Application on Measurement of Pre-stress loss in Concrete Structure with Fiber-optic Sensors

Tang Hongwei[1], Li Wansheng[2], Li Yuhong[2]

(1 Testing Center of Mechanics & Engineering, South Campus, Shan Dong University, Jinan, Shandong Province, People's Republic of China, 250061

2 Shandong Institute of Metrology, Jinan, Shandong Province, People's Republic of China, 250014)

ABSTRACT: As one of the important works in the pre-stressed concrete structure design, magnitude of the pre-stress loss has not been measured conveniently until now. A suitable measuring technique for pre-stress loss is the studying goal of researcher in a long time. In the present work, the fiber-optic measuring technique has been introduced to measure the pre-stress loss, and all of the measuring works were conducted on the model of a wastewater tank. Result of the measurement shows that optical fiber sensor can be used to measure the pre-stress loss in engineering, and the short-term pre-stress loss of steel strand is strongly effected by the arranging manner of steel strand, the magnitude of pre-stress loss measured in the present work is less than 20%.

Key words: Fiber-optic sensor; Pre-stress loss; Concrete structure

Pre-stress loss (PSL) in concrete structure, the difference between stress produced by preloading on the structure and the pre-stress held in the normal service, which mainly caused by: friction between steel bar and its tube, anchor deformation and pre-stressed steel bar shrinking effect, elastic-compressing deformation during applying tensile force, relaxation of pre-stressed steel strand, and shrinkage and creep of concrete. Among of them, the pre-stress loss due to the previous three factors is called instantaneous stress loss. While the pre-stress loss produced by the later factors named long-term stress loss, because of its magnitude increasing along with the prolonging time. For the pre-stressed concrete structure, whether the pre-stressed system built by the anchors and steel strands meet the needs of engineering design, it not only influence on the structural life but also on its safety and durability. With respect to estimating the pre-stress loss of structure accurately, including the instantaneous stress loss and long-term stress loss in service (especially the instantaneous stress loss), it will bring out a great value in engineering. However, the pre-stress loss magnitude is usually estimated in engineering design, no suitable measuring technique founded still now.

Since the feasibility of fiber-optic sensor applied in on-line measuring for steel-bar concrete structure and civil building demonstrated firstly by Mendez et al. [1] of Brown University in 1989, the measuring technique of optic fiber, for its advantages of small bulk, strong corrosion-resistance, high precision, accurate locating and anti-electromagnetic-wave interference etc, has been developed rapidly in monitoring and controlling of the stress, strain, temperature, vibration and the crack initiation and growth. The rational results have been obtained by adopting this technique in engineering [2~3]. In the present work, taking a large-scale sewage-treating cesspit (a pre-stressed concrete structure) as the engineering background, the fiber-optic measuring technique is adopted firstly to establish the instantaneous stress loss on the special experimental model.

1. Theory for measuring pre-stress loss by optical fiber sensor

The shape of the fiber-optic sensor adopted in experiment is shown in Fig. 1. The measure of sensitivity can up to 0.025μm because the deformation of steel-strand is gauged through measuring the reflected intensity of light. During the test, a semiconductor laser is employed as the light source. The measuring range is affected by the measure of the fiber-optic sensor section, and it is limited in the distance in front of light apex to obtain the result accompanying good linearity and sensitivity, according to the distinguishing feature of displacement-voltage curve of the semiconductor laser.

Fig 1 Fiber-optic sensor used in the pre-stress loss measurement

The detailed measuring theory is shown in Fig. 2. The light produced by laser irradiates to the steel-strand through the sending optical fiber, and a reflector that is fixed on the steel-strand will reflect it. Then, it is collected by a receiving optical fiber and transmitted to the photo-electricity checker. To explain the relationship of the received light-intensity and displacement changes quantificationally, the reflector should hold vertical state with the optical fiber probe during its moving, for the received light-intensity would change along with the distance changing between the reflector surface and optical fiber probe. A piece of reference optical fiber is added in measuring system to avoid the metrical error due to light-intensity change during long-time measuring, and the ratio of light-intensity is utilized to obtain the displacement.

