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System for real-time monitoring and controlling of elongation of post-tensioning tendons

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ABSTRACT

In moderate-to-high seismic regions, construction of post-tensioned structures is increasingly popular due to its excellent seismic performance associated with large lateral drift capacity and elastic restoring or pre-compression characteristics. In the post-tensioned construction, tendon elongations have been used to determine tension forces of the tendons. The tendon elongations are measured using analog method. A worker measures the elongation after seating directly using a ruler and/or reads the piston movement by eye during stressing. In the conventional practice, a hydraulic pump is controlled manually, and the critical measurement and the pump control do not happen at the same time. Therefore, losing the stop point of the hydraulic jacking can cause the tendon to be tensioned to a specific range that is substantially offset from a pre-determined value or even momentarily yielded. In terms of accurate measurement, an initial slack of each strand needs to be removed since the initial slack affects the measured total elongation of tendons, particularly multi-strand tendons. However, the measurement of the initial slack has required an extra process, which spends additional time and money. In this study, a novel system was developed for accurate measurement and management of tension forces in tendons based on sensor data including pressure and elongation length data.

1. INTRODUCTION

In moderate-to-high seismic regions, construction of post-tensioned structures is increasingly popular due to its excellent seismic performance associated with large lateral drift capacity and elastic restoring characteristics. Cast-in-place post-tensioned structures utilize energy absorption and ductility of mild reinforcing bars together with high (elastic) prestressing force and/or in-plane compression. Also, structural integrity is superior due to the use of continuous tendons over the supporting elements and in-situ

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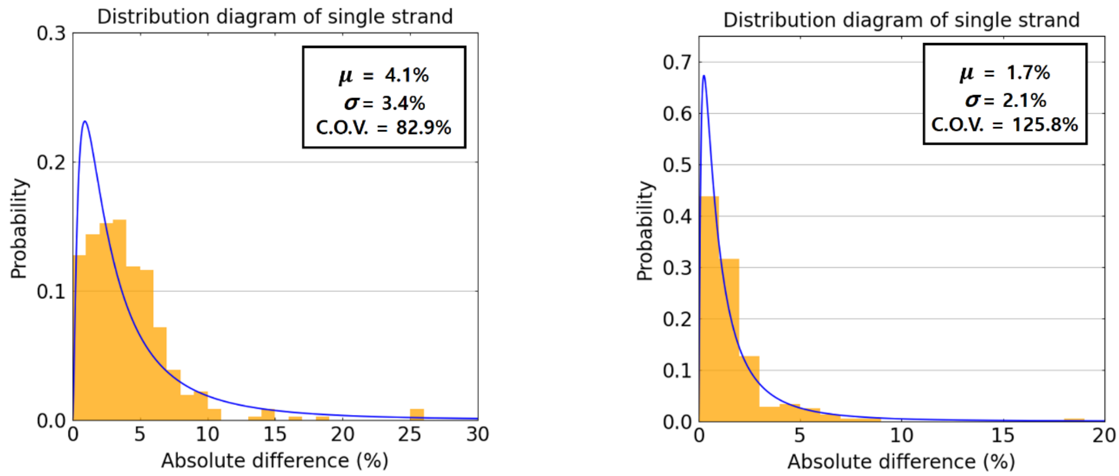
concrete placement. After a single-strand tendon is tensioned, the force inside the tendon is examined by measuring tendon elongation and comparing it with theoretically predicted elongation. Due to initial slack in each tendon, pressure and piston movement of hydraulic jack during stressing are required for calculating effective tendon elongation. The field conventional tensioning process has been performed with the analog method. An operator reads the piston movement using ruler and the pump pressure gauge by eye during stressing. The measurement is inaccurate with uncertainties from human error and various individual tendon properties. In this regard, available code provisions allow for reasonable tolerance; however, the specified tolerance is often no met in the field. To overcome such issues, Kang and Jeong (2016, 2020) developed an IoT system for measuring prestressing forces of tendons in the post-tension method. The system measures the tendon elongation according to the conventional measurement process, but it digitalizes and automatizes the process. Based on the previous research and field data, this study redeveloped a system to improve it for site application.

2. REVIEW OF FIELD DATA AND SYSTEM DEVELOPMENT

2.1 Field data analysis result



(a) Effective tendon elongtion (b) Effective maximum pressure

Fig 1. Histograms and distributions of the tendon elongation and pressure deviations for tendons

From field test of the previous system, there are a set of data consisting of 361 stressed tendons from nine construction sites in Korea. Before tensioning a tendon, predicted elongation and target pressure are calculated theoretically. The absolute deviation between the predicted elongation and measured elongation is investigated (Fig. 1(a)). In general, ACI 318-19 (2019) and other codes propose up to 7% criteria. In actual data, the average deviation is about 4%. The tendon elongation deviation occurs because deviation already exists between the applied maximum pressure and the target pressure when manually operating the hydraulic pump (Fig. 1(b)). The difference is usually slight, but the C.O.V. of 125.8% shows that the fluctuation is large with the max difference of 9% in the dataset. Result shows necessity for system that can apply accurate pressure to tendon and measure accurate tendon elongation to adjust the deviations.

2.2 Novel system development

The novel system follows the main format of the previous system but aims for a more improved system to increase its field applicability. A lighter data logger is manufactured for measurement unit (Fig. 2). The data logger measures elongation and pressure with each sensor. The inner algorithm of data logger calculates the effective tendon elongation, which is calibrated with real-time data. The novel algorithm is simpler and more automatic than the previous one. Additionally, the novel system provides not only general modes but also additional modes for extra tensioning work (re-tensioning and dead-end tensioning).

