The Feasibility Study of Quantitative Flaw Detection of Grouted Sleeve Connection by Ultrasonics

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Abstract. Grouted sleeve connection has been widely used to connect rebars in prefabricated concrete (PC) structures. Due to the complexities of materials and internal configurations, the flaws or defects are inevitable, which may cause the negative impact on the mechanical properties of reinforcement sleeve connection, ultimately leading to the hidden risk in the PC structures. It is challenging to explore a reliable and efficient flaw detection method for the grouting sleeve. In this paper, an active grout defects detection approach for grouted sleeve connectors using UT wave measurement is proposed, where piezoelectric-lead-zirconate-titanate (PZT) transducer are mounted on surface of the sleeve as transmitter and receivers; and experimental study is carried out to validate the feasibility of the proposed method. In order to investigate the effect of grout defects on UT wave measurement, five grouted sleeve specimens with different degrees of the artificial grout defects are designed and analysis on the PZT transducer was used for measurement. By comparing the PZT transducers measurement of different specimens with different grout defects under an identical impulse excitation signal, the grout defect is detected. Experimental results indicate grout defect leads to decrease in PZT transducers measurement UT energy, the relationship between the UT energy ratio and the internal grouting flaws is established: the UT energy decreases with the increment of flaw size. Therefore, the UT method provides a feasible option to evaluate the internal flaws of grouted sleeve connection.

1. Introduction

In PC structures, the reliable connection between longitudinal steel bars between two adjacent precast concrete members plays an important role in ensuring the bearing capacity and seismic performance of PC members [1-3]. From 1970s, the grouted sleeve connection has been utilized to various engineering structures, such as bridges, houses, air traffic control towers and other buildings, because of their advantages of simple operation, and welding-free on the construction site [4-5]. At the same time, the grouted sleeve connection provides excellent mechanical performance (e.g. tensile and compression resistance) due to the bond slip resistance of grouted cement material and the mechanical gripping ability of steel bars [6]. However, in practice, even by using non-shrinkage and high-strength grouting material, due to leakage of the grouting material, many types of flaws and defect still existed, such as undischarged air in the sleeve, worker error in the construction process, mortar backflow and other reasons [7]. The corresponding grouting defects weaken the bond between the steel bar and the casing, eventually leading to a negative effect on mechanical properties of PC structures [8-9]. In the PC structure, the internal structure is complex: the defect size is unpredictable due to the combined factors of the surrounding...
concrete and reinforcement. Therefore, the detection and evaluation of internal defects in the grouted sleeve connection is very essential to ensure the mechanical performance of the connection and even for the entire PC structure. Aiming to this situation, many detections methods have been proposed: conventional destructive testing methods, such as pull out method, core drilling method. It will damage the concrete structure and cannot be applied to the grouting sleeve connector in PC structure. The testing technology of grouting plumpness of sleeve based on embedded steel wire drawing method [10], vibration testing of an embedded damping transducer [11] and an endoscopy inspection through a drill hole in the grouted sleeve [12], as many destructive methods, which involves costly and complex post-operation. To this end, those mentioned methods may not be suitable options for rapid on-site test. Meanwhile, some nondestructive testing methods, such as X-ray testing [13], electromagnetic microwave (EM) testing [14], ground penetrating radar (GPR) testing [15], are not effective or low-sensitive in detecting grouting defects. X-ray detection methods require the specialized equipment and it is not safe, which makes it impractical to detect defects in grouted sleeve connections in PC structures. The electromagnetic microwave (EM) method was mainly limited by its penetration: because of the shielding effect of steel sleeve, the electromagnetic wave cannot penetrate metal medium; so, it is not suitable for grouted sleeve connection. The application of ground penetrating radar (GPR) method is constrained by the resolution and also it is not cost-effective. Recently, Ultrasonic testing (UT) draws more attentions of researchers due to the efficiency, cost, and sensitivity to microstructure [16]. Therefore, we proposed a UT based method to detect the internal defects of grouted sleeve connections in PC structure in this paper.

2. Methodology
In PC structures, for the beam-to-beam joints, grouted sleeve connectors where one bar is threaded into one end and the other rebar is grouted into the opposite end. Sleeve grouting is injected from the grouting inlet. When the mortar flows out from the grouting outlet, it indicates that the mortar in the sleeve is dense. as shown in figure 1. The actual working situation is as shown in figure 2. In order to detect the internal defects of grouting sleeve, two PZT transducers R6 and R3 models are set at the outlet and inlet of grouting sleeve, and the upper and lower sleeve surfaces. PZT transducers used as transmitter and receivers are mounted on outer surface of the sleeve to generate and measure UT wave propagating along the surface and within the cross section of grouting sleeve connectors, as shown in figure 3.

