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# Measuring geo-grids stress using distributed fiber-optic sensors based on pulse-prepump-Brillouin optical time domain analysis

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## ABSTRACT

The technique of geo-grid reinforced piles has been proven to be an effective solution for preventing the failure or excessive settlement of embankments over soft soil. Many design methods have been developed to assess the performance of geo-grids. However the methods were seldom validated due to the difficulties of the measurement of geo-grid stress. For this reason, full-scale model tests on the performance of geo-grids under the embankment was conducted. The distributed fiber-optic sensors were used to measure the distribution of longitudinal stress in the geo-grids. The measuring system was based on pulse-prepump-Brilliouin optical time domain analysis (PPP-BOTDA). Two ribs of the geo-grids with length of 4m were totally measured under different loading conditions. The spatial resolution was 5cm and the accuracy was ±15 $\mu\varepsilon$ in the measurement. The results of the tests show that the PPP-BOTDA is reliable and effective for measuring the distribution of longitudinal stress in geo-grids.

**Key words**: PPP-BOTDA; fiber-optic sensor; geo-grid; piled embankment

## 1. INTRODUCTION

Geogrid-reinforced piled embankment over soft soils has been increasingly used in highway, high-speed railways. Compared with other kinds of embankment over soft soils, the geogrid-reinforced piled embankment has the advantages of rapid construction, small and controllable deformations, and global stability (Chen et al. 2007). The inclusion of geo-grids increases loading efficiency of piles (Cao et al. 2007). The distribution of tensile force in geo-grid in piled-embankment is greatly concerned in practice.

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Many researchers have measured the tensile force or strain in geosynthetic reinforcement with different methods. Van Eekelen et al. (2011) used traditional strain gauges and bicycle gear cables. However there were great differences between the measured strains. The results obtained by bicycle gear cables could only be considered qualitatively throughout the analysis. Force sensors by clamping the two measuring points of the geo-grids were also used by Cai et al (2011). Flexible displacement sensors to test the strain of geo-grid which could be transformed to tensile force by the stiffness of the geo-grid were used by Zhang et al (2010). The force sensor and flexible displacement have strong stiffness and large size, and could hardly deform in coordination with the reinforcement. Hence, this impacts the measuring accuracy greatly.

In comparison with other sensing technologies, optical type sensors, including optical fiber sensor, fiber Bragg grating (FBG), provide many advantages, including light weight, small size, and immunity to electro-magnetic interference, long distance monitoring, wide measurement range, and independence from applied circumstances (Yoon et al. 2007). Briancon and Simon (2012) used FBG to measure the geosynthetic strain. However, FBG could only measure the geosynthetic forces or strains at several points.

In order to study the distribution of the geo-grid force in the piled embankment, a full-scale test on geo-grid reinforced embankment was conducted. The distributed fiber sensors based on pulse-prepump-Brillouin optical time domain analysis (PPP-BOTDA) were used to measure the geosynthetic tensile forces.

## 2. EXPERIMENT

### 2.1. Experiment equipment

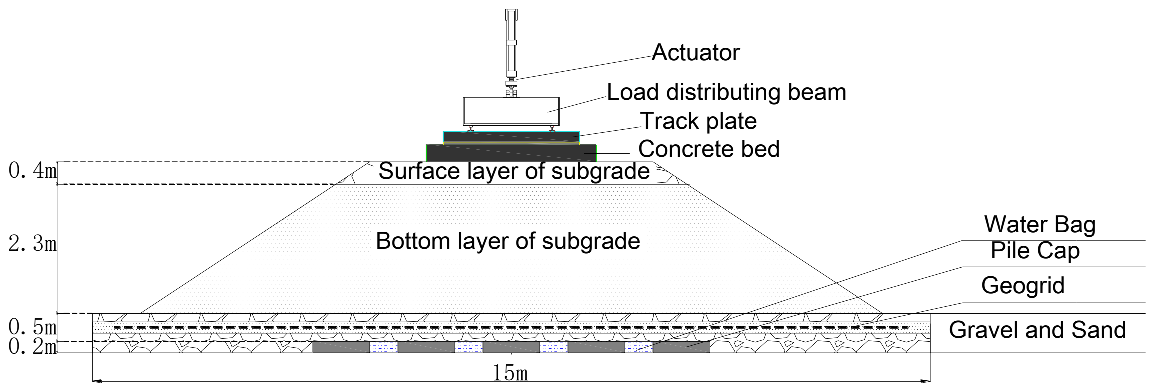


Fig. 1 Typical site cross section and geometric characteristics

The model subgrade of high-speed railways has been constructed in a test chamber with 5.5m width, 15m length and 4m height at Zhejiang university, China. The typical cross section, including with model foundation, geo-grid reinforced cushion, subgrade, track structure, and loading system is presented in Fig. 1

## 2.2. INSTRUMENTATION

Two optical fibers with a length of 4m were installed on the ribs of the geo-grids within the cushion on the pile caps (see Fig. 2). Eighteen Bragg gratings measured by an optical instrument, called Micro Optical sm130, were also installed on the ribs of the geo-grids (see Fig. 2). The Bragg grating can measure the local strain with a high accuracy without disturbance from the outside circumstance (Briancon et al. 2004). The results from the Bragg gratings can be compared to the results from the distributed optical fibers.

