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Effects of pump-induced conditioning on nonlinear coda wave interferometry in concrete

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Nonlinear Coda Wave Interferometry (NCWI) is an effective technique for detecting closed cracks in complex materials such as concrete, often missed by conventional linear ultrasonic methods. Combining the sensitivity of Coda Wave Interferometry (CWI) with a nonlinear modulation effect induced by a pump wave, this method activates nonlinearities in materials. Pump waves are conventionally applied in ascending order from smaller to larger amplitudes, and then the relative velocity change at each pump level is plotted against pump amplitude, followed by fitting a quadratic polynomial to the resulting plot. The coefficient of the quadratic term of this fit is ultimately considered an NCWI observable called α_θ. Previous NCWI studies have related α_θ to the level of nonlinearity in materials. However, the role of non-equilibrium dynamics—specifically, conditioning effects induced by the pump wave—remains unexplored.

In this study, we investigate how pump-induced conditioning influences NCWI measurements in concrete. Two concrete blocks—one intact and one containing a closed crack—are subjected to a series of controlled laboratory experiments, where we vary the standard pumping parameters. For this purpose, different experiments are carried out, each evaluating the effect of a specific parameter, such as changing the pumping durations or applying the pump levels in reverse order.

Our results show that NCWI observables are indeed sensitive to the specifics of the pumping, indicating that they reflect a combined response due to both material nonlinearity and non-equilibrium effects. In fact, with an increase in the pumping durations, larger relative velocity change values are observed, which indicates a larger share of conditioning effects on the results since the pump amplitude is the same and the only difference is an increase in the duration of pumping. On the other hand, keeping the pump for a relatively long duration or applying it in reverse order from larger to smaller amplitudes leads to smaller relative velocity changes due to pre-conditioning effects.
Nevertheless, across all experiments, the damaged block consistently shows larger values of observables than the intact one, showing that, regardless of the differences in measurements, the method can still distinguish intact and damaged blocks.

This work highlights the importance of considering non-equilibrium effects in the interpretation of NCWI results for materials that are affected by non-equilibrium dynamics.

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