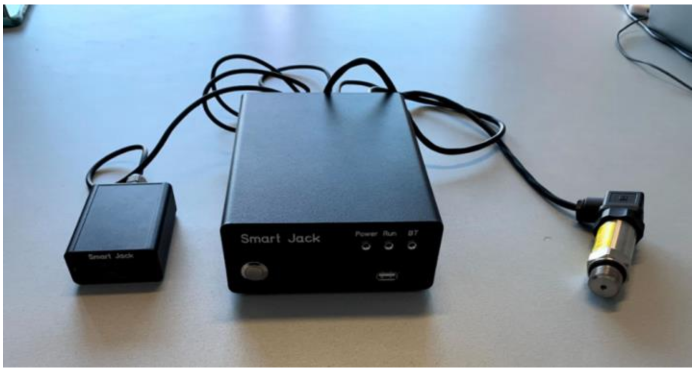


Fig 2. Manufactured measurement unit for novel system

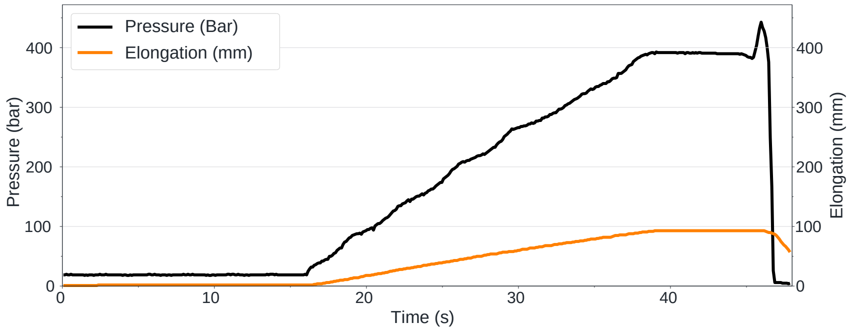
2.3 Performance test

Firstly, the calculation accuracy of inner algorithm is tested for 33 raw pressure and elongation field data recorded by previous system. Calculation results from the algorithm are compared with exact values manually calculated from the analysis of raw data. Secondly, the system is applied to a field mock-up site to verify the system operation and field applicability. Testing is done using a steel frame where a bare strand is inserted. Because the initial slack in the strand embedded in the steel beam is previously removed, the elongation length manually measured after the tensioning is the same as the effective elongation. The system accuracy is verified by comparing the manually measured elongation with the tendon elongation given by the developed system.

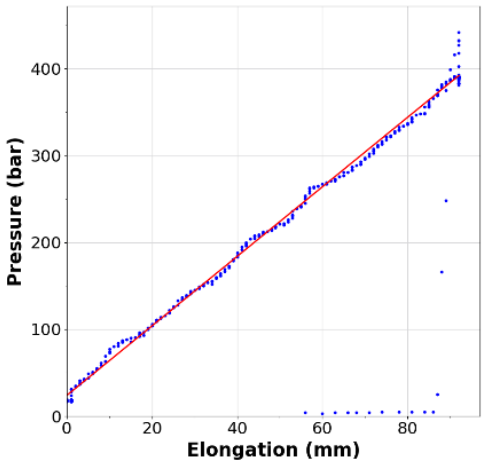
3. SYSTEM TEST RESULT AND FUTHER DEVELOPMENT FOR AUTOMATIC PUMP CONTROL

3.1 Test result

The novel algorithm returns the almost exact result for 32 tendons and the error is within ± 0.3 mm. For one tendon, an error of 2 mm occurs, but unusual pump control appears to be the main reason. The measured real-time elongation and pressure data measured in a field test are shown in Fig. 3(a). The inner algorithm calibrates elongation-pressure relationship and finally calculates tendon elongation (Fig. 3(b)). In Table 1, the manually measured elongation is 85 mm and the system returns 92 mm as tendon elongation. A difference of 7 mm is observed, which occurs for every jacking case because the piston moves while the hydraulic jack grabs the strand. Thus, the difference needs to be removed by calibration with a constant deduction value. After being calibrated, the tendon elongation read by digitalized system is almost equal to the conventionally measured one.



(a) Raw elongation and pressure data



(b) Effective elongation-pressure relationship

Fig 3. Real-time data of test tendon

Table 1. Comparison of the manually measured elongation and elongation monitored by the novel system for the tested strand

ID	Elongation		Result compare	
	Final elongation (A) (mm)	Direct method check (B) (mm)	D=A-B (mm)	Rate=D/B*100
Test	92	85	7	8.24%

3.2 Automatic pump control

Automatic pump control is a further achievement goal for deviation reduction, saving labor and prevention of strand damage, as well as convenient jacking process. Mechanism test is performed with a data logger manufactured using the popular development board (*Arduino MKR 1000*). The goal of automatic pump control is limiting the pump pressure not to exceed the target pressure only during the process of tensioning the tendon. Referring to the existing automatic pump valve products on the market, there is a method of turning the current on/off to prevent the pump from applying pressure over the limit pressure value. To implement the mechanism, the data logger sends a signal to a relay module when the pressure exceeds the limit value and the signal makes the relay break the circuit. The pressure limit should only work when the hydraulic jack is moving in the tension direction. The data logger judges the direction by measuring the angle of jack direction control lever with an angle sensor.

4. CONCLUSIONS

In this study, the system for measuring tension force in post-tensioning tendons is developed further using IoT technologies and improved from the previous system. The system digitalizes and automates the tendon elongation measurement process in typical post-tensioning construction fields. The accuracy and necessity of the developed system are investigated through field data analysis. As a result, the system operation and field applicability are verified with field application tests. The concept for implement of automatic pump control is proposed.

ACKNOWLEDGMENTS

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