

# Application of distributed optical fiber sensing technique in pile foundation monitoring

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**Abstract:** Compared with traditional point monitoring technique, distributed optical fiber sensing technique, with the advantages of long transmission distance, good durability, high precision and continuous monitoring, has been used widely in slope, tunnel and pile foundation engineering et al. Based on a bridge pile foundation project, the distributed optical fiber was used to monitor the stress and deformation of pile foundation during the construction process. Through comparing the results with traditional point monitoring technique, it shows that the distributed optical fiber sensing technique is of high accuracy and with good consistent with the traditional monitoring technique.

## 1. Introduction

The conventional monitoring method of pile stress and deformation usually adopts the traditional point monitoring technique, such as steel stress meter, strain gauge and so on[1-2], as shown in Figure 1. However, the traditional point sensor has the disadvantages of high cost, low survival rate and complicated operation. It is easy to be disturbed by the outside environment and the measuring points are selected according to the experience, which has a certain blindness.

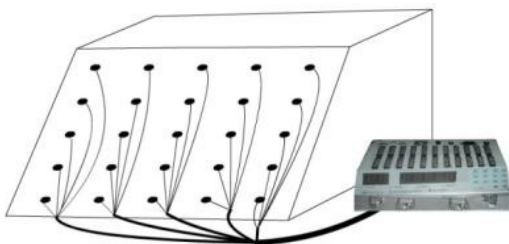


Figure 1. Point monitoring technique

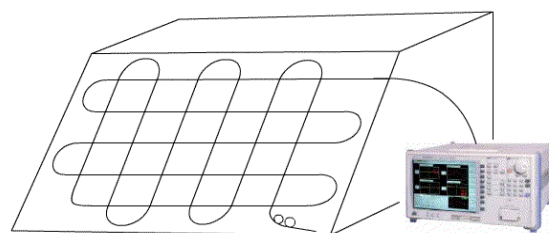


Figure 2. Distributed monitoring technique

Distributed optical fiber sensing technology, due to its long transmission distance, good durability, high precision and continuous monitoring, has been gradually used in the safety and health monitoring of civil engineering, geotechnical and other industries[3-8]. In recent years, some international research institutions and enterprises have launched the Brillouin optical frequency domain analysis (BOFDA), of which the biggest advantage is the extremely high measuring accuracy of  $\pm 2\mu\epsilon$  and the high spatial resolution up to 20cm[9,10], overcoming the problems of low spatial resolution and low testing precision of the Brillouin optical time domain technology.

In this paper, based on a bridge pile foundation project, the optical fiber sensing technology, in view of its advantages compared with traditional point monitoring technique, was adopted to monitor



the stress and deformation of pile foundation during construction process and the results were tested by steel stress meter.

## 2. Field test scheme

### 2.1. Engineering geology

The supporting project is an important part of Shanxi expressway network. The main line is 64.448 km long and is designed according to the technical standards of two-way four-lane expressway, and the project investment is 4.74 billion yuan.

The field test site, next to a freight railway bridge already in operation, is shown in figure 3, the pile foundation is composed of four groups of pile foundations arranged in square form. The pile length is 39 m and the diameter of pile is 1.5 m. The pile foundation is designed as artificial bored pile and the thickness of concrete shield is 30 cm. In this paper, two of them are selected as test pile, named 1# and 2#, respectively.



Figure 3. Field test site

The stratigraphic conditions are as follows: a). collapsible loess (silt): brown-yellow, slightly dense, slightly wet, with III gravimetric collapsibility. The natural moisture content is 16.9%, natural weight is 15.6 kN/m<sup>3</sup>, relative density is 2.71, void ratio is 1.03, plastic limit is 17.0, liquid limit is 26.8, compression modulus is 2.3 Mpa. And the thickness of this layer is 15 m. b). Loess (silt): brownish-red, medium dense, slightly wet, with thin silty clay and scattered round gravel. The natural moisture content is 16.8%, natural weight is 18.0 kN/m<sup>3</sup>, relative density is 2.71, porosity ratio is 0.76, plastic limit is 16.4, liquid limit is 24, and the thickness of this layer is 16 m. c). silty clay: brownish-red, plasticized, containing scattered boulders and ferromanganese films. The natural moisture content is 25.3%, natural weight is 19.8 kN/m<sup>3</sup>, relative density is 2.73, porosity ratio is 0.73, plastic limit is 20.8, liquid limit is 36.8, and the thickness of this layer is 9 m. d). silt: reddish, slightly wet. The natural moisture content is 19.0%, natural weight is 19.7 kN/m<sup>3</sup>, relative density is 2.71, porosity ratio is 0.64, plastic limit is 16.9, liquid limit is 26.5, and the thickness of this layer is 6 m.