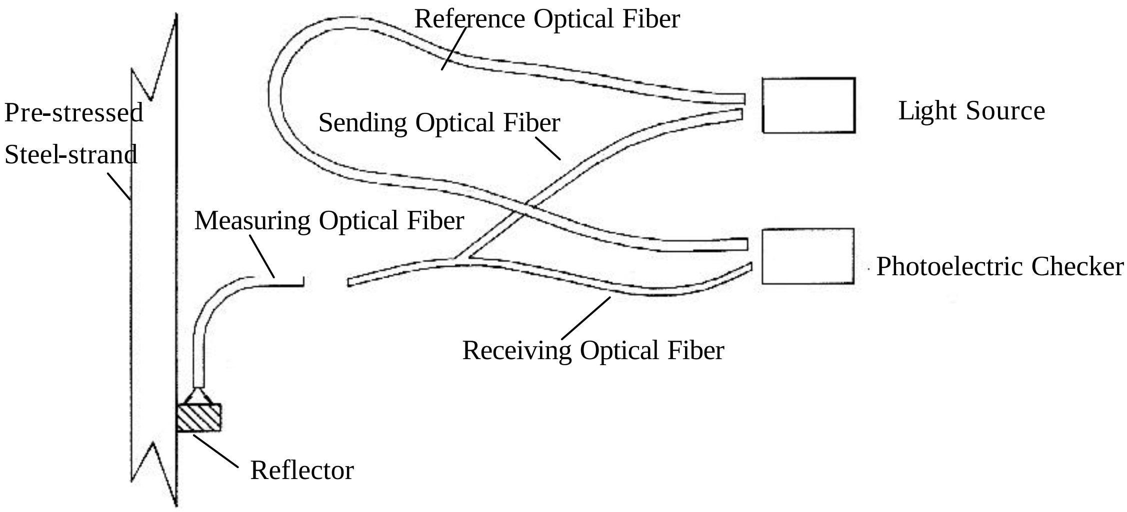

Fig.2 Measurement theory of optical fiber sensor

Before conducting the test, an optical fiber sensor was installed on the steel strand and a reflector was fixed on the same steel-strand. To make the optical fiber sensor probe vertical with the reflector surface, the normal of reflector was set paralleling with the displacement direction of steel-strand. The calibrating distance of the sensor is assumed L=200mm, and the magnitude of section area of he sensor is defined by the displacement of steel strand in the calibrating distance. The light-intensity received by the reference optical fiber and receiving optical fiber is transmitted to photoconductive element, after magnified, compared and analyzed by the interrelated electric circuit, and then it will be transformed into the displacement and be outputted. Further more, the optical fiber sensor is calibrated on the SCHENCK-RSA250 electric material-testing machine in order to obtain the curve of tensile stress on steel strand and the voltage outputted by the optical fiber sensor. The calibrating equipment system is shown in Fig. 3.

Fig 3 Calibrating system for the fiber-optic sensor

Fig 4 Testing model for wastewater tank

2. Procedure and approach for measuring pre-stress loss by using optical fiber

In order to measure the pre-stress loss on steel-strand integrally and conveniently and not influencing the constructing course and quality of the sewage-treating cesspit, a testing model which is provided with the same materials and structural size with the sewage-treating cesspit is constructed at the working spot, as shown in Fig.4. The shape of testing model appears arc, and its radius is 27m. There are four pieces of steel-strand arranged in the model: two of those appear arc-shape with radius 27mm, and the others show straight line. The preloading is putted on those steel-strands from one-end. Eight windows are arranged in the model to place the measuring fiber-optic sensor. For the sake of convenient marking, the bottom and top arc-shape steel-strands are numbered as II and I respectively, and other two straight-line steel-strands are numbered III (top) and IV (bottom). There are 5 points for measurement on No. II and I, while 2 points are arranged on No. III and IV respectively. One fiber-optic sensor is installed at every measuring point on the steel-strand. During the course of tensile, Computers are conducted to collect the output signal via some secondary meters. Eventually, the stress of steel-strand at each measuring point can be obtained after analysis and treatment.

The step-by-step procedure for measuring pre-stress loss is the following:

(1) Measurement for pre-stress loss due to friction between steel-strand and its tube

The identical tensile force with that thrown on the sewage-treating cesspit is applied on the testing model, and at the same time, the pre-stress of steel-strand at each measuring point is monitored until the test is over.

