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DETECTING FREEZING AND THAWING DAMAGE IN CONCRETE USING SIGNAL ENERGY

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ABSTRACT

An experimental program was developed to detect freezing and thawing damage in Portland cement concrete using ultrasonic waves. The ultrasonic measurements were conducted, using the indirect method, at 54 kHz. Signal energy of ultrasonic waves was found more sensitive than ultrasonic wave velocity in detection of freezing and thawing damage at initial stage. However, ultrasonic wave velocity was found more sensitive when the damage is severe. Variations in the power spectra were also used to indicate freezing and thawing damage. © *1998 Elsevier Science Ltd*

Introduction

This paper focuses on detecting freezing and thawing damage in Portland cement concrete using signal energy of ultrasonic waves. Freezing and thawing damage is one of the major problems of concrete in cold climates. Cracking and spalling are the most common results of freezing and thawing damage in concrete (1,2). The most common method of assessing concrete deterioration caused by freezing and thawing is to measure the change in the flexural dynamic modulus of elasticity (3,4). However, this technique is usually used on laboratory specimens. The present research introduces a new parameter, which is the signal energy to detect freezing and thawing deterioration in concrete. Results may be used for an early detection of freezing and thawing deterioration in concrete. This may save a lot of money in maintenance and repair operations. The signal energy introduced in the study may be defined by Equation 1 (5):

$$SE = T \sum A^2 \tag{1}$$

where SE = Signal energy, volt^2·s; T = Time interval of the digitized signal, s; and A = Amplitude of the digitized signal; volt.

The signal energy was used earlier (6,7) to detect alkali-silica reaction and basic properties of concrete. The results showed that the signal energy is more sensitive to variations in strain levels, caused by alkali-silica reaction deterioration, than ultrasonic wave velocity, especially when the strain levels are low. In this study, the signal energy is used to detect freezing and thawing damage in concrete.

Experimental Program

Sample Preparation

Limestone aggregate, obtained from Bluefield, West Virginia, was used in the study. The maximum aggregate size was 25 mm, while the fine aggregate was grade A in accordance with Virginia Department of Transportation specifications. Fresh concrete was cast in 70 × 100 × 400-mm beams. After the required curing period, concrete specimens were placed in the freezing and thawing machine which operates at 6 cycles per day with a temperature ranging from −17.8 to +5.6°C in accordance with ASTM C 666 testing specifications. Specimens were removed from the freezing and thawing machine after each 20 cycles and placed in the curing room for 24 h before measurements were taken. This step was essential to make sure that all ice inside the concrete pores had melted completely.

Equipment

The ultrasonic equipment used in the study consisted of a pulser/receiver model C-4902 “V-Meter.” The system generates and receives ultrasonic waves and has a LCD screen showing the time of flight, and a pair of transducers having a diameter of 5 cm each driven by 54 kHz signal pulses. Wavefoms were captured by a Tektronix 7854 digital oscilloscope with a sampling frequency of 512 kHz connected by a parallel port to a PC to transfer the digitized signals.

Measuring Technique

The indirect method, due to its applicability in the field, was chosen to be used in taking ultrasonic measurements. To ensure uniform and constant pressure between the transducer

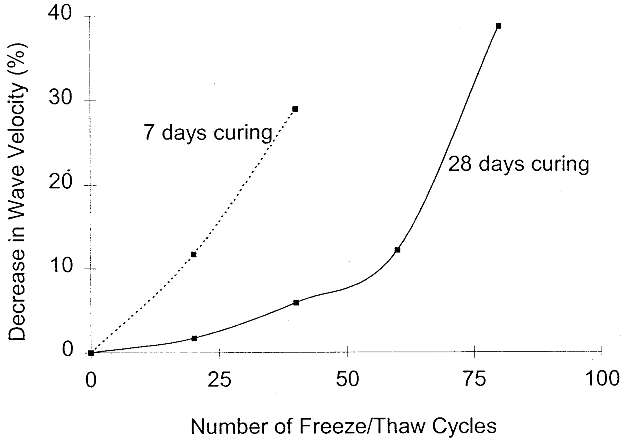


FIG. 1.
Decrease in ultrasonic wave velocity with number of freeze/thaw cycles.

