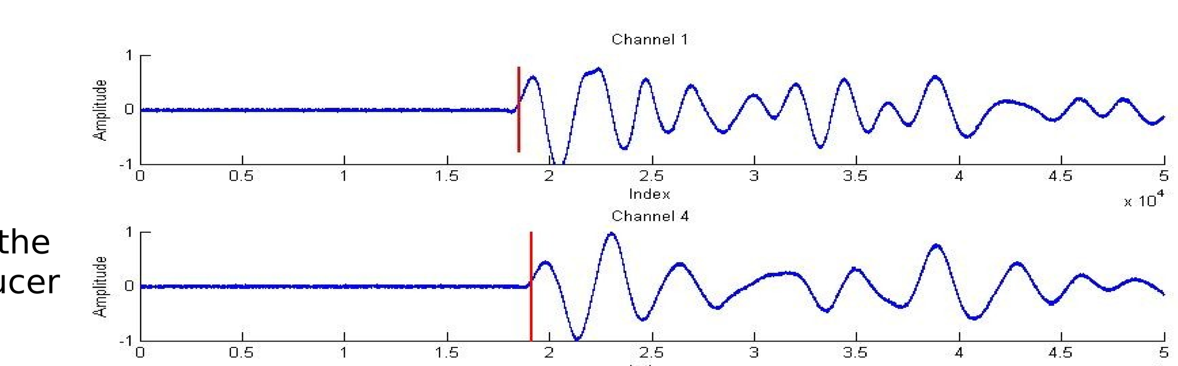
3) Δt is calculated using the following equation:

$$\Delta t = t_2 - t_0$$

where t2 is the arrival time at the transducer on the other side of the crack and t0 is calculated as follows:

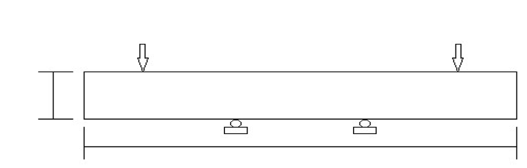
$$t_0 = t_1 - H_0 / C_R$$

where t1 is the arrival time at the transducer on the same side of the crack as the impactor, H0 is the distance from impactor to transducer and CR is the Rayleigh wave speed in the concrete.



Experimental Results

Test Setup:



Cracked Specimen:

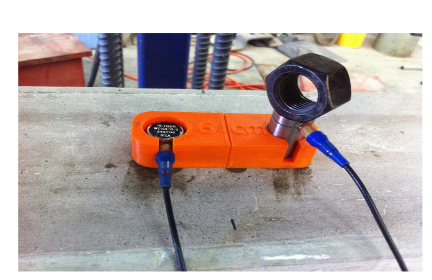
Characteristic Wave Speeds:

CP(m/s)	4030
CR(m/s)	1697

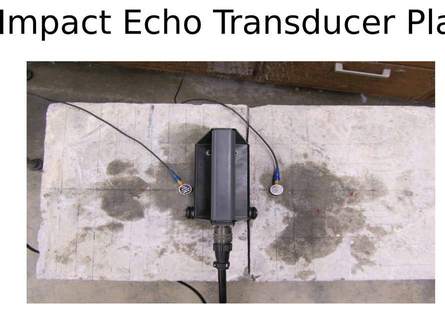
Characteristic Diffusion Parameters:

Diffusivity (m2/s)	10
Dissipation (1/s)	21000

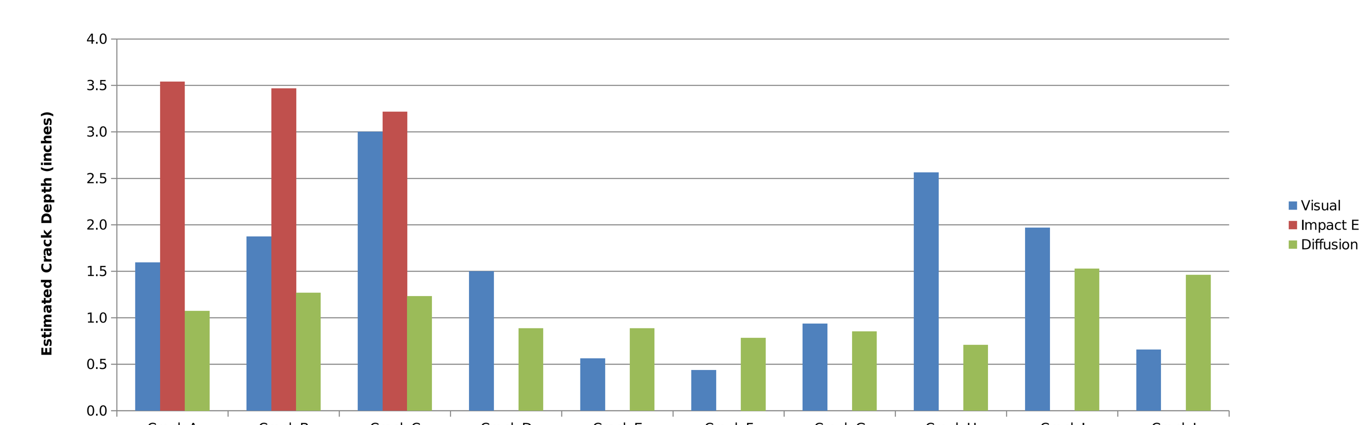
Diffusion Transducer Placement:



Impact Echo Transducer Placement:



Crack Depth Estimations:



Conclusions and Future Work

Conclusions:

- The diffuse ultrasonic method underestimates the crack depth based on visual inspection
- Further work is necessary to emphasize the strengths and weakness of both measurement techniques
- Impact Echo has space requirements that may limit its usability

Future Work:

- Drill cores to confirm true crack depth
- Test both methods on different sized cracks
- Investigate surface wave transmission method
- Validate Impact Echo method on a notch
- Provide recommendations for field ready device