A feasibility research on foundation pit monitoring using BOTDR

J. Liu, B. Shi, D. Zhang, H.B. Sui & W.B. Suo
Center for Engineering Monitoring with Opto-Electronic Sensing (CEMOES), Dept. of Earth Sciences, Nanjing University, 210093, China

ABSTRACT: The stability of foundation pit with supporting system such as piles and retaining wall is an important issue during excavating, therefore the deformation, strain and stress of foundation pit of most engineering must be monitored using the relevant devices. For large-scale foundation engineering, the traditional monitoring techniques can't often satisfy the monitoring requirement any more. In this paper, the Brilliouin Optical Time Domain Reflectometer (BOTDR), a newly developed distributed measurement technique, was introduced and an experiment was made to simulate the practical deformation of foundation pit. A sensing optical fiber was bonded to the inclinometer tube to apperceive the deformation distributed on it under loading, then measured using BOTDR, finally the measured results was in contrast to the results measured using strain gauges .The comparison results show that the strain measured by BOTDR has a good relationship with the values from strain gauges. And meanwhile BOTDR is also able to measure the strain distribution of the tube with a sample resolution of 5 cm that can reflect the deformation in the longitudinal direction of the inclinometer tube. The above-introduced method has been used in a practical foundation pit monitoring. The monitoring results indicate that it is feasible and effective for foundation pit monitoring.

1 INRODUCTION

In the recent decade, China has experienced a constructional revolution. More and more projects have been carried into practice, and a large number of infrastructures have been built very quickly, especially high-rise or super high-rise buildings. Meanwhile, the foundation pit projects have been widely developed as well accompanying with the construction of the buildings. Thus, it becomes a big issue how to monitor and assess the stability of the foundation fit or its impact on the surroundings. Since it is a conventional and necessary work to monitor the foundation pit engineering using relevant devices such as gradienter, inclinometer, etc.. However these conventional measuring and monitoring instruments have some obvious deficiencies in use, for instance most monitoring methods belong to pointed mode, not distributed, and must monitor in site and can't measure and monitor the objects in long distance. (Du F. &Chen Z.L., 2000, Yun J.R, et al, 2002). Brilliouin Optical Time Domain Reflectometer (BOTDR) is a newly developed distributed measurement technique with its advantages followed (Komatsu K, et al, 2002, D.Zhang, et al, 2004, Kurashima T, et al, 2002):

First, BOTDR is a kind of distributed optical fiber sensors; only from one end of an optical fiber it can continuously and simultaneously get the strain and the temperature distributions at any points of the structure along the optical fiber. Second, the maximum monitoring distance of the BOTDR is 80km, so it can monitor and measure the deformation distributions of the big structure such as tunnel, dam, levee, slope, etc.. On the other hand, the optical fiber in BOTDR serves as both purposes: the sensor and the signal transmission medium, so that BOTDR can be able to monitor the structure from the remote monitoring center and do not need anybody in the field to do it. Third, optical fiber is made of quartz glass which is a non-metal material, so it has the ability of resistance to rust and erosion, and it can also be used in most of severe conditions such as humid, arid or acid conditions, high or low temperatures. Finally, BOTDR can be connected to the network monitoring, so that it can be controlled through remote Internet.

Based on this technology, an experiment was carried out to investigate the behavior of distributed optical fiber sensors using BOTDR to monitor the deformation of foundation pit, and discussed the feasibility of using the gradienter tube to monitor the deformation of foundation pit based on BOTDR.

2 BASIC PRINCIPLE OF BOTDR

The detection principle of BOTDR is briefly outlined as followed: continuous light emitted from the DFB-LD laser light source can be separated into the probe light to be output to the optical fiber. The probe light can be modulated into the pulse light by an intensity modulator. The Brillouin backscattered light takes place as the pulse light launched into the optical fiber interact with the acoustic phonons, and the frequency shift of Brillouin backscattered light occurs compared with the frequency of the launched pulse light. The frequency shift amount is in proportion to both the longitudinal strain of the optical fiber and its temperature (Komatsu K, et al, 2002, D.Zhang, et al, 2004, Kurashima T, et al, 2002, Bao, X.Y., et al, 2001). Figure1 shows the strain dependence of the Brillouin frequency shift.