(2) Measurement for pre-stress loss due to anchor deformation and steel bar shrinking effect

In the test, a single-hole arch marked OVM15-1 and a squeezed arch are installed respectively at the stretched end and the fixed end of a steel-strand, just as adopted in the sewage-treating cesspit. The tensile load exerted on the model system is controlled in the light of engineering design demand. The collets of testing machine are held when the tensile load come up to the demand loading, and then the varying course of loadings is recorded by computer.

(3) Measurement for pre-stress loss due to pre-stressed steel bar relaxation

The special clamping tool and steel-strand identified with used in the previous test are adopted in this course. The loading is conducted according to the demand in the engineering tensile technology. The control mode of testing machine is changed into strain controlling when the tensile load come up to the demand loading, and then the varying course of loadings is recorded by computer.

3. Results and discussion

The evolutive rule of instantaneous stress loss at each metrical point of steel-strand No. I, II, III and IV, due to the friction between steel-strand and its tube, is shown in Fig. 5. It can be seen from the results that: there is about 18% tensile loading lost at a distance 4m from the fixed end of steel-strand No. II and I. Following this rule, it is could be deduced that the tensile force loss does not exceed 20% at the fixed end. Moreover, the value of tensile force loss at a distance 7.4m from the fixed end of the steel-strand No. III and IV is about 7%, and no more than 9% at the fixed end estimated.

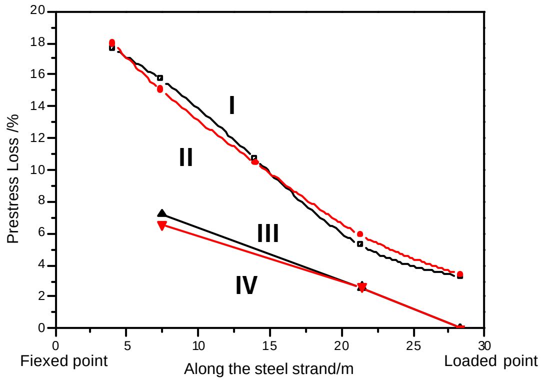

Fig 5 Pre-stress loss caused by friction between steel strand and tunnel in testing model

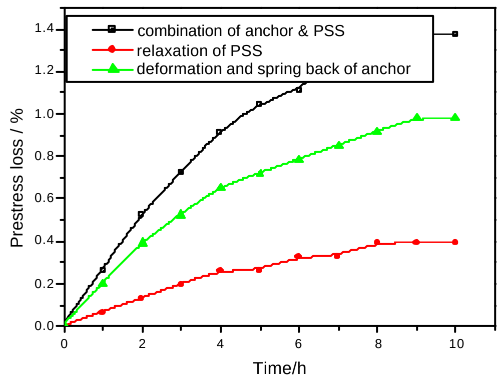

Fig 6 Curves of pre-stress loss vs. time

Fig. 6 shows the varying law of times with pre-stress loss magnitude measured by using fiber-optic sensor within 10 hours after tensile ending. It can be seen that the pre-stress loss magnitude increase along with time increasing, and the losing rate is very great within the previous 5 hours. At the same condition, the stress loss due to pre-stressed steel bar relaxation is less than that due to anchor deformation and steel bar shrinking effect. Furthermore, the magnitude of pre-stress loss caused by anchor deformation and steel bar shrinking effect is by less than that due to friction between steel-strand and its tube, within 10 hours after tensile ending.

4. Conclusion remarks

1. The fiber-optic sensor can be applied in measuring pre-stress loss of concrete structure conveniently and accurately.
2. The arrangement style of steel-strand in concrete structure will affect the pre-stress loss: the value of stress loss on steel-strand arranged in arc-shape is large than that on straight-line arranging steel-strand. If the arranging style of steel-strand is different with that in engineering design, the pre-stress loss will large than value estimated in design.
3. According to the testing results measured on the special model, the magnitude of instantaneous pre-stress loss on steel-strand in sewage-treating cesspit does not exceed 20% of applied tensile force.

References

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