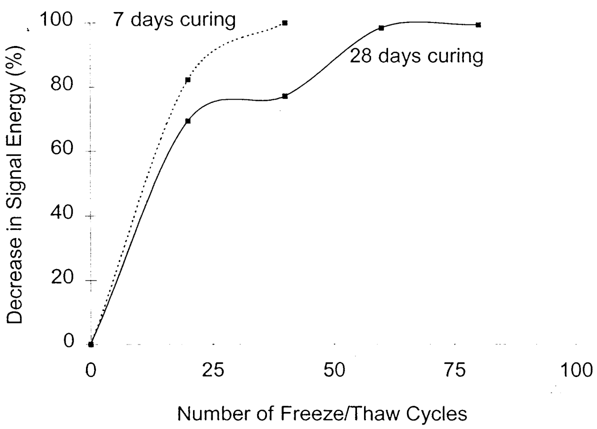


FIG. 2.
Decrease in signal energy with number of freeze/thaw cycles.

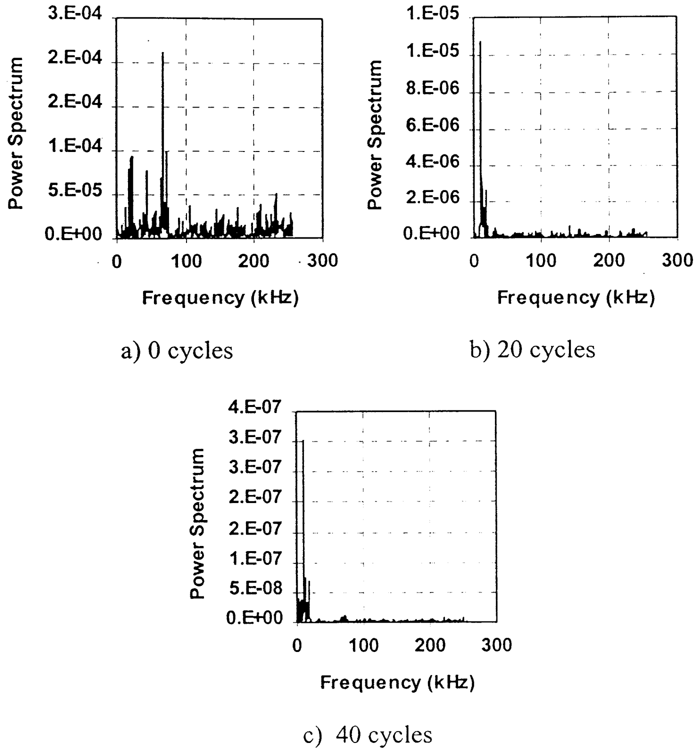
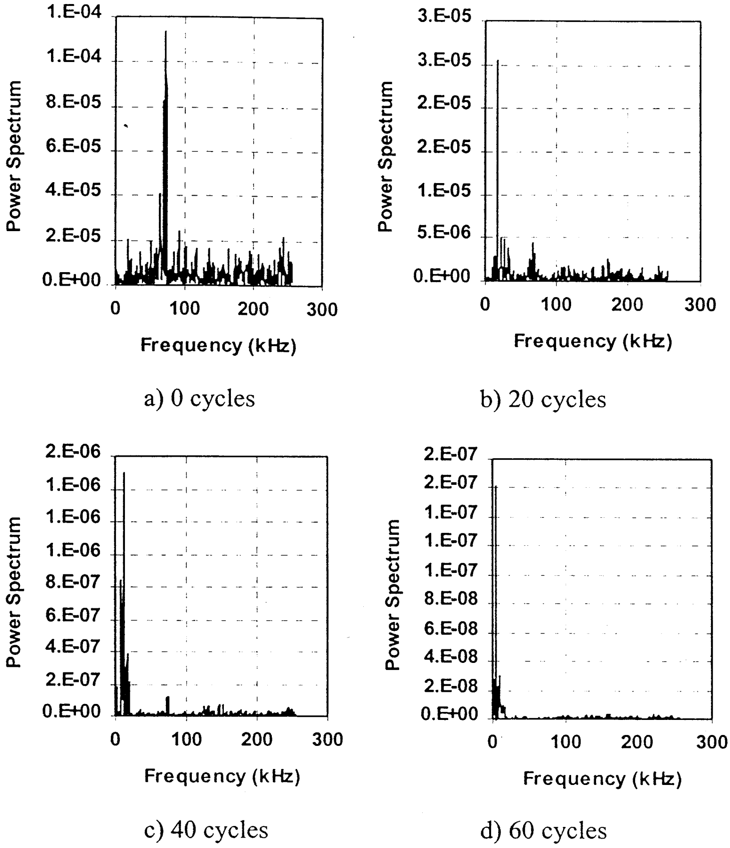


