Research on Foundation Defect Identification Technology of Transmission Tower Based on SSP Technology

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Abstract. Transmission tower foundation defect identification has become more and more important. However, conventional detection methods are inefficient, which can cause secondary damage to the structure, and are limited by the inability to achieve large-scale detection. For this reason, the SSP technology is introduced in this paper which is applied to the foundation defect identification of transmission tower. Firstly, the feasibility of applying SSP technology to the foundation defect identification of transmission tower is analyzed. Secondly, the field test flow and data processing of SSP technology for foundation defect identification of transmission tower are introduced. Finally, the basic model of a transmission tower is tested to verify the feasibility of SSP technology for the foundation defect identification of transmission tower.

1. Introduction
The foundation is very important for the safe operation of transmission lines [1], and it has been found from the existing tower collapse accident that the power transmission tower damage caused by foundation defects has been common [2]. Because the foundation is often buried underground, it is very difficult to find out its defects, especially the detection of its shape size can only be carried out by manual excavation. However, this method is not only time-consuming and laborious, but also causes secondary damage to the foundation, especially for large-scale detection. Therefore, it is necessary and urgent to find a convenient, fast and nondestructive testing method.

SSP technology is a new geological exploration technology developed in recent years [3, 4], whose principle is based on seismic scattering profile. Compared with seismic reflection technology which can only reflect large interface changes, seismic scattering profile can reflect small, local changes. Therefore, the detection results of seismic scattering profile are more accurate and sensitive, and the geological information reflected is also more abundant. As soon as it came out, it attracted much attention of engineers. In 2006, Zhao et al. [5] first applied SSP technology to tunnel geological advance prediction. Then, Li et al. [6] obtained satisfactory results by applying it to the geological exploration in goaf. In 2013, Luo [7] successfully used SSP technique in the diagnosis of tunnel diseases. All these results show that SSP technology has a good application prospect in geological exploration. However, SSP technology has not been used in the foundation defect identification of transmission tower at home and abroad, therefore, the research on SSP technology to the foundation...
defect identification of transmission tower is carried out in this paper based on the practical engineering needs.

2. Technical Principle of SSP Technology for Defect Identification

Seismic scattering profile (SSP) technology is a new seismic exploration method developed in seismic reflection technology. Seismic reflection technology is essentially a special case of SSP technology, which is only suitable for homogeneous layered media model. The traditional seismic reflection exploration theory assumes that the seismic wave propagates with steady velocity in the layer, satisfies the continuous condition of boundary displacement and stress at the interface layer, and forms reflection, refraction and waveform conversion between the interfaces. Suppose that the total seismic wave field is $U$, composed of the incident wave field $U_I$, the reflected wave field $U_T$ and the scattered wave field $U_S$, that is

$$U = U_I + U_T + U_S$$ (1)

The wave equation is satisfied in the propagation of seismic waves in medium

$$\nabla^2 U - \frac{\partial^2 U}{v^2 \partial t^2} = 0$$ (2)

where $v$ is wave velocity and $t$ is time.

Reflection and scattering occur when local seismic waves propagate to areas where wave impedance changes (different lithology, stratified geology). The reflection wave will be generated where the wave impedance interface changes continuously and neatly, while seismic scattering will occur where the wave impedance interface changes sharply and in a small range. The intensity of these small-range anomalous body, is expressed by the scattering intensity $\alpha(r)$, which is

$$\alpha(r) = \frac{v^2 - v_0^2}{v^2}$$ (3)

where $v_0$ is wave velocity of anomalous body.

It can be seen from Equation (3) that the scattering intensity is the percentage of the square difference between the abnormal body wave velocity and the background wave velocity. For the regular arrangement of $\alpha(r)$ can also react to the large scattering interface, the difference in the square of wave velocity is essentially the difference in the modulus of the medium, therefore, the wave equation of the medium can be expressed as

$$\nabla^2 U - \frac{\partial^2 U}{v^2 \partial t^2} = \frac{\alpha(r)}{v_0^2} \frac{\partial^2 U}{\partial t^2}$$ (4)

By taking Equation (1) into Equation (4), and according to the BORN approximation [3], the scattering wave is considered to be much weaker than the intensity of the incident wave and the reflected wave, the equation of the incident wave, the reflected wave and the scattered wave can be obtained as follows:

$$\nabla^2 U_I - \frac{\partial^2 U_I}{v_0^2 \partial t^2} = 0$$ (5)
\[ \nabla^2 U_r - \frac{\partial^2 U_r}{v_0^2 \partial t^2} = 0 \quad (6) \]

\[ \nabla^2 U_s - \frac{\partial^2 U_s}{v_0^2 \partial t^2} = -\frac{\alpha(r)}{v_0^2} \frac{\partial^2 U_f}{\partial t^2} \quad (7) \]

