Research on Wire-Broken Monitoring of Bridge cable based on Acoustic Emission technique

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Abstract. Acoustic emission signals generated by broken prestressed steel strand of cable can transmit up to 29.5 meters without maintaining significant attenuation of the amplitude. Therefore, the installation of a few acoustic emission sensors can comprehensively monitor the damage of the entire prestressed steel strand. Thereby, detection of unknown defects is realized, and the structural health status can be quantitatively evaluated. In this paper, the acoustic emission technology is used to test the broken wires of a concrete-filled steel tubular arch bridge. The correlation of the broken wires test results of the bridge is qualitatively analysed, including the stress state of the cable, the location of the measuring points and whether there is a PVC sheath at the measuring points. Therefore, a safe, reliable and efficient method is sought to monitor the damage status of the in-service cable-supported bridge.

1. Introduction
Acoustic emission is a stress wave in the ultrasonic (generally 20~1000KHz) frequency range generated by the release of transient energy when the material reaches micro or macroscopic damage under stress. The amplitude, energy, and count of the wave are directly related to the material defect in the propagation[1,2], and the dynamic process of the defect itself can be monitored[3,4,5]. Casey’s tests show that the acoustic emission signal generated by the broken prestressed steel strands can transmit up to 29.5 meters without maintaining a significant attenuation of the amplitude[6]. Therefore, the acoustic emission sensor with a few layouts can fully monitor the damage of the entire prestressed steel strand[7]. Thereby, the detection of unknown defects is realized, and the structural health status can be quantitatively evaluated[8,9]. Li Dong sheng et al. introduced the fractal dimension of time series fractal features into the acoustic emission monitoring of prestressed steel strand failure, and studied the acoustic emission identification technology of multi-age cable and corrosion damage[10-11].

Based on this purpose, the tensile test of prestressed steel strands is designed in this paper. The characteristic parameters of acoustic emission signals related to stress damage and fracture are obtained, which can provide relevant monitoring data for the tension of prestressed steel strands in the future.
2. Acoustic emission monitoring test scheme for stress damage of prestressed steel strands

2.1. Model Description
In this test, the sprayed prestressed steel strand is used as the test piece, and the prestressed steel strand is composed of 7 steel wires wound, the total length is 3000mm, which is passed through the connecting cylinder and the jack, and then the prestressed steel strand is clamped by the clip to perform tensioning. The test device is shown in Figure 1. The acoustic emission sensor is arranged on the anchors at both ends, wherein the sensors 1 and 2 are at the right chuck; the 3rd and 4th channels are at the left chuck, as shown in picture 2.

Figure 1. Photo of the test machine
Figure 2. Anchorage and sensor

The line positioning technology is used to determine the position of the broken wire. The specific acoustic emission parameters are set as follows: the center frequency of the sensor is 150kHz. The gain of the preamplifier is 40 dB. The filtering frequency is 100–600 kHz, and the system threshold first tests the ambient noise level. The noise level was found to be below 45 dB, so the threshold was set to 45 dB and the main gain was 20dB. Impact signal timing parameter setting: peak definition time PDT is 300μs, impact definition time is 600μs, and impact lock time is 1000μs. This test uses acoustic emission parameter analysis methods to reveal the acoustic emission characteristics of steel strand damage. The test was carried out in ten stages by loading 40kN per step. When loading to 400kN, it is considered that the prestressed steel strand has no working ability and the acoustic emission monitoring is carried out in the whole process.

2.2. Attenuation and coupling test
Before the test begins, the test device and the acquisition device are first subjected to signal attenuation test. With the centre punch, the impact is three times on the left side of the prestressed steel strand near the 3rd and 4th channels, and the amplitude of the received signal is compared with the acoustic emission channel. After comparison, the signal attenuation is small. The sensor and test device have been arranged reasonably to meet the test conditions. The result is shown in Figure 3 below:

(a)
(b)
2.3. Prestressed stranded wire breaking test

Damage monitoring of prestressed steel strands is the most important purpose of applying acoustic emission technology. In order to quantify the damage process, the most appropriate parameter analysis method is related-point-graph analysis method.

In order to judge the degree of damage of the broken wire, the broken wire factor diagram is used to monitor the breakage of the prestressed steel strand during the loading process. When the test is carried out to 750s, the remaining six wires are broken except only the one in the center remained intact. The break position is at the right chuck. During the 700 seconds monitoring period, the noise levels included due to tension and friction between the wire and the clamp during stretching continue to present low signal levels. However, at the moment when the prestressed steel strand is broken, the breaking factor is increased by at least two orders of magnitude.