![Figure 1. Grouted sleeve connector.](image-url)
3. Experimental Program

3.1. Grouting Sleeve Connector Specimens
In this study, in order to validate the applicability of the proposed UT detection method for grouting sleeve connectors, the typical half grouting sleeve connection specimens are fabricated. Details of grouting sleeve connection is shown in Figure 4.

![Figure 4. Details of grouting sleeve connection (mm).](image)

3.2. Design Of Artificially Grout Defects In Grouted Sleeve Connector Specimens
In the actual construction, there are pores in the sleeve mortar, and the mortar grouting is insufficient, which may be parallel or perpendicular to the steel bar surface, resulting in the grouting defect. In order to verify the testing strategy, the artificial grouting flaws, which is made by plasticene, was designed and introduced to simulate the insufficient grouting of PC structure, as shown in figure 5. The volume of adding plasticene was used to mimic the flaw size. The grouting sleeve specimens with different defect sizes are shown in figure 6, and the material properties in the test are shown in table 1.

![Figure 5. The grouting sleeve with different flaws.](image)  ![Figure 6. The specimen with defects.](image)
### Table 1. Material properties in the experiment.

| Properties | Density (kg/m³) | Young’s modulus (GPa) | Poisson’ ratio |
|------------|----------------|-----------------------|---------------|
| Rebar      | 7850           | 210                   | 0.30          |
| Sleeve     | 7300           | 162                   | 0.29          |
| Grout      | 2300           | 20                    | 0.20          |
| Plasticene | 1384           | 0.003                 | 0.40          |

#### 3.3. Test Setup for Grout Defect Detection

The experimental setup is shown in figure 7. In the test, the excited signal is generated by the function generator. The transmitted ultrasonic guided wave signal is recorded by the oscilloscope.

![Figure 7. The setup of the active grout defect detection system.](image)

In this study, the excitation signal is the 5-cycle burst sinusoidal signal with a frequency of 120 kHz and 200 kHz.

#### 4. Experimental Result Analysis

The collected signals are imported into MATLAB for filtering. In order to eliminate the influence of reflected waves, only the first arrival wave pocket is analyzed. Taking the signal from receiver 2 for example, the time domain signals from different samples are shown in figure 8(a) (b). The UT energy was calculated in terms of the signal envelope [17]. The calculation procedure was illustrated in the figure 8(c). The energy of the signal envelope of the first arrival wave was calculated and summarized in Fig. 9. As shown in the figure 9, for the response to 200 kHz, the transmitted UT energy decreases with the increase of the defect rate, which shows good trends with flaws; however, the trend of 120 kHz excitation shows more fluctuation due to lack of resolution.

Due to the wave propagation path problem, the receiver 2 can better characterize the existence of defects. The sketch of the propagation path of the receiver 2 is shown in figure 10.

![Figure 8. The time domain of receiver 2. (a)The time domain after filtering. (b) first wave. (c)An example of Receiver2 signal in time domain indicating the envelope (red line) to calculate the ultrasonic energy.](image)
Figure 9. The UT signal energy from (a) Receiver 1 and (b) Receiver 2 and (c) Receiver 3

Figure 10. The sketch of UT wave propagation within a cross section.

5. Conclusions
In order to investigate the feasibility of UT method to evaluate the defects of grouted sleeve connections, the influence of the defects in the grouted sleeve on the ultrasonic wave propagation was studied. The relationship between signal energy and grouting defect rate was established by experiment. Comparing with 120 kHz excitation, 200 kHz provides better detectability. Compared with receivers 1 and 3, the propagation path of receiver 2 provides better detection performance. However, due to the complex situation of grouting sleeve inside PC structure, the UT penetration is another issue which needs to consider. In conclusion, the proposed approach based on ultrasonic method shows the good potential to detect and evaluate grouting defect.

6. Perspective
In this paper, the feasibility of UT is discussed, the experiment results were reported. More important, the schematic of UT is proposed and proved to be feasible. In the actual working condition, the grouting sleeve is embedded in the reinforced concrete structure as a connecting node. How to use UT to detect the feasibility of grouting sleeve defects in PC structure is the next problem to be considered.

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