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Dispersion Velocity Profiles: Experimental Study with Artificial Void Simulating Different Void Ratios in Cold Joints †

Hong-Yao Cai [1]*†, Chia-Chi Cheng [1], Yung-Chiang Linand [1]

[1] Department of Civil and Construction Engineering, Chaoyang University of Technology, Taichung City 413310, Taiwan; cccheng@cyut.edu.tw
* Correspondence: s11211610@gm.cyut.edu.tw;
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Abstract:. This study evaluates the bonding condition of concrete slabs with varying porosity levels (20% to 80%) at cold joint interfaces by analyzing surface wave dispersion velocity profiles. A dual-receiver setup was employed to compare the waveform and dispersion characteristics along the test lines that crossed cold joints and those that did not. While wave velocity reduced for lower wavelengths at lower void levels, more significant reductions were observed across the entire wavelength range at higher porosity levels. This demonstrates that Rayleigh-wave dispersion can effectively assess cold joints generated by artificial voids with known void ratios.

Keywords: cold joint, concrete, Rayleigh wave, dispersion curve, void ratio

1. Research Objective

Any negligence during the placement process for concrete structure, especially when new concrete is poured onto an already hardened layer, can lead to the formation of cold joints. These discontinuities at the interface result in increased porosity and permeability, allowing harmful ions to penetrate more easily, which in turn significantly compromises strength and durability of the structural.

To address this issue, the present study aims to evaluate the severity of cold joints using the propagation characteristics of Rayleigh waves. the research investigates the effects of varying porosity on waveform and wave velocity. The ultimate goal is to establish a reliable and effective non-destructive testing (NDT) method for rapidly assessing the impact of cold joints on concrete structures.

2. Materials and Experimental Methods

In this study, self-compacting concrete (SCC) was used, with a design compressive strength of 280 kg/cm², a water-to-binder ratio of 0.39, and a slump flow controlled at 65 ± 5 cm. As shown in Table 1, the cold joint interface was simulated using randomly distributed polystyrene (EPS) sheets measuring 1×1 cm² in area and 1.2 mm in thickness. The designed porosity levels included 20%, 40%, 60%, and 80%, as well as two partial-depth variants: 60% porosity occupying half the thickness (60%-Half) and 60% porosity occupying one-quarter of the thickness (60%-Quarter).

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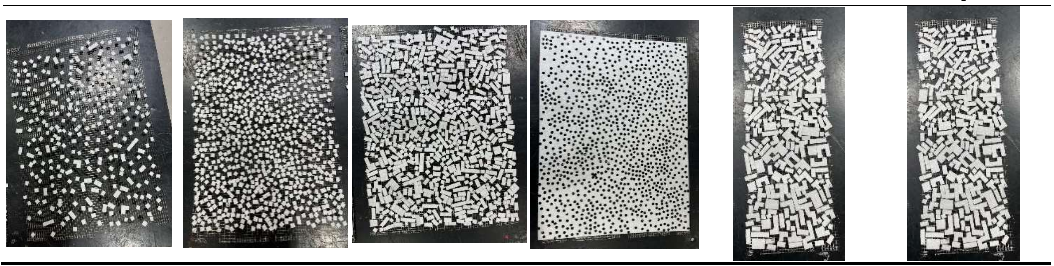
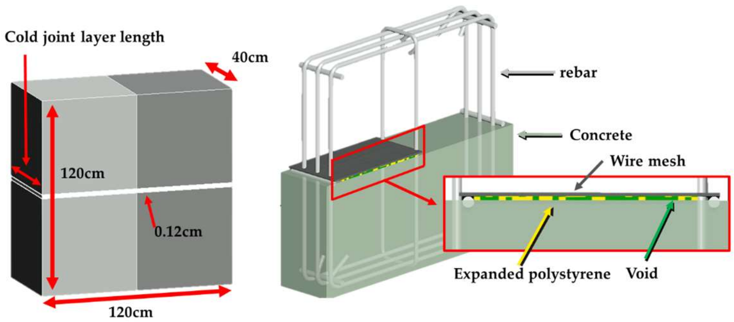
As shown in Fig. 1(a), the test specimens were 120×120×40 cm blocks, each with two distinct porosity regions. Fig. 1(b) illustrates the porosity distribution and realistic simulation of cold joints. For the 60% porosity group, we manufactured the interface by randomly distributing clusters of EPS patches (1 to 5 cm in side length) instead of individual 1 cm square patches to ensure uniform sheet distribution. In the 80% porosity group, voids were simulated by cutting through-holes in the interface.

Table 1. Schematic diagram of porosity distribution.

