Comparison and Applicability Research of Prestressed Duct Pumpness Contemporary Major Nondestructive Detection Technology

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Abstract. Prestressed reinforcement is one of the most hidden and important project in bridge engineering. It directly determines the structure of the bending, shear, anti vibration, anti impact performance, it also has influence on the safety and durability of the structure. To evaluate old bridge structure, it is required to detect the internal reinforced distribution (quantity, specifications, protection layer thickness). In addition, due to poor construction quality, position of prestressed tendons biased, and grouting can not get guarantee, which leads to serious corrosion of prestressing tendons, consequently in potential safety hazard. All above indicate that by using nondestructive method, it is significant to locate the prestressed tendon and define the quantitative and distribution in structure. Then, it is required to evaluate the grouting condition of prestressed ducts, and regrouting for the flaw ducts. This paper focuses on several current famous prestressed grouting nondestructive detection methods, combining the characteristics of the actual bridge structure, and the accuracy of each method is obtained. Results is compared with applicability and pertinency. Research results provide method and basis for detecting subsequent prestressed bridge.

1. Introduction
For in-service and new bridges, post-tensioned and bonded prestressing construction methods are often adopted for the in-body prestressing steel bundles of concrete main girders. Prestressed steel strand in concrete body is a concealed project. The quality control of grouting in the conduct is usually carried out in the casting process and the casting site. Once the concrete is casted into shape, it is difficult to directly detect the quality problems by non-destructive method. This also brings unknown factors for future bridge maintenance.

2. Major nondestructive detecting methods and principles for grouting conducts
Stress wave method is based on the use of impact generated by the instantaneous stress wave, a short-term mechanical impact with low-frequency stress wave is activated on specimen surface, then stress wave is propagated to the structure and finally reflected by the bottom surface. Therefore, MEM (Maximum Entropy Method) method \cite{1} \cite{2} \cite{3} is introduced in this experiment, which greatly improves the accuracy of the test.

By measuring the thickness and reflection time, the propagation velocity of impact echo in concrete can be calculated according to (1), and the principle that the propagation velocity of shock echo in the same concrete block or structure is equal. The reflection time is taken as the demarcated reflection
time, and it is compared with the reflection time of the measured pipe to judge inside situation of the conduct.

$$C = \frac{2h}{t}$$  \hspace{1cm} (1)

Ultrasound detection of concrete defects generally uses a lower emission frequency, because the concrete is a heterogeneous elastic-viscoplastic material, ultrasonic pulse can be absorbed and scattered with high frequency, and easier to attenuate.

The ultrasonic method can be determined by the depth of the defect according to (2) by shear wave velocity, echo time and the distance between the excitation probe and the receiving probe.

$$d = \sqrt{(C \Delta t)^2 - X^2}$$  \hspace{1cm} (2)

Electromagnetic wave propagates in lossy media with typical characteristics. The transmitting antenna transmits high-frequency pulsed electromagnetic wave (MHz-GHz) to the ground. When it encounters an underground inhomogeneous body (interface), it will reflect part of the electromagnetic wave. Its reflection coefficient mainly depends on the dielectric constant of the underground medium. The main radar transmitter will reverse this part. [4][5][6]

3. Experimental platform for grouting pumpness of prestressed conduct

3 solid box girder models with different kinds of typical defects are designed and deployed by normal engineering casting procedure. Girders A and B are normal cable span bending prestressing channel, Girder C has counter-cable span bending prestressing channel. The prestressed duct is a corrugated iron pipe with an inner diameter of 5.5cm, with 15.2mm-5 strands inside.

The main technological process: pouring concrete component main tenance demolition grouting (after the concrete strength reaches 95%) channel. Concrete is labelled with C50 concrete. The concrete is vibrated in time and the test block is maintained. A and C beams are made by intelligent circulation grouting method. The B beam adopts traditional grouting method and artificially prefabricate defects according to the amount of grouting.

Each non-destructive testing method carries on the qualitative test and the localization test respectively to the pre-stressed pipeline in the measurable range of A, B and C beams, the qualitative
test distinguishes the grouting integrity of each pipeline, and the localization test unifies the defect localization along the outside of the pipeline.

4. Result and analysis of single point impact echo test
The above figure is a typical single-point shock echo test defect analysis diagram. From the diagram, the blue line position is the reflection time of the shock echo without defect, but the actual reflection time lags as shown in the red area. It shows that the grouting inside the test area is not full. Although the pipe grouting indexes of the test were all above 90%.

5. Result and analysis of impact echo scattering method
In this work, the 1, 2, 3, 4, 9, 10, 11, 12 conducts of A beam were tested in the range of 1.5m. The total length of the line was 24m. According to the test results, no defects are found.

Conduct 2, 3, 11 of B beam were tested and calculated, of which 2, 3 were divided into N and S sections because of the diaphragm partition. The total length of the line was 87.4m. No. 11 conduct were found no obvious defects, 2-N section, 2-S section, 3-N section, 3-S section bellows were detected grouting void.

Finally, C beam 1, 4, 9, 11 conducts at both ends of 4.5m and 3 m across the middle of the test line length of a total of 48m. According to the test results, no defects of grouting were found.
6. **Result and analysis of ultrasound test method**

As shown in the figure, the red area is the internal defect of the pipeline. Because the test beam is a solid structure, the thickness of the test exceeds the range of ultrasonic equipment, the test effect of interference is large, the effect is not good.

