Non-Linear Ultrasonic Test for Fiber-Reinforced Concrete using 3rd Harmonic Generation

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Summary

This paper presents non-linear ultrasonic behavior observed in ultrasonic transmission test for fiber-reinforced concrete cubes 150mm x 150mm x 150mm with three water-cement ratios 40%, 50% and 60%. The fibers used were short steel fibers having 1% volumetric ratio. Modes of failure were documented using pictures to relate the behavior of the 3rd harmonic amplitude as load patterns were varied. The normalized 3rd harmonic generation were generated thru Fast Fourier Transform FFT frequency spectra and normalizing it at fundamental frequency of 100kHz. The difference (3rd harmonic dB difference) from each varying step load for the 3rd harmonic amplitude and baseline of zero load's 3rd harmonic amplitude were analyzed. Categorization of modes of failure was done to generalize the behavior of 3rd harmonic dB difference according to the step load pattern. The satisfactory mode of failure produced similar pattern with respect to the step load variation. The 3rd harmonic dB difference increases as load increases, and decreases when the load decreases.

Keywords: Non-destructive testing in concrete; Non-linear ultrasonic test in concrete

1. Introduction

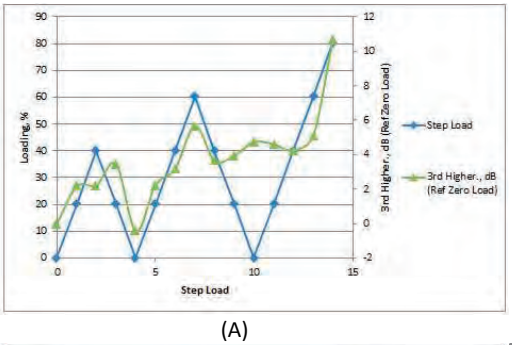
Concrete has been predominant in structures. From the changes due to natural disasters, non-destructive inspection should be done to check the structural integrity of the concrete structure. Unlike other materials, concrete is complex. There were a lot of linear ultrasonic testing procedures in concrete from the past. Combination of linear ultrasonic test using ultrasonic pulse velocity (UPV) and rebound hammer was introduced to test on site strength of concrete. For the aforementioned methods, non-linear ultrasonic provides promising development due to its sensitivity in crack detection and damage growth. Studies in non-linear ultrasonic waves proved to be sensitively interact with contact-type defects. This includes the opening and closing of cracks formed when loading and unloading occurs.

Ultrasonic waves passing thru damaged concrete interacts with micro cracks that result to generation of higher harmonics. In particular, harmonic ratio generated from damaged concrete was sensitive to micro structural changes and micro-cracking in the interfacial transition zone. Variation of concrete mixture also influences the generation of higher harmonics. Increase in water-cement ratio in concrete proved to be increasing with the non-linear parameter. Third harmonic ratio was sensitive compared to the 2nd harmonic ratio. Defect detection using 3rd harmonic generation were sensitive to damage.

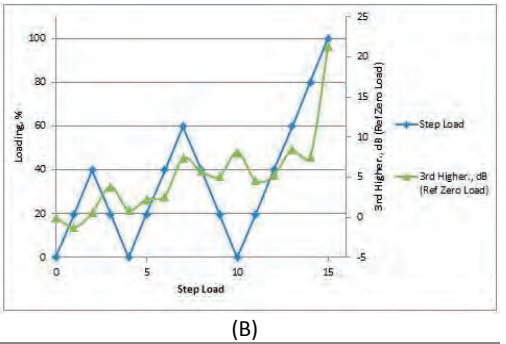
Third harmonic dB difference was sensitive to the changing loads when the concrete cubes were categorized having satisfactory failure.

2. Results and Discussions

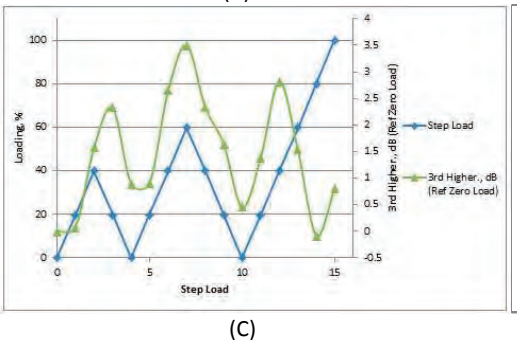
Shown below, the 3rd harmonic dB differences from the baseline values' ranges were different for each water cement ratio. The water cement ratio of 60% provided wider range from (-) 0.44dB to 10.68dB and (-)1.26dB to 21.45dB respectively. While the water cement ratio of 50% and 40% provided smaller range from (-)0.08dB to 3.5dB and (-)2.85dB to 2.98dB. This shows that the non-linear interaction between the ultrasonic waves and the damaged concrete varies with respect to the mechanical properties like stress-strain diagram. Higher generation of 3rd harmonic dB difference occurred in concretes having water-cement ratio of 60%, which may mean that higher water-cement ratio provides higher order non-linear elastic constants when defects occur. In addition, it exhibits evident behavior of ultrasonic waves passing thru the medium which experiences opening and closing of cracks, or stick and slide mode during loading and unloading respectively.



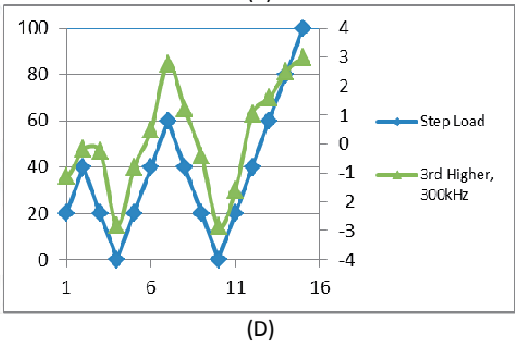
(A)



(B)



(C)



(D)

(A) WC60% Specimen#1.(B) WC60% Specimen#2.
(C) WC50% Specimen#3. (D) WC40% Specimen#1

3. Conclusions

The concrete cubes tested were classified into two modes of failure – satisfactory and unsatisfactory. For the satisfactory mode of failure, clapping motion of cracks and/or frictional forces was experienced. It shows good sensitivity to the changing load. When load increases, the 3rd harmonic difference increases, when load decreases, the 3rd harmonic difference decreases.