Experimental study on grout defects detection in precast shell wall based on wavelet packet analysis

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Abstract. Due to construction problems, grout defects always exist in precast structure with rebars spliced by sleeves. However, research on grout defects detection faces great challenges owing to the complexity of the problem. This study presents a nondestructive grout defects detection method based on wavelet packet analysis. First, experiment is carried out on two precast shell walls, then, acceleration responses are analyzed, and defects detection indexes ERVD and ERVDs are proposed. The results show that ERVDs is more sensitive to the grout defects than ERVD, and can be used as a good defect detection index in prefabricated shear wall.

1. Introduction

Precast shell wall structures have attracted much attention currently, in which the sleeve grouting connection of rebars is most widely adopted in the world [1-2]. However, due to the leakage of slurry, the eccentric defect of the steel rebars and other construction problems, defects always exist in sleeves that lead to structural failure. It is necessary to develop a defects detection method for the sleeves to guarantee the structural safety.

Structural physical parameters will be altered due to structural damage, which will result in a difference in the corresponding dynamic characteristic (e.g., natural frequency, mode curvature, and strain mode) [3-6]. Combined with wavelet packet analysis, the structural damage can be identified [7-9]. As the sleeve grout defects detection researches on precast shell wall structure are few, this paper proposes a method combining the dynamic excitation technique and wavelet packet analysis to detect sleeve grout defects in precast shell wall. Experiment is conducted on two precast concrete shell walls with column rebars spliced by grout sleeves. According to wavelet packet analysis, the acceleration responses of measuring points are analyzed, energy ratio variation deviation (ERVD) and total energy ration variation deviations (ERVDs) are adopted to identify the grout defects in sleeves, and good results are obtained.

2. Theory

2.1 Wavelet packet analysis

The energy of each frequency band of excitation responses in defective structure is different from that in nondefective structure. By decomposing the low-frequency signal and high-frequency signal simultaneously, wavelet packet is a refined signal analysis method. The energy value of each
frequency band is extracted to form the characteristic vector that can identify structural defects. In this paper, sym8 is chosen as wavelet function, and the decomposed level is 13.

### 2.2 Defects detection index

Energy ratio variation deviation (ERVD) is adopted as defects detection index \(^{[10]}\), which is calculated in equation (1)-(3).

\[
I_i = \frac{E_j^i}{(\sum_{k=1}^{2^j} E_j^k)/2^j}
\]

\[
ERV = \{ERV_i\} = \{|I_{d,i} - I_{u,i}|\}
\]

\[
ERVD = \sqrt{\sum_{i=1}^{2^j} (ERV_i - \overline{ERV})^2}
\]

Where \(E_j^i\) represents the signal energy of the \(i\)-th frequency band in the \(j\)-th layer, \(I_{d,i}\) represents normalized energy ratio in defective structure, \(I_{u,i}\) represents normalized energy ratio in nondefective structure, \(\overline{ERV}_i\) represents the average value of \(ERV_i\).

### 3. Experimental study

#### 3.1 Experimental model

The experiment is conducted on two full-scale precast concrete shell walls that all the longitudinal rebars are spliced by grouting sleeves. The designs of the two models are the same, except the defects degree in sleeves. Figure 1 shows the overview of the model.

![Figure 1. Experimental model.](image)

#### 3.2 Layout of defects

The two specimens are named W1 and W2, respectively. Figure 2 shows both specimens are divided into four strips (the shaded part), S1 and S1’ constitute case 1, S2 and S2’ constitute case 2, S3 and S3’ constitute case 3, and S4 and S4’ constitute case 4.
Figure 3 shows the grout defects in every case, where the red circle represents the sleeve is grouted tightly, and the black circle represents the sleeve is not grouted. It is seen that the defects in case 4 is most severe, followed by case 1, then is case 3, and in case 2 is the slightest.

3.3 Layout of hanging, excitation and measuring points

The excitation points (EP) are located in the center of each strip. The excitation points and the measuring points are shown in Figure 4, in which MPi-j represents the j-th measuring point in Si (i=1, 2, 3, 4, 1’, 2’, 3’, 4’; j=1, 2, 3, 4 ). For example, MP1-4 represents the fourth measuring point in S1. Any two measuring points that located in the same position of W1 and W2 form the pair-wise measuring points. In case m (m=1,2,3,4), there are four pair-wises measuring points, recorded as MPmm’-n (n=1,2,3,4). For example, MP2-1 in W1 and MP2’-1 in W2 compose a pair-wise measuring points recorded as MP22’-1.
3.4 Experimental equipment
A stainless steel swing ball with a diameter of 60mm and weight of 870g is used as the excitation source. The vertical height between the hanging point (HP) and the excitation point is 500mm, as shown in Figure 4. The swing ball is pulled to a predetermined height, and then is released to freely fall against the wall to form excitation. Acceleration sensor is used to collect the acceleration response of each measuring point. The acquisition system of Beijing Oriental vibration and noise technology research institute is used as data collection system. Taking the S1 of W1 as an example, the experimental equipment is showed in Figure 5. During the experiment, each strip is excited by the ball, and the dynamic responses of the four measuring points are recorded.

3.5 Results and Analysis

3.5.1 Acceleration responses. Acceleration responses of all measuring points are collected. Taking MP1-3 as an example, the response excerpts is shown in Figure 6.

3.5.2 Defects detection index. In every case, there are four ERVD values (recorded as ERVD1, ERVD2, ERVD3 and ERVD4) that are calculated based on the acceleration responses of four pairwise measuring points, as shown in Figure 7. In case i (i=1,2,3,4), ERVD1 is calculated based on MPii’-1, ERVD2 is calculated based on pair-wise MPii’-2, ERVD3 is calculated based on pair-wise MPii’-3, and ERVD4 is calculated based on pair-wise MPii’-4. Compared the indexes of MPii’-1, the value in case 4 is the biggest, followed by case 1, then case 3, and in case 2 is the smallest, showing the ERVD value is positively correlated with column defects degree. The same rule is also found in MPii’-3 and MPii’-4, except for MPii’-2.
Then, total energy ration variation deviations ERVDs is chosen to identify grout defects \cite{10}, which is defined as follows,

\[
ERVDs = \sum_{i=1}^{4} ERVDi
\]  

ERVDs of the four cases are presented in Figure 8, which shows that with defects degree increases, the ERVDs value becomes larger.

4. Conclusion

This study proposes a sleeve grout defects detection method based on wavelet packet analysis. Results show that the defects detection index ERVD are not so positively correlated with grout defects degree and detection error may occur. But total defects defects indicator ERVDs is highly sensitive to the grout defects, and can be used as a good defect detection index in prefabricated shear wall.

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