The key of BOTDR is Brillouin spectroscopy and Optical Time Domain Reflectometry (ODTR) that enables BOTDR to measure strain generated in optical fibers as distributed in the longitudinal direction. When the strain occurs in the longitudinal direction of optical fiber, the backscattered light of Brillouin undergoes a frequency shift that is in proportional to the strain. Brillouin frequency shift is function of strain (ε) and can be expressed by equation (1):

$$v_B(\varepsilon) = v_B(0) + \frac{dv_B(\varepsilon)}{d\varepsilon}\cdot\varepsilon \qquad (1)$$

Where $v_B(\varepsilon)$ is Brillouin frequency shift with strain; $v_B(0)$ is Brillouin frequency shift without strain; $dv_B(\varepsilon)/d\varepsilon$ is the proportional coefficient of strain that is about 0.5 GHz (/ % strain), and ε is the strain.

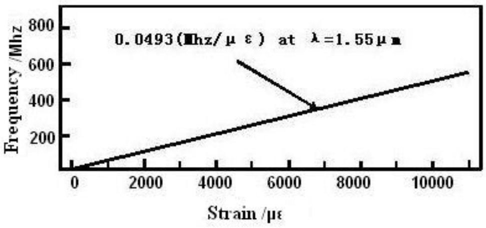

Fig. 1 Strain dependence of Brillouin frequency shift change

3 ANALYSIS OF THE EXPERIMENT

In the laboratory, an inclinometer tube was used to simulate the deformation of the foundation pit. And the optical fiber was bonded to the inclinometer tube tightly to obtain the distributed deformation along the inclinometer tube, which was under loading test step-by-step. In order to compare with the results obtained by BOTDR, some dial indicators are also used to measure the deformation of the inclinometer tube.

The distributed strain of the inclinometer tube at any points can be gotten by BOTDR, the deformation of the inclinometer tube under different loadings can be calculated. The deformations obtained by both BOTDR and dial indicators can be put together to contrast. Figure2 shows the contrast result, where the different type lines mean the deformation curves of the inclinometer tube gained through BOTDR under different loadings, and the dispersive points are the deformation value get through dial indicators.

The result shows the deflection calculated by the strain of BOTDR approached very well with the value of dial indicators, and also the strain gotten from BOTDR can be regarded as linear data, it can reflect the deformation in the longitudinal direction of the tube. The negligible errors of the values obtained from BOTDR and dial indicators can be contributed to the 1m spatial resolution of BOTDR.

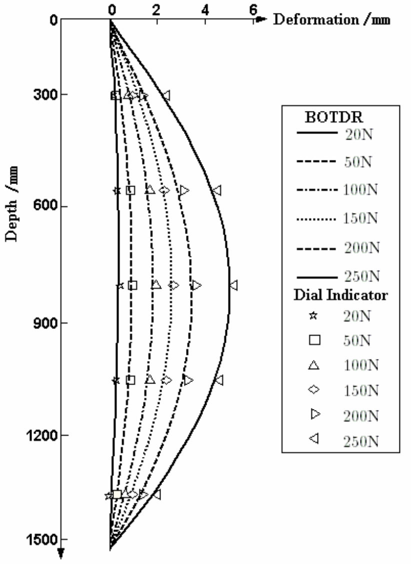

Figure 2 The comparison of the deflection getting through dial

4 APPLICATION TO FOUNDATION PIT MONITORING

In order to apply the technology mentioned above to the practical engineering, the research group did some practical test in a foundation pit in Nanjing city. The foundation pit was excavated 14.9m in depth; prepared to take cast-in-situ pile to support. Around the foundation pit, using some artifices, the inclinometer tubes was embedded in the surrounding earth. And the optical fibers were bonded to each side of the inclinometer tube. The constructional approaches are as followed: first, cut two grooves on each side of inclinometer tube, and then, adhered two-piece of optical fiber on each side of the grooves with epoxy adhesive. One of them was used to monitor the deformation of the inclinometer tube passed by the soil while the other was used to eliminate the influence of the temperature (Ohno H, et al, 2001).