Actual Porosity Distribution					
Specimen 1 (1S)		Specimen 2 (2S)		Specimen 1 (3S)	
20%	40%	60%	80%	60%-Half	60%-Quarter





(a) (b)

Figure 1. Schematic of physical setup. (a) Specimen dimensions, (b) Schematic diagram of EPS attachment to rebar)

2.1 Testing Method

In the experiment, piezoelectric impact hammers (3 mm and 5 mm diameters) acted as excitation sources to determine the initial impact time. Two displacement receivers and a digital data acquisition card then captured the surface wave responses. For each hammer impact, we took two simultaneous measurements: one intersecting the cold joint (joint-pass test) and the other avoiding it (joint-avoid test). The data acquisition system recorded 25,000 data points per measurement at a 20 MHz sampling frequency, totaling a 20 ms recording duration. The impact and receiver positions are labeled in Table 2. Distances of 0.4 m were designated A, B, and C, and 0.6 m distances were designated D, E, and F.

Table 2. Measurement line configuration

sample points			
Impactor-receiver distance (D)	Impact point	Receiver point: Passing through cold joint	Receiver point: Not passing through cold joint
0.4 m	A2、B2、C2	A1、B1、C1	A3、B3、C3
0.6 m	D2、E2、F2	D1、E1、F1	D3、E3、F3

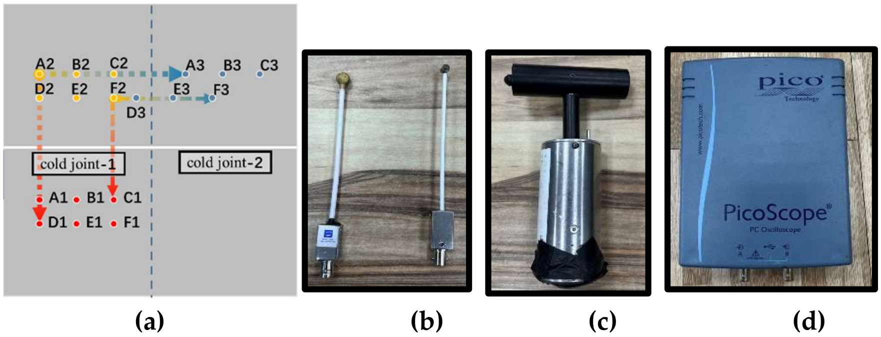


Figure 2. Experimental Instrumentation and Setup (a) Schematic diagram of sensor layout, (b) Piezoelectric impact hammer, (c) Displacement receiver, (d) Data acquisition card

3. Experimental Results

The time-domain signal obtained from the experiment, as shown in Fig. 3(a), was first transformed into the time-frequency domain using the Short-Time Fourier Transform (STFT). Subsequently, a reassigned spectrogram [1] was employed to enhance the resolution of the time-frequency representation, thereby providing a clearer illustration of the surface wave group velocity dispersion characteristics (Fig. 3(b)). The maximum value at each wavelength interval of 0.4 mm were picked to obtain a clear dispersion curve, which further elucidated the wave propagation characteristics within the material Fig. 3(c). Fig. 3(d) compares the dispersion curves from joint-pass and joint-avoid tests.

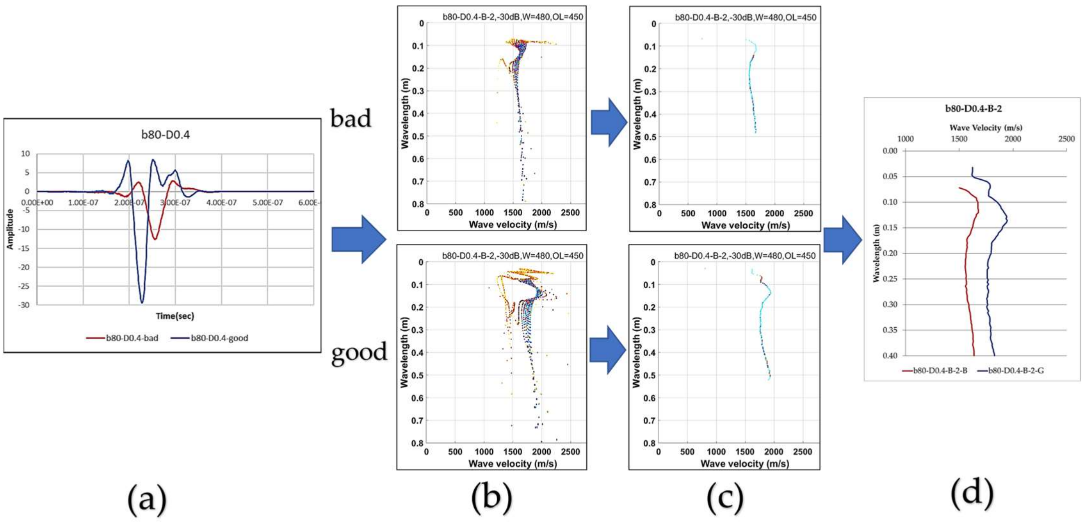


Figure 3. Signal Processing and Dispersion Analysis (80% Porosity Experimental Data), (a) Raw experimental waveform; (b) Time-frequency distribution via Short-Time Fourier Transform (STFT) with spectrogram reassignment; (c) Dispersion curve derived from maximum amplitude at constant wavelengths; (d) Comparison of dispersion curves for cold-joint "pass" and "avoid" tests.