In order to judge the position of the broken wire, the acoustic emission linear positioning method is used to predict the fracture position of the prestressed steel strand. The position of the source determined by it is on the line or arc of the line connecting the two transducers. The positional coordinates of the acoustic emission source $P(x)$ can be determined by the following formula (1):

$$P(x) = \text{sgn}(u(\Delta t)) \cdot \frac{\Delta t}{2} \cdot v$$

Where $\text{sgn}(\Delta t)$ is the sign function; $\Delta t$ is the time difference between the arrival of the two transducers; $v$ is the speed of sound. The acoustic emission location map is shown in Figure 5:

Figure 4. Location map(The red column position in the figure is the fracture position of the software.)

Figure 4 shows the positioning of the broken wire, wherein Figure 4(a) shows the number of positioning and the positioning position, that is, the positioning occurs at the sensors 1 and 2 near the right. Since the six broken wires are simultaneous, the number of times of positioning is one. Figure 4(b) shows the time and location of the positioning, that is, the broken wire occurs 750 seconds after the start of monitoring, and its position is close to 1st, 2nd sensors.

3. Engineering Application

In a concrete-filled steel tubular arch bridge as shown in Figure 5, the original cable of the bridge needs to be replaced in the bridge deck replacement and repair and reinforcement project. Monitoring the broken wire that will be removed on the bridge cable. In order to simulate the evolution process of the broken wire damage of the cable, oxygen cutting is adopted to break the wire.
The bridge cable uses PES7-61 high strength parallel steel wire as shown in Figure 6. The process of removing the cable is as follows: firstly, the bridge deck near the cable is cut off, and then the pulling force of the cables on both sides is controlled by the hoist to reduce the tension of the cable until the drawbar is bent and does not bear the force, and then the oxygen is cut respectively. Cut off the cable and bridge arch at the junction with the bridge deck to complete the disassembly of the cable.

The sensor is placed at three positions of the cable, the upper anchor head (position 3), and the bridge deck (position 1, position 2). As shown in Figure 7–8:

The probe at the upper anchor head and the position near the bridge deck is directly in contact with the steel wire, and is protected by the PVC sheath. The probe is in contact with the PVC sheath at position 2 near the deck.

3.1. Noise test
During the test, both ends of the bridge were closed and no vehicles were allowed to pass, and there were cutting bridges near the cable. From the data collected, the noise is relatively low and the monitoring conditions are met as shown in Figure 9.

![Figure 9. Noise test (magnitude vs time)](image)

3.2. Attenuation Experiments

During the test, the center punch is used to perform the impact at position 2 (removing the PVC sheath), and each impact is equivalent to transmitting a signal. It can be seen from the test comparison that the presence of the PVC sheath has a large attenuation of the signal. Therefore, when installing the sensor, the sensor should be placed as far as possible in the metal contact with the tie rod wire or the tie rod fastening member, such as position 3. The collection threshold is 40dB. The two sets of data are as Table 1 and Figure 10. The position of the determined signal is accurate as figure 11.

### Table 1. Sling Acoustic Emission Test Signal Attenuation Data Unit: dB

| Position          | First group(sling natural extension state) | Second Group(the sling force is initially tightened) |
|-------------------|------------------------------------------|---------------------------------------------------|
|                   | Position 2 •● | 97  | 97  | 90  | 96  | Position 2 •● | 93  | 96  | 99  |
|                   | Position 1    | 69  | 89  | 57  | 88  | Position 1    | 74  | 75  | 88  |
|                   | Position 3    | <40 | <40 | <40 | <40 | Position 3    | 53  | 53  | 51  |

Note: ● is the impact position

![Figure 10. Attenuation test (magnitude vs time)](image)

3.3. Wire-broken monitoring

When the wire-broken monitoring, the hoist is used to control the cable until the cable is in a straight state from bending to initial tension, and the position of the hoist is kept fixed. At this time, the wire is
cut by oxygen welding, and a total of 7 wires are cut. The specific test results are shown in the following figure 12.

![Figure 12. Broken wire factor monitoring](image)

As can be seen from the above figure, the acoustic emission signal corresponding to the wire being fusing is very significant. Moreover, the wire-fused acoustic emission signals corresponding to different stress levels are significantly different. The normally used high-stress state sling wire breakage acoustic emission signal is more significant and easy to identify.

### 4. Conclusion

The main purpose of this paper is to judge the damage degree and position of the steel strand, and to conduct the wire-broken monitoring and evaluation by the broken wire factor and the position criterion. Finally, the test results are in good agreement with the monitoring results, and the error is about 5%. Acoustic emission technology is used to test the broken wire of a concrete-filled steel tubular arch bridge. The correlation qualitative analysis between the cable stress state, the position of the measuring point and the measuring point of the PVC sheath on the wire-broken monitoring result of the acoustic emission suspension system is studied. The experimental results show that in the low noise environment, the force of the cable is positively correlated with the apparent effect of the test. It fully demonstrates that the whole process of monitoring the cable damage by using acoustic emission technology has a good tracking effect, which can not only determine the moment of occurrence of the cabledamage, but also determine the location of the cable-broken.

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