Safety Science 50 (2012) 783–786

Contents lists available at SciVerse ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Special Issue Article: The First International Symposium on Mine Safety Science and Engineering

Experimental study on non-destructive testing of rock bolts based on pseudo-random signal ☆

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ARTICLE INFO

Article history:
Available online 9 September 2011

Keywords:
Pseudo-random signal
Rock bolts
Non-destructive testing
Correlation analysis

ABSTRACT

The quality of rock bolt anchoring is closely related to the stability and safety of underground engineering and slope protection. In this paper, non-destructive testing of rock bolts is proposed based on pseudo-random signal, owing to the deficiencies of the conventional detecting method of stress wave reflection. The characteristics of pseudo-random signal for non-destructive testing of rock bolts are introduced. And the rock bolts are tested in the experiment, the time of reflection wave is identified and the length of rock bolts is calculated through cross correlation analysis between the extracted wavelet signal and the test signal. It is proved that the testing results of non-destructive testing methods based on pseudo-random signal are of low deviation. The experiment has shown that non-destructive testing of rock bolts based on pseudo-random signal is feasible with high precision.

1. Introduction

The rock bolt anchoring has been applied in underground engineering and slope protection to ensure its stability and safety, and widely used in mines, hydropower, highways, railways and other geotechnical engineering constructions. Therefore, the efficient and accurate detection of rock bolt anchoring is relevant to the safety of underground engineering. Thus, the non-destructive testing of rock bolts is important and meaningful in underground and slope building. At present, the testing method of non-destructive testing of rock bolts is stress wave method, including ultrasonic method (ultrasonic waves, guided ultrasonic waves) and acoustic stress wave method. Ultrasonic method is mainly for experimental study (Beard and Lowe, 2003; He et al., 2006; Madenga et al., 2006; Zou et al., 2010). The acoustic stress wave method is the major one in the non-destructive testing on the quality of rock bolts anchoring. It is theoretically based on the small strain dynamic testing pile technology. This method has been widely used in the engineering prospecting in China and abroad. Many researchers made intensive studies and achieved promising results (Li and Wang, 2000; Wang and Wang, 2001; Zhu et al., 2002; Zhang et al., 2006; Madenga et al., 2006). However, the study of non-destructive testing in the system of rock bolts anchoring is still at the stage of exploration and the testing results are, to some extent, unsatisfactory. The means of excited signal source and identification of reflection wave still need further research.

Therefore, in this paper the non-destructive testing of rock bolts is proposed based on pseudo-random signal for experimental study. Correlation analysis and other signal processing methods are applied to analyse the testing signals to find a feasible method for exploring rock bolts and provide theoretical foundation for the non-destructive testing of rock bolts quality.

2. Pseudo-random signal and its characteristics

Pseudo-random signals are produced with hammers of different materials striking the end of rock bolt. With different strength and signal frequency in each striking by different hammers, different pseudo-random signals in the rock bolts are produced. It is called

☆ The First International Symposium on Mine Safety Science and Engineering (ISMSSE2011) will be held in Beijing on October 26–29, 2011. The symposium is authorized by the State Administration of Work Safety and is sponsored by China Academy of Safety Science & Technology (CASST), China University of Mining & Technology (Beijing) (CUMTB), Datong Coal Mine Group, McGill University (Canada) and University of Wollongong (Australia) with participation from several other universities from round the world, research institutes, professional associations and large enterprises. The topics will focus on mines safety field: theory on mine safety science and engineering technology, coal mine safety science & engineering technology, metal and nonmetal mines safety science & engineering technology, petroleum and natural gas exploitation safety science & engineering technology, mine safety management and safety standardization science & technology, occupational health and safety in mine, emergent rescue engineering technology in mine, etc.

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doi:10.1016/j.ssci.2011.08.034

pseudo-random signal mainly because it is seemingly random and irregular, but actually regular for parts of the signals. Its characteristics are as follows:

- First, it is not completely, but approximately random.
- Second, it is a signal in between standard signal and random signal. It seems irregular, but actually with its specific rules. To be exact, this is a statistical rule obtained from massive observations and analyses.
- Third, it cannot be described with a certain mathematical relationship or repeated by experiments.
- Fourth, it is sampling results of continuous random signals, and the signals are discrete.

3. Experimental test

Hammers of different materials are used as excitation wave sources in testing rock bolts based on pseudo-random signal. A pseudo-random signal is excited at the end of rock bolts. The effect of pseudo-random signal test could be verified by analysing test signals.

3.1. Experimental device

WYS-EGS06 rock bolt testing instrument and SD1409-type three-component sensor are used in experiments. The charge sensitivity of the latter is 3.0 PC/ms^{-2}, frequency range 0.3–4 kHz, resonant frequency 13 kHz, and with three-dimension vibration characteristics. Three components correspond to the *x*-axis, *y*-axis, and *z*-axis which are perpendicular to each other in three directions, each component receiving signals from each direction. Three hammers of different materials are an iron hammer, an ebonite hammer and an aluminium hammer. The rock bolt is spiral steel, 1800 mm in length and 20 mm in diameter.

