Local Interfacial Damage Identification of Grouted Rock Bolt Anchorage Based on Piezoceramic Wave Method

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ABSTRACT

Grouted rock bolts (GRBs) are widely used in geotechnical engineering and underground structures. However, the problem of health monitoring and damage identification (DI) for anchorages of GRBs has not been well resolved. A research on local interfacial anchorage identification of GRBs is performed in the paper, aiming at proposing a local interfacial damage identification method based on longitudinal piezoelectric ultrasonic guided wave (UGW) echo technology. The proposed method not only reveals wave propagation behaviors of UGW propagation in the structure, but also quantitatively represents the relationship between the echo signal energy and the characteristics of damages. Dispersion characteristics, radial distribution and propagation energy attenuation characteristics of UGWs in a multi-layer cylindrical structure are studied. A model test is carried out to investigate the influence of local interfacial anchorage characteristic changes such as different damage lengths and levels on propagation characteristics of the UGW, and a DI method based on the change of the UGW energy is proposed. Through finite element analysis (FEA), the quantitative relationship between parameters of material and geometric characteristics as well as properties of the excitation signal and received signal is studied. The results show that the energy of the echo longitudinal UGW is changed to a certain extent due to the local interfacial anchorage damage, and the greater damage range and level result in the smaller energy value of the echo signal and the greater value of the damage index.

KEY WORDS: Grouted rock bolts (GRBs); local interfacial damage identification; piezoceramic-based ultrasonic guided waves (UGWs); impulse echo signals; signal frequency dispersion properties.

INTRODUCTION

Grouted rock anchor system (referred to as an anchor system) is widely used in construction projects such as coal mining, highway and railway tunnels, subways, deep foundation pits, and high slope maintenance, etc. Grouted rock bolt (GRB) method is one of the typical grouted rock anchor systems. There are many factors that affect the mechanical performance of the anchor system, such as geotechnical engineering conditions, the design of the anchor structure, the interaction between the anchor system and the surrounding rock system, construction, professional technical level and experience, etc. In addition, the construction of the anchor system is highly concealed which is difficult to find quality problems, and the accident may be catastrophic if it happened. Therefore, the real-time, rapid and non-destructive testing of the anchoring quality of the anchor system has become an important issue to be solved urgently (Liew and Long, 2006; Yelp, Alcala and Pereda, 2008; Wang and Wang, 2001).

As a new type of non-destructive testing (NDT) technology, the guided wave technology can be applied to the detection of anchoring quality of anchor system (Madenga, Zou and Zhang, 2006). Guided waves are waves that propagate in a medium with a certain boundary. Guided waves can propagate in many kinds of waveguides including thin plates, rods, tubes, and multilayered structures. In this case the ultrasonic waves reflect back and forth inside the waveguide, leading to interference phenomena (Rose, 2014). Since anchors are a structural system with special boundary conditions, elastic waves that propagate in the anchor system can be considered as guided waves (Li, Gan and Zhu, 2003). When the frequency of the wave is greater than 20 kHz, the guided wave propagating in the waveguide is usually named UGW. One of the NDT characteristics of UGWs is using a small number of sensors to perform a large-scale and long-distance detection on the structure and detecting defects at different positions on the full cross-section of the structure (Sun and Zhu, 2017; Wang and Liu, 2006; Auyeung, Balaguer and Chung, 2000). Health assessment of structures based on UGWs can be performed at different excitation frequencies by selecting suitable singles or multiple modalities (Zou and Cui, 2011; Cui and Zou, 2012). Piezoelectric ceramic materials as actuators and sensors (transducers) can be widely used in structural NDT; its advantages are large coupling coefficient, fast response, strong piezoelectricity, and low cost (Zheng, Xiao and Xia, 2003). Lead zirconate titanate (PZT) as a typical piezoelectric ceramic material is used for producing piezoelectric components, and PZT-based transducers are applied in this paper to produce UGWs for the interfacial DI of the GRB system.

Because the anchor system is usually considered as a three-layer columnar structure, it is easy to cause adhesion failure at the contact surfaces of different materials, especially the interface separation