### 2.2. Optical fiber layout scheme

The laying steps of distributed sensing fiber are as follows: (1) the fiber optic cable is fixed to a main reinforcement of the steel cage by the way of binding, and the PVC hose is arranged on the bottom of the pile for transitional protection. The U loop is formed by binding the fiber optic cable at the symmetrical main reinforcement on the other side, and sufficient length is reserved at both ends. (2) the steel cage is slowly lowered to the pile hole by using the crane, and the fiber is arranged on the subsequent sections of the steel cage in the process of slowly dropping; (3) the fiber optic cable is guided along the foundation ditch to the hillside for subsequent regular monitoring.

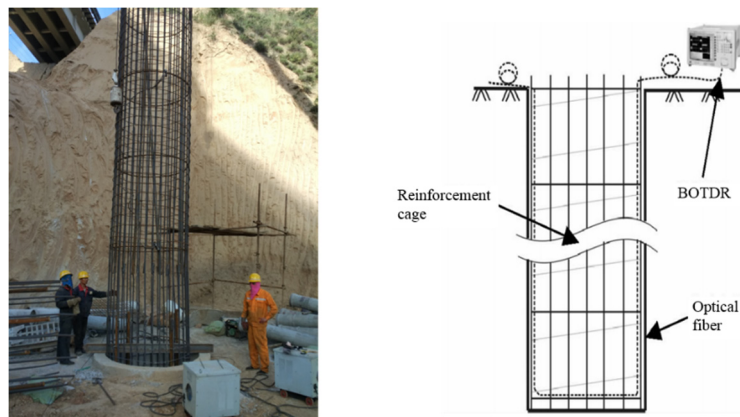
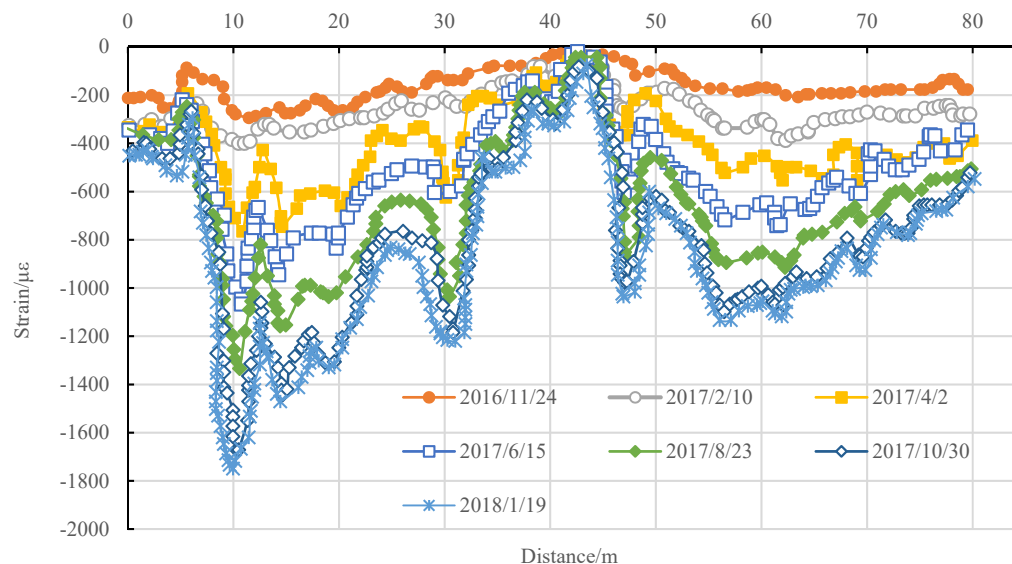


