Method for
“Measuring Tendon Force Using an Optical Fiber Sensor”

「光ファイバを用いた PC 張力計測システム」の概要




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1. Background

Applying and maintaining a designated force on a tendon is required to ensure higher quality and durability of a prestressed concrete (PC) structure. When under construction, the tensioning force is calculated indirectly by both a pressure gauge of the hydraulic pumping unit and elongation of a strand measured by a scale. Besides such conventional methods for measuring a force at specific location, there has been no method to monitor the force along the tendon. Integrating an optical fiber strain sensor (OFSS) into a prestressing steel strand, the authors tried to develop a method that can directly monitor the tensioning force along the whole length of a tendon both during construction and in service.

2. Measuring Tendon Force [1]

(1) Optical Fiber Strain Sensor

Over the past decades, OFSSs have attracted increasing attention because Brillouin-based sensors in particular can make fully distributed strain measurements. When a light wave passes through an optical fiber, Brillouin scattering occurs spontaneously because of acoustic phonons. Therefore, the scattering occurs all along the optical fiber, and it is well known that the wavelength of the scattering depends on the strain at the location where the scattering occurs. An example of Brillouin-based measurement is illustrated in **Fig.1**. Injecting a pulsed light wave, Brillouin scattering occurs along the optical fiber. The frequency of the backscattered light wave gives the strain information, and the return time of the scattering gives positional information. As a result, the strain profile along the whole length of the optical fiber can be measured.

(2) OFSS-embedded PC Strands

Leveraging the advantages of OFSSs, the authors integrated an OFSS into a PC strand. The optical fiber is embedded with the strands, and thus the force distribution can be calculated by measuring the strain distribution, as shown in **Fig.2**. Currently, a bare strand and an epoxy-coated and filled (ECF) strand have been fabricated, as shown in **Fig.3**. For both types, the optical fiber is placed into the gap between the stranded wires, thereby preventing damage during delivery and construction. Because of such insertion, stressing, and anchoring of the strands, the OFSS-embedded PC strand can be handled as if it were a common strand. Various laboratory experiments have been conducted

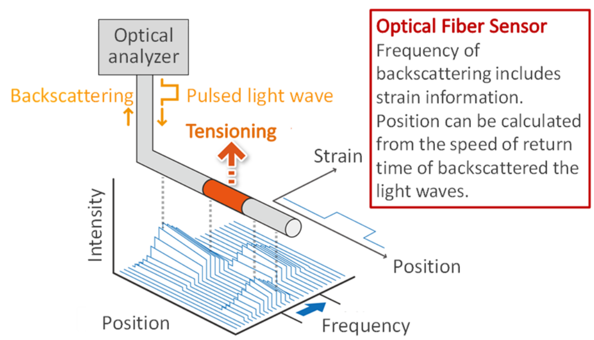


Fig.1 Strain measurement principle

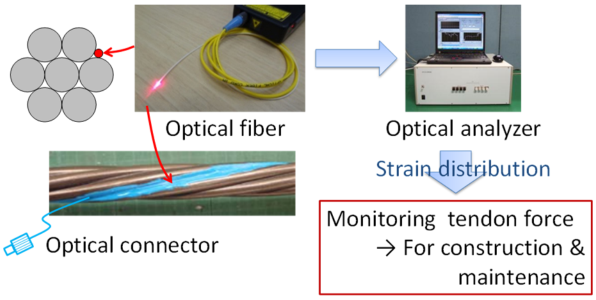


Fig.2 Methodology of tendon force monitoring

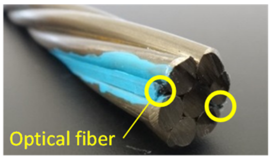
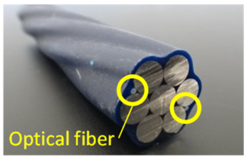
Bare strand (For bonded tendon)	ECF strand (For unbonded tendon)
	
Optical fiber is directly bonded to strands with adhesive.	Optical fiber is embedded into epoxy coating.

