Study on Signal Processing of IES of Tunnel Lining Based on Wavelet Analysis

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Abstract. As we all know, high-speed rail is a very important business card in China, and the rapid development of high-speed rail is inseparable from the rapid development of tunnel construction, so tunnel construction has become very important. The quality of the tunnel lining directly affects the construction quality of the entire tunnel construction. This paper first introduces the use of IES, one of the most advanced testing methods for non-destructive testing, to achieve non-destructive testing the quality of tunnel lining. The signal is more or less affected by the surrounding environment and human factors, so In this paper, wavelet analysis is used to eliminate the signal noise, so as to more effectively diagnose the defects of tunnel lining and realize the intelligent diagnosis of the defects of tunnel lining.

1. Introduction
With the rapid economic development, the infrastructure construction is playing an increasingly important supporting role, and the high-speed railway has become a business card of China. The quality of tunnel lining plays an important role in tunnel construction. Therefore, it is very important and necessary to seek a safe, reliable, time-saving and convenient non-destructive testing technology. Based on such conditions, the method of IES (Impact Echo Scanner) came into being, which is one of the most advanced testing methods for non-destructive testing. IES is mainly used to continuously and quickly test the thickness and defects of concrete slabs, concrete pavements, tunnel linings, and other concrete structures. It can perform two-dimensional and three-dimensional imaging of thickness and defects, but the test is often interfered by the surrounding environment or human factors, so this paper proposes to use wavelet analysis to eliminate the signal noise, so as to more effectively diagnose the quality of the tunnel lining[1-2].

2. Experimental research
2.1. IES Instrument
IES instrument as shown in Figure 1 is currently the most advanced shock echo tester, which was first successfully developed by Olson company in the United States. In addition to having all the functions of a general shock echo instrument, it not only speeds up the test speed and reduces labor, but also adds many new functions, such as two-dimensional and three-dimensional imaging of concrete thickness changes.
2.2. The test principle of IES
When a small vibrator is used as an excitation source to impact on the concrete surface to generate a
stress wave, then a receiving sensor placed near the vibrator receives the reflected compression wave.
After the host computer analyzes, it is used to calculate the thickness of concrete and detect internal
holes, cracks, peeling and other defects. This project uses the IES Instrument, as shown in Figure 2. It
adopts an original rolling sensor or automatic impact, which only needs to be tested while walking at a
slower walking speed. It can scan and test the internal defects of various structures at a nearly
continuous speed.[3-4].

2.3. Specimen testing
The project is located in the Dongshan Tunnel in Zhangjiakou City, Hebei Province of China. In the
same tunnel, the testers should select two identical concrete tunnel linings as specimen specimens.
One of the specimens is an intact lining specimen, and the other is a defected lining specimen, which
has a lining defect simulated by the tester with foam before being forced.

3. Analysis of test results
3.1. The signal of the intact specimen 1
Use MATLAB wavelet analysis toolbox to load the signal of specimen 1, and use wavelet function
db5 to decompose it to the fifth layer, as shown in Figure 3. In order to remove the interference
information and obtain useful information to better reflect its essential characteristics, it should be
processed, with the appropriate threshold of 2.726. The signal of specimen 1 after processing is shown
in Figure 4[5].
The purple curve is the retained energy curve, which represents the percentage of the compressed information retained before the compression. The green curve is the zero-setting coefficient curve. The larger the zero-setting coefficient is, the greater the compression is. That is, the larger the zero-setting coefficient is, the better the compression effect is, in the case of keeping as much energy as possible after compression. It can also be seen that the green curve and the purple curve intersect at a point 1.292e+04, which is used as the optimal threshold parameter to ensure the enough useful information and enough compression. The signal comparison before and after compression is shown in Figure 5, where the red curve is the original signal, and the yellow curve is the compressed signal.

According to Figure 5, the frequency of general noise is relatively high, but the coefficients of the high frequency part are set to zero during compression, so the signal can be processed at the same time during the compression process. While retaining 95.50% of useful information, the compression is as high as 95.77%.

3.2. The signal of the defected specimen 2
The processing method to specimen 2 is the same as that of specimen 1. Load the signal of the defected specimen 2 by MATLAB wavelet analysis toolbox. Similarly wavelet function db5 can be selected to decompose to the fifth layer, as shown in Figure 6.
Perform the same processing on the signal of specimen 2 as specimen 1. In order to facilitate the comparison with specimen 1 and specimen 2, the parameters of the soft threshold and the white noise scale should be also the same, that is, the threshold value of each layer should be taken as 2.726. The signal of specimen 2 after processing can be shown in Figure 7.

As shown in Figure 8, similar to the intact tunnel lining specimen 1, the signal of the defective tunnel lining specimen 2 can be compressed by the same method. The green curve and the purple curve intersect at a point, which not only ensures that enough useful information is retained after compression, but also obtains a large amount of compression. The final selected threshold parameter is 3.835e+04.

According to Figure 8, the frequency of general noise is relatively high, but the coefficients of the high frequency part are set to zero during compression, so the signal can be processed at the same time during the compression process. While retaining 96.00% of useful information, the compression is as high as 96.24%.

3.3. Comparison of Wavelet Analysis between Specimen 1 and Specimen 2
In order to facilitate the identification of the intact tunnel lining and the defective tunnel lining, the same processing parameters are selected when their signal are used to eliminate the noise, which can obstruct the correct signal. In the subsequent compression process, due to the difference in the internal integrity between the intact tunnel lining specimen 1 and the defective tunnel lining specimen 2, the compression threshold parameters of them are very different, in order to ensure that the useful information is retained after compression and the amount of compression is so large.

As shown in Figure 5 and Figure 8, the compression threshold of the defective tunnel lining is almost 3 times that of the complete tunnel lining. It can indicate that the wavelet analysis method of the signal of the tunnel lining is suited by the compression threshold parameter to judge the integrity of the tunnel lining.

4. Conclusions
This paper uses wavelet analysis of the dynamic response signal of the tunnel lining system to find the parameters reflecting the structural system. Due to the existence of defects, certain components of the response signal in a specific frequency band can be attenuated or enhanced. Therefore, comparing the intact tunnel lining with the defective tunnel lining, their dynamic response and energy can be significantly different in some specific frequency bands. The energy of the structural vibration response signal composed of various frequencies contains enough information about structural defects,
so the energy change of one or several frequency components of the signal can predict a specific state of tunnel lining defects, so as to realize the diagnosis on the defects of tunnel lining.

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