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Influence of Loading Frecuency on the Fatigue Life of Concrete

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Concrete structures such as bridges and wind turbine towers are subjected to a significant number of load cycles throughout their service life. This repeated loading leads to progressive damage accumulation, commonly referred to as fatigue degradation. The evolution of fatigue damage in concrete is influenced not only by the amplitude of the applied stress or strain but also by the frequency of the cyclic loading. Previous studies have shown that such dependencies are characteristic of nonlinear micro-inhomogeneous solids, including rocks and soft metals, where both amplitude and frequency strongly affect damage mechanisms. In our investigations, experimental observations of the evolution of nonlinear acoustic parameters and the shape of hysteretic stress-strain loops during fatigue testing confirm that similar dependencies are also present in plain concrete under compressive fatigue loading.

A central challenge is to understand how the evolution of nonlinear acoustic parameters and the morphology of hysteresis loops correlate with the fatigue resistance of concrete. Additionally, it is crucial to examine what insights these observations provide into the physical mechanisms underlying damage initiation and progression in concrete. Identifying these relationships may enable more accurate prediction of fatigue life and offer structural indicators for early damage detection.

To investigate this, fatigue tests were conducted on concrete specimens at various loading frequencies. During these tests, both the nonlinear acoustic parameters and the evolution of the hysteresis loops were continuously monitored. A novel aspect of the experimental approach lies in integrating principles from dynamic acoustoelastic testing (DAET) into the fatigue testing protocol. In this context, the cyclic mechanical loading imposed by the testing machine is interpreted as the "pump" wave, while ultrasonic measurements using longitudinal (P) and shear (S) waves function as the "probe" waves. This method facilitates the measurement of acoustic nonlinearity during fatigue degradation. Additional standalone acoustoelastic tests were carried out to validate and compare the evolution of the nonlinear parameters under quasi-static, non-fatigue conditions.

The experimental results show that the fatigue loading frequency significantly affects both the trajectory of nonlinear parameter evolution and the shape of the hysteresis loops. Specimens subjected to the same loading amplitude but different frequencies displayed distinct nonlinear responses and damage accumulation paths. These findings suggest that frequency influences not only the rate of fatigue damage progression but also the dominant underlying damage mechanisms. Based on the experimental results, we propose a physical interpretation model that links the measured nonlinear acoustic parameters to microstructural changes induced by fatigue.

The measured data demonstrate that loading frequency is a critical factor in determining the fatigue resistance of concrete. Furthermore, nonlinear acoustic parameters provide valuable insight into the damage evolution process. The observed correlation between frequency, hysteretic behavior, and nonlinear elasticity supports the use of acoustic nonlinearity as a sensitive damage indicator for fatigue assessment. A better understanding of how concrete responds to different loading frequencies can also contribute to the development of more fatigue-resistant concrete mixes.

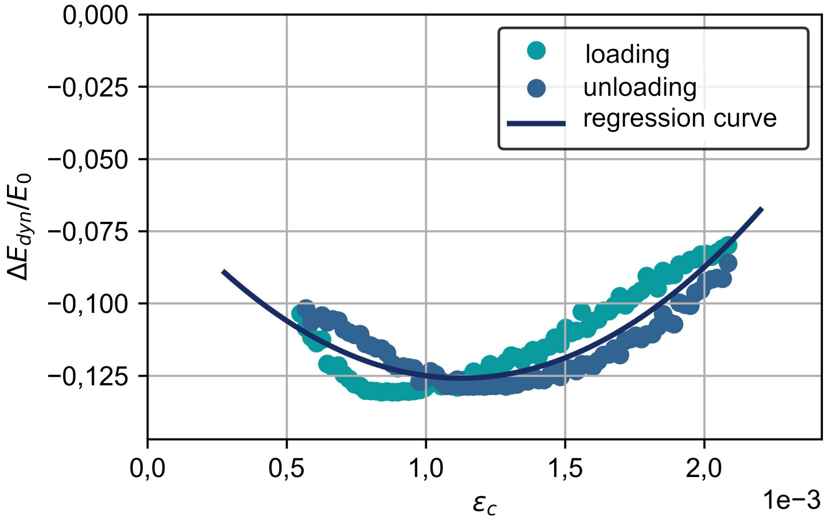

Figure 1: Hystertic loop for a specimen after 1 Million load cycles at a stress level Sc,min/Sc,max = 0,05/0,65 and a loading frequency of 7 Hz.

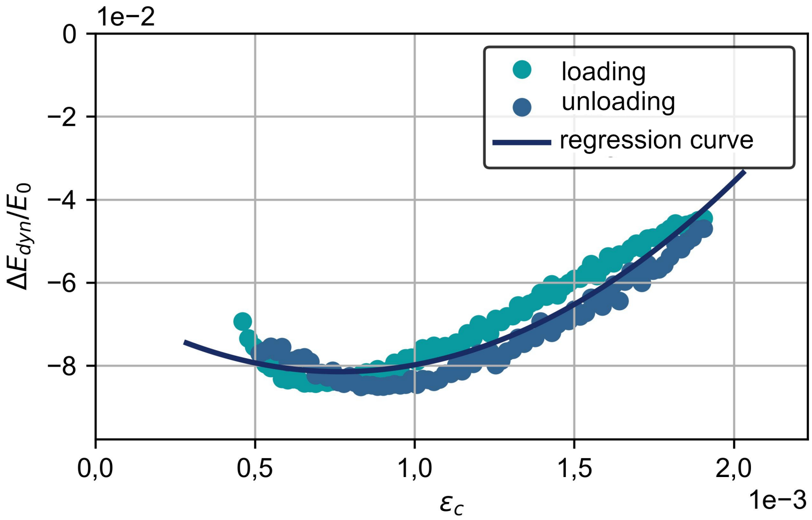

Figure 2: Hysteretic loop for a specimen after 1 Million load cycles at a stress level Sc,min/Sc,max = 0,05/0,65 and a loading frequency of 5 Hz.

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