Fig.3 Two types of OFSS-embedded strand

to evaluate the strands in terms of quality, workability, and durability. For instance, the performance was examined by tensile tests in straight and curved lines at first. Then, tests on single and multiple strands with or without grouting were conducted. Of course, a pinhole test was done on the ECF strand to confirm its long durability.

(3) In Situ Monitoring during Construction

The OFSS-embedded strands were applied to tendons of the upper slab and web of the box girder under construction. **Fig.4** shows the longitudinal cross section of the pier of the Tsukidate Viaduct. It should be noted that the slab tendon is almost a straight line and the web tendon is a curved line. The following are the specifications of Tsukidate Viaduct:

Location: Fukushima prefecture, Japan
Structural type: 6-span continuous rigid-frame girder bridge
Bridge length: 462.0m
Span: 44.5m + 4 × 91.0m + 51.5m
Effective width: 12.0m and 14.5m
Design: Sogo Engineering Inc.
Construction: Kajima Corporation

Construction was completed successfully on site, and the OFSS survived. During tensioning by hydraulic jacks at both ends, the applied force on the strands was measured. **Fig.5** and **6** show the measured tensioning force along the tendon on the web and the slab, respectively. On the web tendon at final stressing, the tensioning force clearly decreased from both ends to the center because of friction loss. Also, the anchoring loss is revealed on both the slab and the web. Consequently, the applied force satisfied the design along the whole length of the tendon. After anchorage, the use of the OFSS was extended for long-term maintenance so that the force could be monitored if required.

3. Conclusion

A measurement method has been developed whereby the tensioning force can monitored at any section along the whole length of the tendon by embedding an OFSS permanently in a PC strand. The method has been applied to an internal-tendon post-tensioned concrete viaduct. It is confirmed that this method is capable of measuring the tensioning force at any certain section along the whole length of a tendon during tensioning and after a bridge has been constructed.

Reference

[1] Okubo, K., Imai, M., Chikiri, K., and Nakaue, S.: *PC-tension stress measurement method by optical fiber*, Proc. of the 26th Symposium on Developments in Prestressed Concrete, Kobe, pp. 283-288, Oct. 2016. (in Japanese)

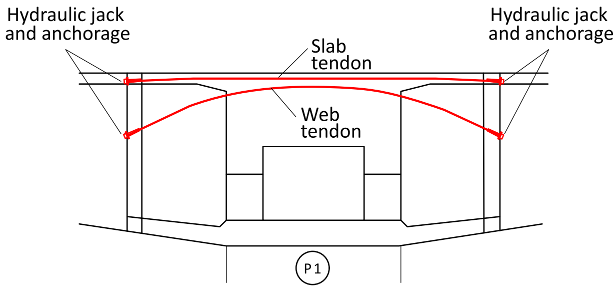


Fig.4 Monitored tendon configurations

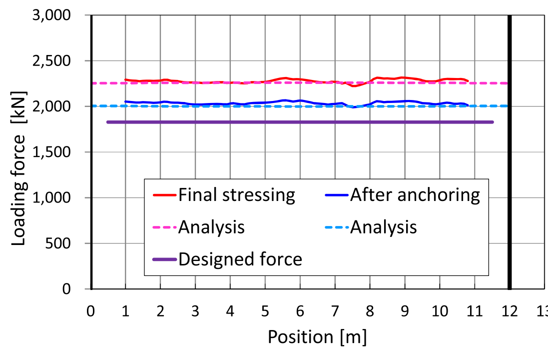


Fig.5 Measured force distributions in slab tendon

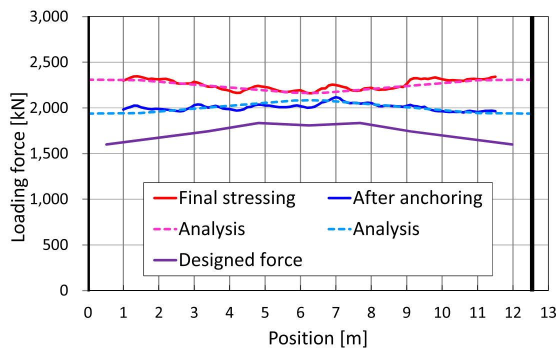


Fig.6 Measured force distributions in web tendon