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

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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 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 Concrete

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:

\[
\frac{\partial E(x,t,f)}{\partial t} = D(\nabla E(x,t,f)^2) + \sigma E(x,t,f) = P(x,t,f)
\]

where D is the diffusion rate of the ultrasonic field (diffusion rate of the ultrasonic field) and \( \sigma \) is the dissipation coefficient, [1/s] (the rate of loss of energy). The solution in a 2D bounded plane is

\[
E(x,t,f) = P \left( \frac{1}{2} \sum_{m,n} \cos \left( \frac{m \pi x}{a} \right) \cos \left( \frac{n \pi y}{b} \right) e^{-D \frac{n^2 \pi^2 t}{a^2}} + \cos \left( \frac{m \pi y}{b} \right) \cos \left( \frac{n \pi x}{a} \right) e^{-D \frac{m^2 \pi^2 t}{b^2}} \right)
\]

where \( a \) and \( b \) are 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 (< 2 in).

Impact Echo

- Upon impact, spherical longitudinal and shear waves that emanate through the material and Rayleigh waves that emanate radially on the surface are generated.
- When the longitudinal wave strikes the crack tip, the crack tip then acts as a new source for pressure and shear waves.

Impact Echo 2,3

Comparing the two crack depth estimation methods: diffuse ultrasonic technique and impact-echo technique.

Impact Echo

1) Measurement

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.

Experimental Results

Test Setup:

Cracked Specimen: Crack Depth Estimations:

Characteristic Wave Speeds:

<table>
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<tr>
<th>Characteristic Wave Speeds:</th>
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<tr>
<td>C (m/s)</td>
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<td>CR (m/s)</td>
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Dissipation (1/s): 21000

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