From the above analysis, it can be seen that seismic waves is actually a combination of incident, scattered and reflected waves, where the reflected wave reacts with a larger layered interface (as shown in Figure 1), while the scattered wave reacts with a small scale mutation interface (as shown in Figure 2). For the defects of transmission tower foundation, the scale is often equivalent to wavelength, or even smaller, therefore, the identification of defects can only be realized by scattering technology. It can be seen from Equation (7) that the scattering wave equation is actually a passive source field, where the abrupt interface is equivalent to a passive field source, which produces scattered waves under the excitation of the inertial force of the incident wave. It can be analyzed that the position of the abrupt interface, the magnitude of the scattering ability and the mechanical characteristics of the scattering place by receiving the scattering wave. The shape of the anomaly can be obtained by combining and inverting these scattering interfaces.

\[ S \]

\[ X \]

\[ X_0 \]

\[ h_1 \]

\[ h_2 \]

\[ v_1 \]

\[ v_2 \]

**Figure 1.** Schematic diagram of seismic reflection.

\[ S \]

\[ X \]

\[ h \]

\[ v \]

**Figure 2.** Schematic diagram of seismic scattering.

SSP is a new technology of fine geological structure exploration, whose refinement exploration under the conditions of engineering geology and disaster geology has been applied. As can be seen from Fig.3, it can accurately identify the local abnormal physical ability by adopting the acquisition mode of small spacing, short arrangement and high frequency. SSP technical core includes: (1) directional filtering, filtering interference, ensuring the accuracy of detection results, improving signal-to-noise ratio; (2) velocity analysis, accurate and intuitive geological interpretation of velocity parameters, accurate velocity is the basis for accurate determination of spatial position, seismic wave velocity distribution image; (3) synthetic aperture migration imaging, the scattering wave energy is returned to the scattering source and the structural geological interface migration image of the underground scatter is reconstructed by seismic recording.
A defect of the electric tower foundation can be considered as a target point, the interface often changes sharply at the defect, therefore, it can be considered as an abnormal body, reflection and scattering will occur after the incident wave enters, and the reflection signal can be filtered out by the later filtering technology, that is, the defect recognition can be realized. At the same time, the lateral resolution and signal-to-noise ratio of deep seismic records can be improved by multiple receivers through multiple sources, which can effectively identify and locate abnormal bodies. The illumination of the abnormal body below can be improved by the latest SSP technology, using the directivity of phased-array vibrator system radiation, and the illumination of the surrounding geological body can be weakened, thus increasing the lateral resolution and increasing the detection depth. Phased-array vibrator system has the following advantages: (1) focusing, increasing vertical illumination, reducing oblique illumination, improving lateral resolution and increasing detection depth; (2) Phased array is realized based on mathematical phased source through software technology, which has the same effect of physical phased array and is convenient for construction.

3. Application of SSP in Foundation Defect Identification of Transmission Tower

3.1. Field Testing Process

It is often very difficult to identify the minor transmission tower foundation defects, which can only be achieved by adopting high resolution acquisition. Therefore, small arrangement and intensive collection are needed in the actual field test, and each excitation only detects the underlying situation near the excitation point. The geophone spacing is 0.5m, the excitation spacing is 0.5m, and the way of rolling forward is adopted, that is, excites every 0.5m interval on the left side of the excitation point line, furthermore the geophone is always located on one side of the excitation point and remains from the relative position of the excitation point, as presented in Figure 4.
The SSP collector adopts 32 seismometers produced by BeiJing Tong Du Engineering Geophysics Ltd., the detector adopts 32 channel detector cable matching with SSP collector, and the force hammer is excited by 24 LB hammer. The main technical index of seismograph is 32 channels, sampling dynamic is 24 bits A/D, sampling frequency is $156kHz/\text{ch}$. The main field acquisition equipment is exhibited in Figure 5.

![Main field acquisition equipment](image)

**Figure 5.** Main field acquisition equipment.

3.2. Data Processing

SSPwin seismic scattering profile system software is mainly used in SSP data processing, the flow can be seen in Figure 6. The flow includes: coordinate input, signal preprocessing, wave field separation, speed scanning, offset imaging.

![SSP data processing flow](image)

**Figure 6.** SSP data processing flow.

Seismic scattering waves are accompanied by various disturbances, acoustic waves, surface waves, multiple waves and traffic noise. Therefore wave field separation is one of the most important links in seismic scattering data processing. F-K is a linear filtering technique, which filters out the interference of direct wave, surface wave and so on based on the difference of visual velocity, so as to highlight the reflected and scattered waves in the ground. However, using F-K filtering must meet the following requirements:

1. The original record must be one-sided excitation, therefore, point arrangement must be arranged in the way of Section 3.1 during field testing.
(2) Select the appropriate wave velocity from shallow to deep according to the geological conditions of the site, such as backfill is at around 500–900 m/s, retaining a reasonable wave velocity range to facilitate later processing.