3.2. Test method

According to hammer percussion position and sensor location, the test uses tip sending and tip receiving, with three different hammers striking the end of the rock bolt respectively and randomly. The instrument could record a waveform with each striking. The schematic diagram of testing methods is shown in Fig. 3.1.

In the testing process, the following aspects should be noted:

- First, keep the sensor axis parallel to the rock bolt axis.
- Second, use silica gel coupling to ensure coupling between the sensor and the end of rock bolt, and it proves effective.

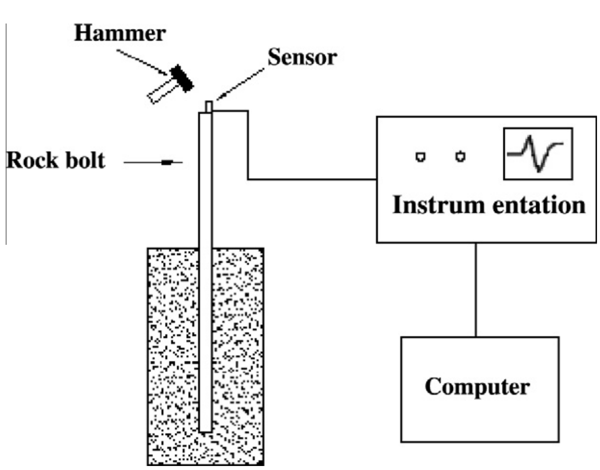

Fig. 3.1. Arrangement diagram of rock bolts testing.

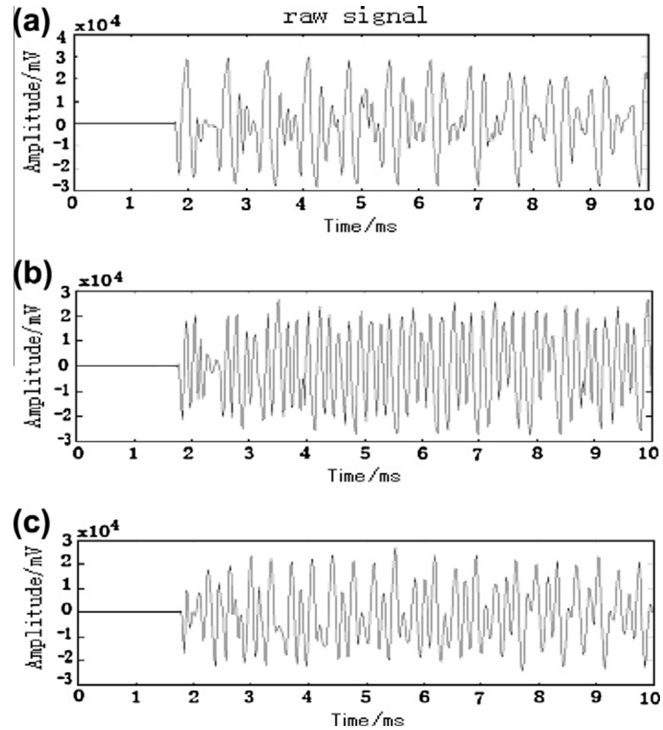

Fig. 3.2. Signal (a), (b), (c) respectively excited by iron hammer, aluminium hammer and ebonite hammer.

- Third, the quality of the first pulse has a direct impact on testing results. The good first pulse can be obtained the following way: the coupling of the sensor must be of high quality without reducing its work frequency. At the same time, the hammer should be dropped on the real point in the percussion and neat striking contributes to a stable waveform.
- Fourth, for the stimulation randomness, the excitation test should be repeated many times to record the reliable receptions.

3.3. The waveform of test signal

Multiple sets of test data were acquired by striking with hammers of different materials to stimulate pseudo-random signal in the experiment. The instrument recorded 2048 sampling points, with sampling frequency 44.1 kHz, and the signal waveform diagram of rock bolt testing is shown in Fig. 3.2.

4. Test signal analyses

By using Matlab program and correlation analysis, reflection time was acquired. The picked wavelet from random signals

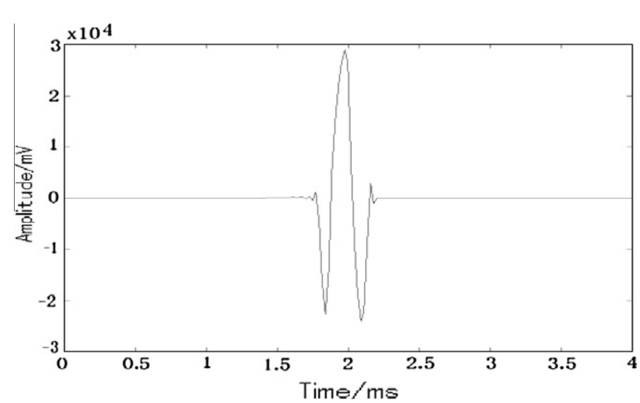

Fig. 3.3. The picked wavelet signal excited by iron hammer.