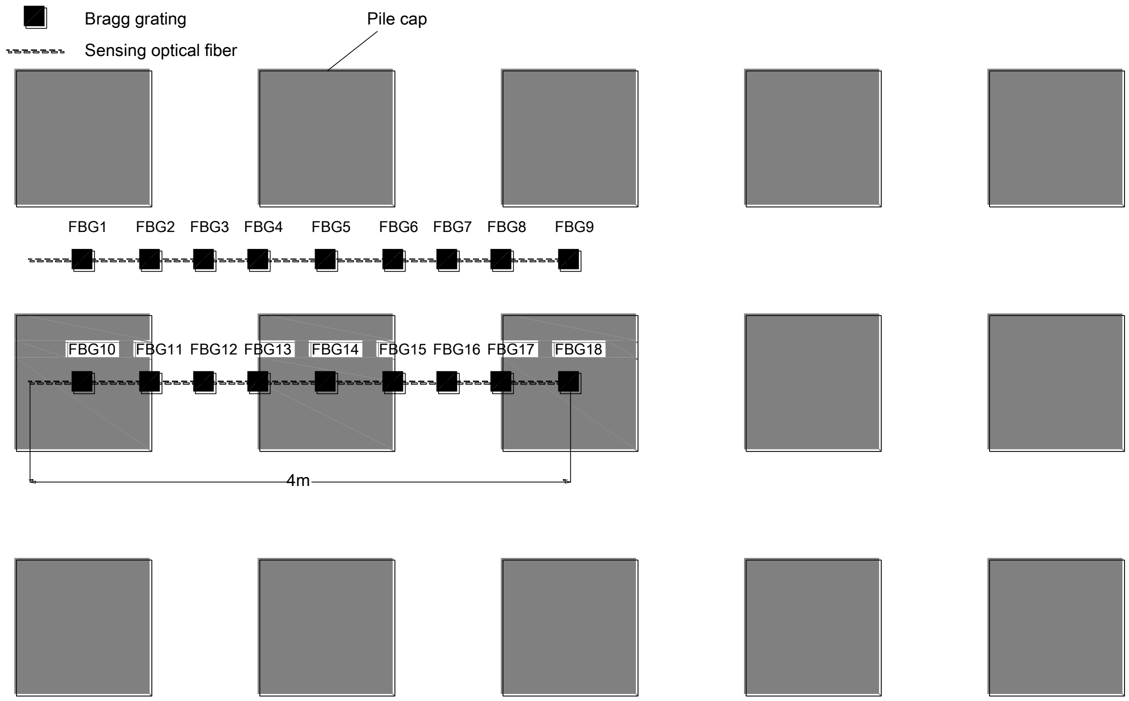


Fig. 2 Location of optical fibers and Bragg gratings relative to the pile caps

## 2.3. TEST PROCEDURES

Tests under static loading were carried out. In the static loading test, the eight actuators applied the static loads to the track rail simultaneously. The static loading test was dived into 11 stages (Fig. 3). After the loading of each stage, the tensile force of the geo-grid was measured by the optical fibers and the Bragg gratings.