Figures 4 and 5 compare the mean and one standard deviation of dispersion curves from cold-joint "pass" and "avoid" tests for each void scenario. Specifically, Fig. 4 presents data for a 0.4 m impactor-receiver distance with a 3 mm impactor, while Fig. 5 shows curves for a 5 mm impactor. From the figures, we can draw the following conclusions:

- The 5 mm diameter impact source consistently produced more stable results, as indicated by generally smaller standard deviations in Fig. 5.
- For 20% porosity, wave velocities showed larger differences within the 0.07–0.15 m wavelength range, a phenomenon more pronounced with the 5 mm impactor.

- At 40% porosity, the mean wave velocities were more easily differentiated between 0.05 and 0.2 m wavelengths.
- For 60% porosity, the 3 mm impact source yielded more consistent results. Beyond 0.20 m, the velocity exhibited an almost parallel trend, with a decrease of about 150 m/s for "avoid" tests.
- At 80% porosity, after 0.10 m, the wave velocity clearly trended toward parallelism, and the decrease in velocity reached 200m/s for "avoid" tests.

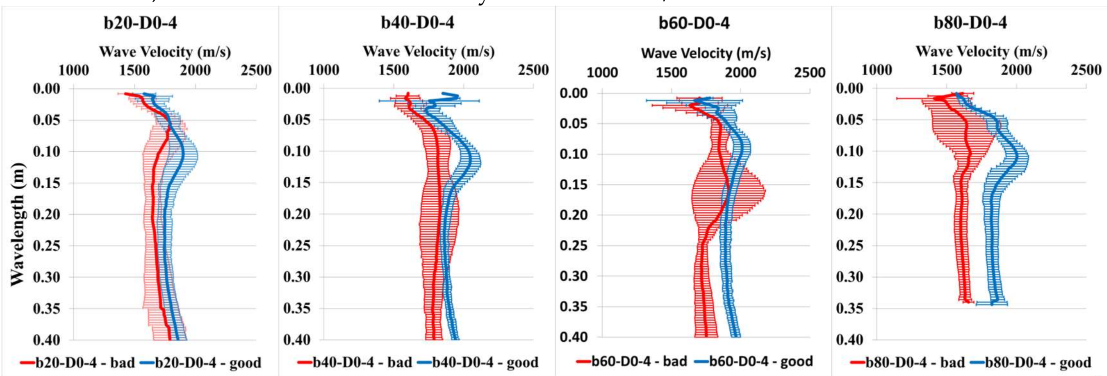


Figure 4. Effect of a cold joint on mean and standard deviation of dispersion curves for a 3 mm impact source, with comparisons for void ratios of (a) 20%, (b) 40%, (c) 60%, and (d) 80%.

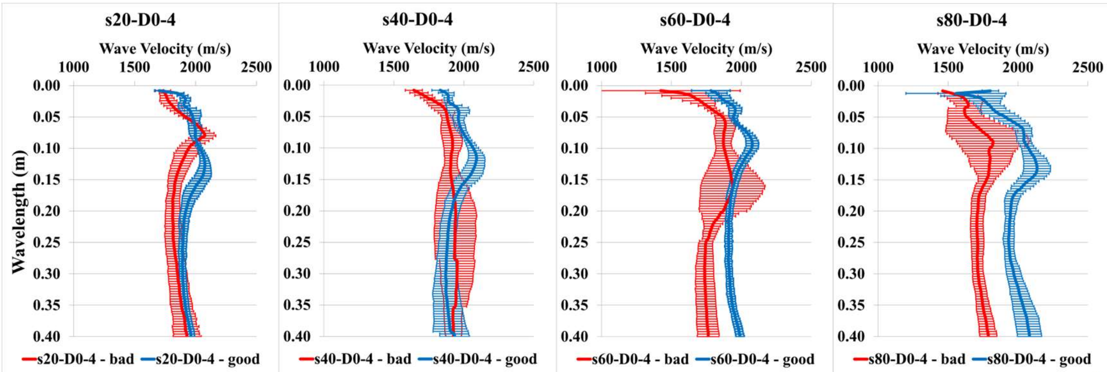


Figure 5. Effect of a cold joint on mean and standard deviation of dispersion curves for a 5 mm impact source, with comparisons for void ratios of (a) 20%, (b) 40%, (c) 60%, (d) 80%.

4. Conclusions

This study evaluated the bonding condition of concrete slabs with 20% to 80% porosity at cold joint interfaces using surface wave dispersion velocity profiles. We employed a dual-receiver setup, comparing waveform and dispersion characteristics along test lines that both crossed and avoided cold joints. Experiments utilized 3 mm and 5 mm diameter impactors and 0.4 m and 0.6 m impactor-receiver distances.

For 20% and 40% void ratios, wave velocity decreased at lower wavelengths, while more significant velocity reductions across the entire wavelength range were found for 60% and 80% void ratios. This indicates that larger void ratios at the cold-joint interface lead to greater velocity decreases. Future research will focus on naturally formed cold joints. We'll correlate those results with this study to estimate the corresponding void ratios of the naturally formed cold joints.

Acknowledgments:

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