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Numerical study on the mechanism of active interfacial debonding detection for rectangular CFSTs based on wavelet packet analysis with piezoceramics

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ABSTRACT

In recent years, Piezoelectric Lead Zirconate Titanate (PZT) based active interfacial debonding defect detection approach for concrete-filled steel tubular (CFST) columns has been proposed and validated experimentally. In order to investigate the mechanism of the PZT based interfacial debonding detection approach, a multi-physics coupling finite element model (FEM) composed of surface-mounted PZT actuator, embedded PZT sensor and a rectangular CFST column is constructed to numerically simulate the stress wave propagation induced by the surface-mounted PZT actuator under different excitation signals with different frequency and amplitude. The measurements of the embedded PZT sensor in concrete core of the CFST columns with different interfacial debonding defect lengths and depths are determined numerically with transient dynamic analysis. The linearity between the PZT response and the input amplitude, the effect of different frequency and measurement distance are discussed and the stress wave fields of CFST members without and with interface debonding defects are compared. Then, the response of the embedded PZT in concrete core is analyzed with wavelet packet analysis. The root mean square deviation (RMSD) of wavelet packet energy spectrum of the PZT measurement is employed as an evaluation index for the interfacial debonding detection. The results showed that the defined index under continuous sinusoidal and sweep frequency signals changes with the interfacial defects length and depth and is capable of effectively identifying the interfacial debonding defect between the concrete core and the steel tubular. Moreover, the index under sweep frequency signal is more sensitive to the interfacial debonding. The simulation results indicate that the interfacial debonding defect leads to the changes in the propagation path, travel time and the magnitude of stress waves. The simulation results meet the findings from the previous experimental study by the authors and help understand the mechanism of interfacial debonding defect detection for CFSTs using PZT technology.

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1. Introduction

Owing to the advantages including high load-carrying capability, stiffness and good ductility under strong dynamic excitations including earthquakes, convenience in construction, concrete filled steel tubular(CFST) columns with large cross section have been widely adopted in civil infrastructures, such as ultra high-rise buildings, large-span bridges, metro stations, industrial plants, and harbor engineering as vertical load-carrying members. With the increasing need in load-carrying capability, the cross section area of CFST members also increases extremely in some high-rise buildings [1]. For example, a mega-column in the Tianjin Goldin 117 Building in China with a design height of 597 m is a six-sided multi-chamber CFST polygon column with a cross sectional area of about 45 m^2 at the bottom of the building [2]. However, due to the obvious non-uniform distribution of temperature in concrete during hydration and hardening, shrinkage and creep effects of the concrete core, and the existence of horizontal diaphragm, interfacial debonding between steel tubular and concrete core occurs possibly. Therefore, there are common concerns on the interface condition between steel tubular and concrete core because the debonding between them will weaken the confinement effect of the steel tubular on the concrete core. It may finally decrease the load-carrying capacity and the ductility of the CFST members. Hence, the monitoring and evaluation approach for the interface debonding defect of CFST members is of great significance.

The development of reliable interface debonding monitoring techniques and concrete qualify evaluation for CFST members have received extensive attention in recent years especially in China where a large number of skyscrapers employing CFST members have been under construction. The detection approach for CFST interface debonding is still a challenging task because it is usually unobservable and cannot be accessed directly. Conventional nondestructive testing technologies (NDT) such as electromagnetic (EM) methods have been rapidly developed for the interface debonding detection for fiber reinforced polymer (FRP)-jacketed reinforced concrete structures [3]. Büyüköztürk and Yu reviewed the inspection for debonding using NDT techniques for FRP-strengthened or FRP-wrapped reinforced concrete structures [4]. In order to “see through” the FRP layer various NDT techniques have been developed, including acoustic emission, ultrasonic, infrared thermography, X-ray, and radar/microwave techniques. It is known that EM waves cannot penetrate metallic media and attenuate obviously in conductive media. Therefore, EM wave approach cannot be used for the debonding detection of CFST members because of the electromagnetic shielding effect of the outside steel tubular. Replacing the EM wave, stress wave based damage detection approach using Piezoelectric Lead Zirconate Titanate (PZT) is an alternative for the debonding detection of CFST members. PZT-based approach has been widely recognized as one of the most promising active structural health monitoring(SHM) techniques for engineering structures in recent years [5–7]. Xu et al.. successfully proposed PZT-based technique in the detection and monitoring of interfacial debonding in steel-concrete composite girders and CFST members and validated them experimentally [1,8,9]. The experimental results showed that the active detection technology based on piezoelectric technology can effectively identify the interfacial debonding defect between steel tubular and concrete core of CFST members [1,8]. A index called as weighted variation of wavelet packet energy spectrum (WVWPES) and an evaluation index based on the wavelet packet energy were defined respectively to achieve the debonding defects detection in the previous studies [1,8]. The major objective of this study is to investigate the mechanism of the proposed interface debonding defect detection approaches proposed by Xu et al.. with a multi-physics coupling finite element model (FEM) composed of surface-mounted PZT actuator, embedded PZT sensor and a rectangular CFST column considering the coupling effect between the PZT actuator and sensor and the CFST member [1,8]. Moreover, different from the damage evaluation indices employed in previous studies described in [1,8], the root mean square deviation (RMSD) of wavelet packet energy spectrum (WPES) of the PZT measurement is employed as an evaluation index for the interfacial debonding detection. The active interfacial debonding defect detecting and monitoring system based on the PZT wave propagation method is shown in Fig. 1.

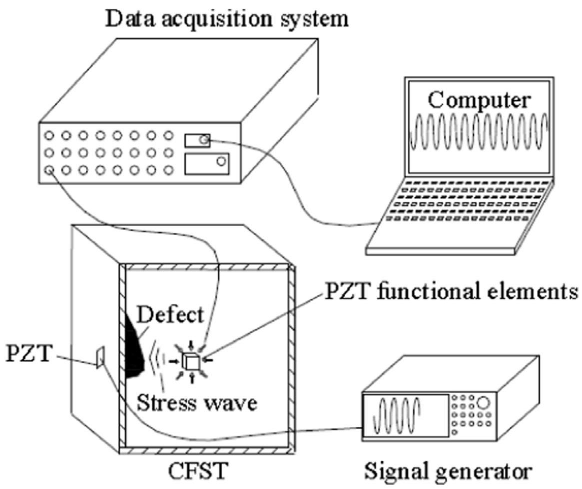

Fig. 1. The active monitoring system based on the PZT.