Figure 4. Layout diagram of distributed sensing optical fiber

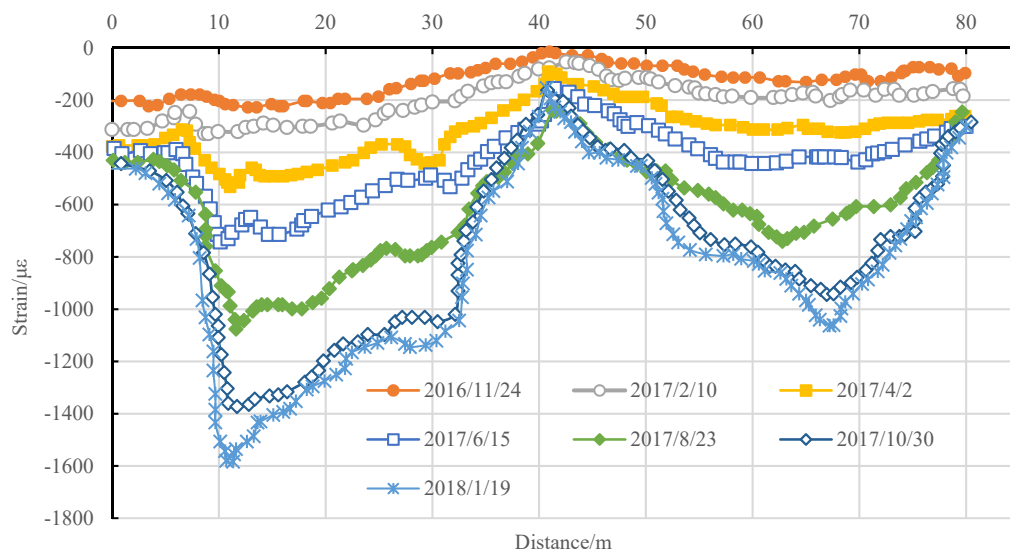
### 3. Analysis of test results

#### 3.1. Strain of pile foundation

The fiber strain distribution curves at different measurement times are shown in Figure 5. If the pile foundation is regarded as an ideal elastic body and when it bears vertical load only, the strain curve of sensing fibers distributed symmetrically along the pile foundation should be the same. When the pile foundation is subjected to horizontal load only, the strain curve of the pile foundation should be a centrosymmetric graph. However, the actual pile foundation buried in slope is subjected to both vertical and horizontal loads, and considering the influence of construction quality and other factors, the strain curves obtained from the field exhibited inhomogeneity as shown in Figure 5. In addition, it can be seen from the diagram that there are some uneven fluctuations in the strain curves of some sections, which are mainly caused by the inhomogeneity of the pile body material.



(a) 1# pile foundation



(b) 2# pile foundation

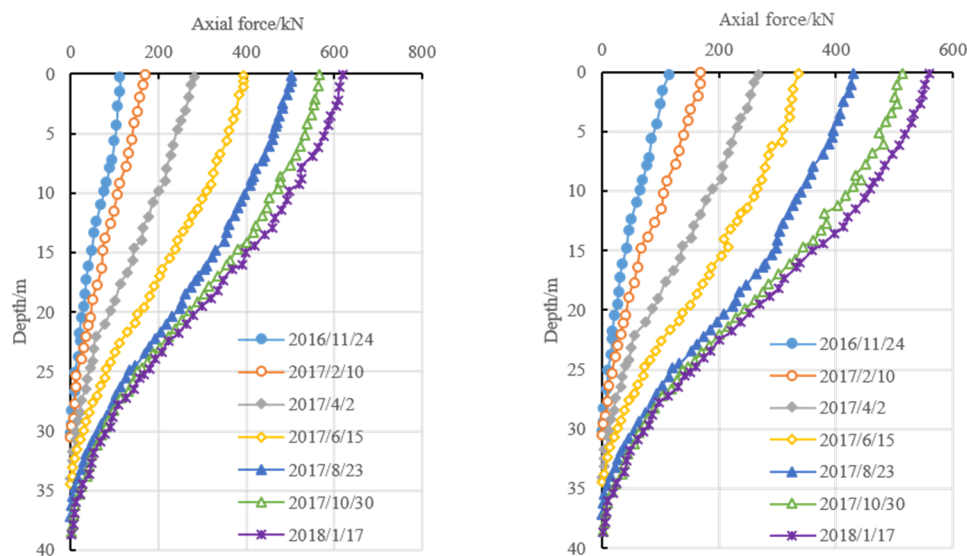
Figure 5. The Curves of Strain Distribution

### 3.2. Stress of pile foundation

The axial force curves at different measuring times are shown in Figure 6. It can be seen from the diagram that the axial force is gradually decreasing from the top to the bottom.