7. **Result and analysis of acoustic testing method**

Among the 28 corrugated conducts of the 3 box girders tested, 18 (64.3%) were grouted with grade A, 9 (32.1%) were grouted with grade B, and 1 (3.6%) was grouted with grade C. The possible defects in the B-N2 pipe of the box girder 7 meters away from the end a were detected by the acoustic scattering method. After analysis and treatment, it was deduced that the grouting may not be full at the 0.4m-1.0m, 2.5m-3.0m, 4.5-4.9m and 5.5m-6.0m parts of the end a. The possible defects in the B-N3 pipe of the box girder 10 meters away from the end were detected by the acoustic scattering method. After analysis and treatment, it was deduced that the grouting may be unsatisfactory at the 0.5-1.3 m, 2.5-2.8 m, 4.5-5.0 m, 5.5-6.0 m, 6.5-7.0 m and 8.7-9.0 m of the end a. The possible defects in the B-N11 pipe of the box girder 10 meters away from the end a were detected by acoustic scattering method. After analysis and treatment, it was deduced that the grouting was not full at the 0.0m-2.0m and 4.5-5.2m.

8. **In-situ verification**

To verify the grouting fullness and the accuracy of non-destructive testing, a professional cutting tool (wire saw) was used to selectively cut the very 3 girder beams. A beam with positive curve prestress is cutted into 6 sections, which were 0.3m, 0.8m and 1.2m at the two ends, and C beam with reverse curve prestress is cutted into 5 sections, respectively, at the two ends of 0.3m, mid span and both side 0.5m of mid span. Observation is under carefully process after cutting, in the development of non-destructive testing of each prestressed conduct, only A2 found defects and voids.
The defects of B beam pre-deployed some defects by manual controlling grouting volume. In order to verify the grouting fullness and non-destructive testing accuracy, the B and C beams were damaged by air pick and percussive drilling. The results of NDT analysis and field verification are shown in Table 1.

| Location   | Conduct Number | Verification                                      | NDT method                  | Remarks          |
|------------|----------------|---------------------------------------------------|------------------------------|------------------|
| S7.8m-8.5m | B2             | The grouting is **full and solidified.**          | Acoustic scattering         | Misjudgement     |
| S7.8m-8.5m | B3             | The grouting is **not full, and the slurry is not solidified.** | Acoustic scattering |                 |
| N6.0m-6.6m | B2             | The grouting is **full and solidified.**          | Impact echo scattering      | Misjudgement     |
| N6.0m-6.6m | B3             | The grouting is **not full, and the slurry is not solidified.** | Single point impact echo/ acoustic scattering |                 |
| N1.6m-2.0m | B11            | The grouting is **not full, and the upper slurry is not solidified.** | Acoustic scattering |                 |
| N8.4m-8.7m | C4             | The grouting is **full and solidified.**          | Acoustic scattering         | Misjudgement     |
| S2.1m-2.6m | C9             | The grouting is **full and solidified.**          | Single point impact echo/ acoustic scattering | Misjudgement     |

9. Test accuracy and applicability of each method

Overall qualitative detection: single-point impact echo, acoustic reflection spectrum energy method, acoustic penetration method results are ideal compared to principles, the test results match the actual cutting section results. But the premise is that the test conditions require that the anchor head of the prestressed duct is not anchored. These 3 overall qualitative detection methods are applicable to the construction of new steel bridges before construction anchoring.

Defect location inspection: single-point shock echo, shock echo scattering, acoustic reflection spectrum energy and acoustic scattering are used to test the defect location inside the conduct. The test results are partly consistent with the results of in-situ verification. In general, the accuracy of single point impact echo and acoustic scattering method is relatively recommended.

In addition, it should be noted that the test box girder is a solid structure, the thickness of the test is thicker, and the thickness of the test box girder bridge web is different from the actual bridge, easy to cause inaccurate bottom reflection of elastic wave, signal interference, resulting in misjudgment.

| NDT method                      | overall qualitative detection | defect location inspection |
|---------------------------------|-------------------------------|---------------------------|
| Single point impact echo        | √                             | √                         |
| Impact echo scattering method   |                               |                           |
| Multi-point phased array        |                               |                           |
| ultrasonic wave                 |                               |                           |
| Acoustic reflection spectrum    |                               |                           |
| method                          |                               |                           |
| Method                        |       |
|-------------------------------|-------|
| Sound penetration method      | √     |
| Scanning impact echo          |       |
| Acoustic scattering method    | √     |

### 10. Conclusion

Single point impact echo, shock echo scattering method and acoustic scattering method are suitable for locating defects in prestressed ducts of existing bridges and new bridges. However, the inspection is affected by the thickness of the component, the depth of the pipeline, the test surface conditions, the structure of the steel bundle and other factors, which need to be corrected. Multipoint ultrasonic array and scanning impact echo method have no result in this test. Because the beam is solid structure, the thickness of the test is limited. According to the previous tests, the two methods can give the location and detection results of the internal defects of the duct under the allowable test conditions (thickness, number of conducts). Due to the obvious shield of radar (electromagnetic wave) by metal materials, this test did not give the results of grouting test, but for the positioning of prestressed pipelines did very accurate and effective.

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