Inclinometer tube with optical fibers attached is buried in the ground. When deformation occurs, strain is produced in the tube and the optical fiber. This kind of monitoring method can make it possible that to determine the underground deformation with depth accurately, which was difficult to conventional measuring equipment that attached strain gauges at dispersed intervals. When a pulse signal was given by BOTDR, the light pass through the optical fiber stuck to the inclinometer tube. Then the signal of deformation and temperature of the ground can be obtained. Figure 3 shows the basic configuration of the monitoring system.

All of the optical fiber adhered to each inclinometer tubes can be fused together to merge into network, and to construct an automatic measuring system. The automatic measuring system can monitor the deformation of foundation pit remotely, set the measurement conditions, transfer the measurement data, as well as analyze the data. Therefore, we can remote monitoring the foundation pit three-dimensionally at the same time. Figure 4 shows the automatic measuring system.

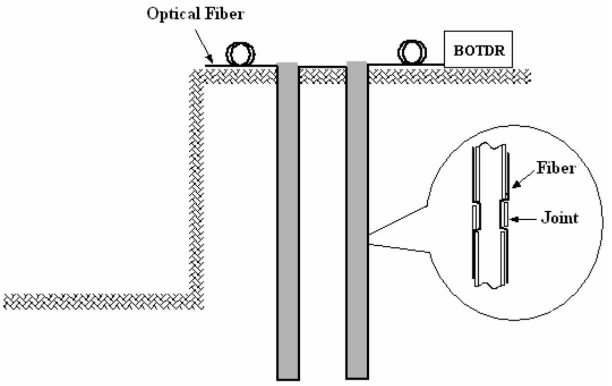

Figure3 The configuration of the inclinometer tube adhered with optical fiber

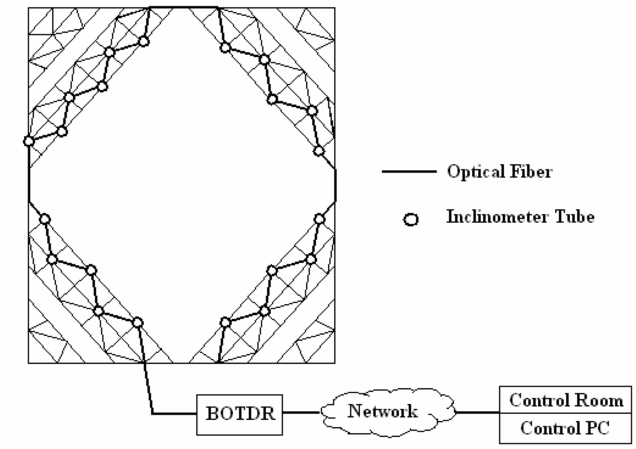

Figure4 The automatic measuring system of foundation pit

5 CONCLUSIONS

From the description above we can see that optical fiber sensing technology like BOTDR can be able to monitor the deformation of foundation pit, and it can be served as a very powerful monitoring technology for large foundation pit monitoring. And it has a great potential and will have wide applications in the future. The results of practical foundation pit monitoring mentioned above will be described in another paper detailedly, and some various issues still remain to further study, such as protecting methods of the fiber sensors, sensor installation methods, and compensating for the temperature effect, improvement of spatial resolution, etc. Therefore, further efforts are needed to solve these issues through fundamental experiment and verification tests.

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