### 3.3. Results comparison

In order to examine the accuracy of distributed optical fiber sensing technique, the results are tested by the traditional steel stress meter. Fig. 7 shows the contrast curve of axial force between two kinds of monitoring methods at different depth of pile foundation. Where F and S represent the distributed optical fiber and steel stress meter, respectively. It can be seen from the diagram that the test results using distributed optical fiber are in good agreement with those of steel bar meter. The accuracy of the test results is verified, and it is further proved that it is feasible to use distributed optical fiber as the monitoring method of pile foundation.



(a) 1# pile foundation

(b) 2# pile foundation

Figure 6. The Curves of Axial Force

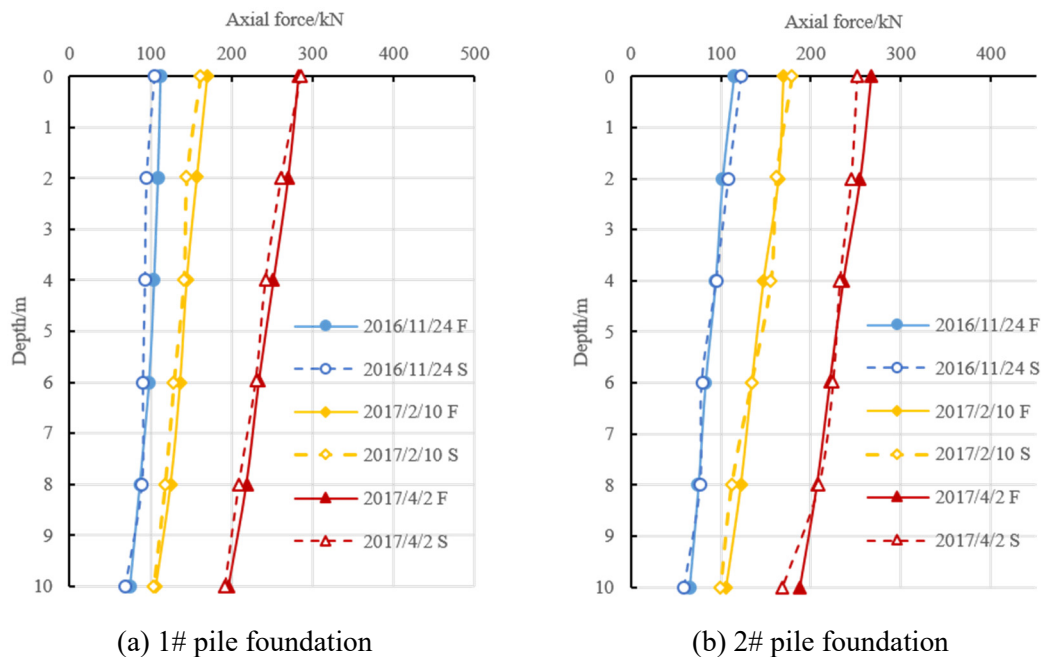


Figure 7. Contrast curve of axial force

#### 4. Conclusion

In this paper, the new distributed optical fiber sensing technology developed in recent years is used to monitor the stress and deformation of pile foundation by arranging the sensing fiber on the main tendons in the field, and the monitoring results was compared with traditional point test. Field test results reveal that the distributed sensing optical fiber technology can detect the local deformation of the pile foundation. According to the characteristics of material and geometry, the deformation and stress of pile foundation can be solved. And the distributed sensing optical fiber monitoring data are in good agreement with the test results of steel bar meter, which indicates that the distributed sensing fiber, as a new type of monitoring method, has high accuracy. So it can be widely used in the detection of similar engineering.

#### Acknowledgements

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