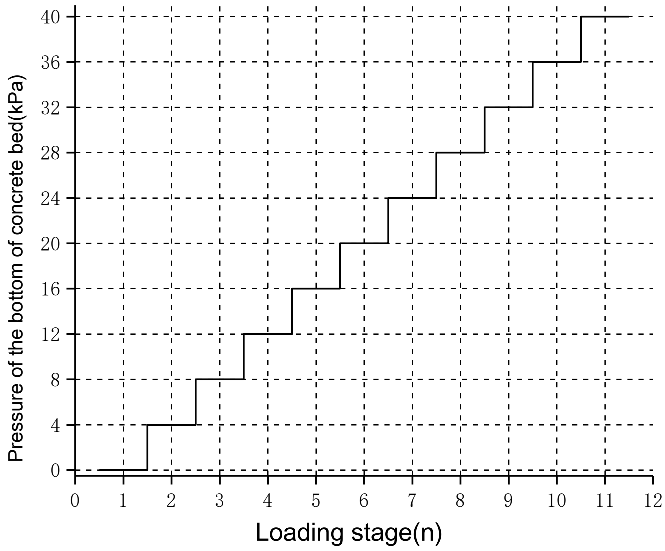


Fig. 3 Static loading test

## 3. RESULTS AND DISCUSSIONS

Figure 4shows the distribution of tensile force shift in geo-grid caused by the average static load of 40kPa. As shown in Fig.4, tensile force shift in geo-grid is largest in the center of the embankment increasing about 0.25kN/m, and reduces gradually along the subgrade slope direction. Figure 5 shows the tensile force in geo-grid at the center of the embankment. As shown in Figure, the tensile force in geo-grid increases as the static load increases, but the increment is not evident. The spreading force in the embankment will slightly increase the tensile force in the geo-grid. However, the increment is too small to be ignored. The existing calculating methods, except Japanese code, overestimate the tensile force caused by the spreading force. However, it can prove that the accuracy and sensitivity of optical fiber are very high to a certain extent. Figures 4 and 5 also show that the results from the optical fiber sensors and the Bragg grating are in consistence. The measuring result of Bragg grating is slightly lager than the result of optical fiber. The difference (nearly 0.05kN/m) is too small to be ignored. The tendencies of tensile force in geo-grid measured by Bragg gratings and optical fibers are nearly synchronous, especially when the static load increased from 15kPa to 20 kPa, both measuring result from the distributed optical fibers and the Bragg gratings have a rather slight increment. It can prove the measuring results of optical fiber are very reliable in further.

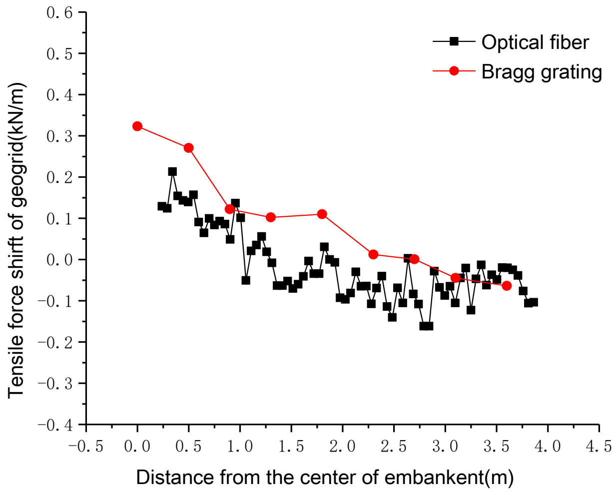


Fig.4 Tensile force shift of geo-grid at the static load of 40kPa

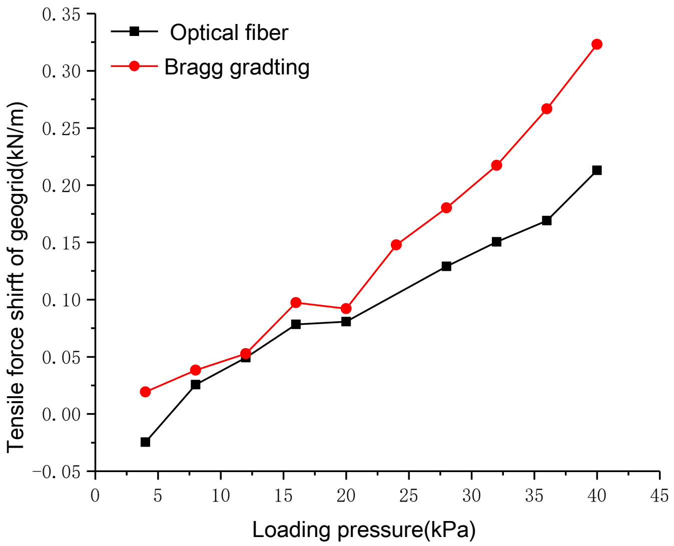


Fig.5The tensile force in geo-grid at the center of the embankment

## 4. CONCLUSION

A full-scale model test on the performance of subgrade of high-speed railway was conducted. Static loading test were completed. A distributed optic-fiber sensor system for measuring the longitudinal tensile force in geo-grid has been installed in the test. The sensor system was based on pulse-prepump-Brillouin optical time domain analysis (PPP-BOTDA). The measuring results by PPP-BOTDA were verified by the result of the Bragg grating. The distributed optic-fiber sensor based on PPP-BOTDA method for measuring the strain is accurate, reliable, and convenient to be installed. The method can be used for measuring the force in geo-grid. Due to the relatively small measuring range (about 10000 $\mu\varepsilon$ ), optic-fiber sensor is more suitable for the small strain measurement. The spreading force in the embankment will slightly increase the tensile force in the geo-grid. However, the increment is too small to be ignored. The existing calculating methods, except Japanese code, overestimate the tensile force caused by the spreading force.

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