The wave velocity of geological medium is the basis for seismic records to shift from time to space. Speed scanning is based on seismic data with different offset distances, the stacking energy of scattering wave synthesis takes the maximum value to determine the wave velocity distribution of underground medium when the wave velocity is consistent with the wave velocity of geological medium.

The synthetic aperture offset imaging is carried out according to the scattering wave travel time by the recorded data of all shock and receiving points on the basis of filtering and velocity scanning. Make full use of the kinematics and dynamics information of seismic waves, the fine image of the infrastructure is reconstructed to identify the foundation defects.

4. Test Validation

The foundation of a certain transmission pole tower is 3 m, deep 6 m, long 12.3 m, and the top surface of the foundation is level with the ground. C25 concrete is used in the foundation, and two types of defects are set in the width direction of the foundation bottom surface respectively. Defect 1 is convex defect, the defect material is consistent with the base material, and the size is 0.5 m × 0.5 m × 5 m, while the defect 2 is a concave defect, the defect interior is filled with surrounding soil material, whose size is unchanged along the width direction of the foundation with 0.5 m × 0.5 m. The electric tower foundation defect setting is shown in Figure 7.

![Figure 7. The electric tower foundation defect setting (unit: m).](image)

Figure 7. The electric tower foundation defect setting (unit: m).

This data collection adopts the small arrangement, the dense collection way, uses 32 towed type geophone, the detector spacing is 0.5 m, and the shot interval is 0.5 m. Each line was excited 15 times, and 37 lines were arranged along the length direction of the foundation, the distance between the lines was 0.5 m. The parameters of the line arrangement are listed in Table 1.
Table 1. Line layout parameter.

| Line Number | position            | length /m | Number of receiving points /distance (m) | Number of excitation points /distance (m) |
|-------------|---------------------|-----------|-----------------------------------------|------------------------------------------|
| 1           | 1.85m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 2           | 1.35m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 3           | 0.85m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 4           | 0.35m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 5~29        | At the foundation   | 7         | 16/0.5                                  | 15/0.5                                   |
| 30          | 0.35m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 31          | 0.85m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 32          | 1.35m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |
| 33          | 1.85m from foundation | 7         | 16/0.5                                  | 15/0.5                                   |

The acquisition instrument uses 32 high resolution seismometers, with a maximum sampling rate of 1/48 milliseconds, a A/D conversion of 24 bits, a maximum detection depth of 10m, a maximum sampling length of 240K and 1~16 towed geophone is selected. Figure 8 shows the data acquisition site, and the seismic data under a certain shock is tested as shown in Figure 9.

![Figure 9. Original earthquake records.](attachment:image)

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The wave velocity distribution image is obtained by processing the original data through SSPwin seismic scattering profile system software. The wave velocity distribution images of a total of 33 profiles are obtained according to the processing, where profiles 9 and 25 are the profiles passing through the defects (A, C sections in Figure 7, respectively) and profile 15 is a section of the intact foundation (B sections in Figure 7). The wave velocity distribution images are shown in Figures 10, 11 and 12, respectively. The transverse coordinates in the figures are coordinates along the base width direction, the ordinate represents the elevation, and different colors represent different wave velocities.
The exploration results show that there are 1 high wave velocity region and 1 low wave velocity region in the wave velocity distribution map, where red is the high wave velocity region, which indicates that the elastic modulus of the medium is high, the low wave velocity region is blue and light blue, which represents the elastic modulus of the medium is low. The foundation defect can be identified by combining geological data and wave velocity distribution map: (1) It can be obtained from Figure 10 that the foundation depth is 6.55 m, width is 3.10 m, that is, the defect height is 0.55 m; (2) As it can be seen in Figure 11, the foundation depth is 5.48 m, width is 3.08 m, and the defect height is -0.52 m; (3) As is shown in Figure 12, the depth of foundation is 6.11 m, width is 3.12 m, and the identification accuracy of depth and width is 1.83% and 4%, respectively, which meets the engineering requirements. It is proved that the SSP technology can be used to identify the defects of
transmission tower foundation, and the accuracy meets the engineering requirements based on the above identification results.

5. Conclusion
The method of foundation defect identification of transmission tower based on SSP technology is put forward in this paper in view of the urgent requirement of foundation defect identification of transmission tower, and the following work is carried out: (1) the principle of SSP technology is expounded, and the feasibility of applying it to defect identification is analyzed; (2) the field test flow and data processing of SSP technology for foundation defect identification of transmission tower are introduced; (3) the feasibility of foundation defect identification of transmission tower is verified by the test results of a transmission tower foundation model.

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