FIG. 3.
Power spectra for concrete specimens exposed to freezing and thawing cycles after 7 days of moist curing.



a) 0 cycles

b) 20 cycles

c) 40 cycles

d) 60 cycles

FIG. 4.
Power spectra for concrete specimens exposed to freezing and thawing cycles after 28 days of moist curing.

and the concrete specimen surface, a constant load of 2 kg was placed on the transducer. The transmitter was placed at 5 cm from the edge of the concrete specimen and the receiver at 10, 15, 20, 25, and 30 cm from the transmitter. For each distance between transmitter and receiver, the time of flight of the ultrasonic waves was recorded. The wave velocity was calculated from the slope of the linear regressing line between the distance between transmitter and receiver, and the time of flight.

Results and Discussion

Fisher's least significant difference test (8), based on a 95% confidence, was used in the study to detect any significant difference for the effect of number of freezing and thawing cycles on ultrasonic wave velocity and signal energy. It was found that the ultrasonic wave velocity and signal energy decreased significantly with the number of freezing and thawing cycles as shown in Figures 1 and 2, respectively. Furthermore, it was noticed that ultrasonic wave velocity did not detect any significant difference with the number of freezing and thawing cycles at early stage of freezing and thawing. It appears that ultrasonic wave velocity is not sensitive to early damage in concrete caused by freezing and thawing; however, it is sensitive to appreciable damage caused at a later stage.

Signal energy, on the other hand, detected significant differences during initial damage. However, at a high number of freezing and thawing cycles, when the specimen approaches failure, the signal energy did not detect any significant increase in damage. A large drop in the signal energy was noticed after the first 20 cycles, and after that the signal energy decreased almost steadily. This shows that initial deterioration in concrete caused by freezing and thawing cycles may cause a great reduction in the signal energy.

More information about the signal energy can be obtained from the measurements of the distribution of power among the frequency components of the fluctuating signal. Such a distribution is obtained from the auto-power spectra. Figures 3 and 4 show the auto-power spectra of the ultrasonic signal for concrete specimens exposed to freezing and thawing cycles after 7 and 28 days of moist curing, respectively. It is obvious that the energy of the signal at all frequencies decreased as the number of freezing and thawing cycles increased. Of more interest is the fact that the increase in the number of freezing and thawing cycles is accompanied by a decrease in the frequency of the component that contains most of the energy. For concrete specimens exposed to freezing and thawing cycles after 7 days of moist curing and before exposing the concrete specimens to freezing and thawing cycles, most of the energy is contained in a band of frequencies around 65 kHz. After 20 cycles of freezing and thawing, most of the energy is contained around 15 kHz. After 40 cycles of freezing and thawing, most of the energy is contained near 15 kHz. For concrete specimens exposed to freezing and thawing after 28 days of curing and before exposing the concrete specimens to freezing and thawing, most of the energy is contained in a band of frequencies around 80 kHz. After 20 cycles of freezing and thawing, most of the energy is contained around 20 kHz. After 40 cycles of freezing and thawing, most of the energy is contained around 15 kHz. Finally, after 60 cycles of freezing and thawing, most of the energy is around 10 kHz. Thus, the auto-power spectra show that the decrease in signal energy is accompanied by a decrease in the frequency of energy-containing components.

Conclusion

Ultrasonic wave velocity, signal energy, and auto-power spectra were used to detect freezing and thawing deterioration in concrete. The results show that ultrasonic wave velocity is not sensitive to early damage in concrete caused by freezing and thawing; however, it is sensitive to appreciable damage caused at a later stage. On the other hand, signal energy detected a significant difference at initial damage caused by freezing and thawing. The auto-power spectra show that the decrease in signal energy is accompanied by a decrease in the frequency of energy-containing components.

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