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VIBRATION-BASED TENSION FORCE ESTIMATION OF EXTERNAL POST-TENSIONED TENDONS: EXPERIMENTAL STUDY

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ABSTRACT

Tendon tension loss is one of the most important damages of pre-stressed, cable stayed and suspension bridges. In this experimental study, vibration based method have been implemented for tension estimation of mono-strand externally tendon. The test has been done in IIEES structural laboratory. In order to identify the natural frequency of system, three methods have been used and their results were compared: 1) Fast Fourier Transform (FFT); 2) Frequency Domain Decomposition (FDD) and 3) Stochastic subspace identification (SSI) as output-only system identification methods. After derivation of natural frequencies of vibration from output measurements, using numerical pre-determined formula of string theory is achieved and compared to the exact amounts of tension in tendon experiment setup. The obtained results show the ability of vibration based method to estimate tension loss of external tendons.

TENDON TENSION ESTIMATION METHOD

Tension determination usually plays the most critical role in the structural health and condition monitoring of cable-stayed bridges and post-tensioned box girder bridges with external tendons (Fang & Wang, 2010; Naser & Wang, 2011; Chen et al., 2018). Even though a number of different methods have been adopted to assess the tension force of these members, limitations like uncertain accuracy, high cost, complicated instrumentation or poor robustness are commonly encountered in practice. The ambient vibration method because of the relatively simple requirements in analysis and measurement due to one-dimensional geometry, is more popular which employed in practical applications.

In this study, the vibration-based tension estimation approach starts with identifying the modal frequencies from the three different tests consist of: ambient vibration, impact and step relaxation test and then by employing a pre-determined formula, cable tension is estimated. According to the string theory, the tension of an elastic cable or tendon is obtained from an analytical formula requiring the identified frequencies together with the given vibration length and mass per unit length. The accuracy of this vibration method can be further improved by considering the effects of flexural rigidity, gravity sag, and complicated boundary constraints.

EXPERIMENTAL RESULTS

The setup as shown in Figure 1-a, include one 0.6 inch seven-wire strand, Gr270, L=10.75 m anchored at both ends with two steel bearing. Also six acceleration sensors with sampling rate 500 Hz and total time =300 sec are used in order to system identification. Figure 1-b and Figure 1-c show a sample of sensor acceleration output in impact test and FFT of that signal, respectively. First three natural frequencies are identified as follows: 4.35, 12.85 and 22.15 Hz. The other system identification methods; FDD and SSI methods lead to similar results. After identification of natural frequencies, using practical formula, tension amount of tendon is estimated and result of impact test in different stage of tensioning is shown in Table 1.

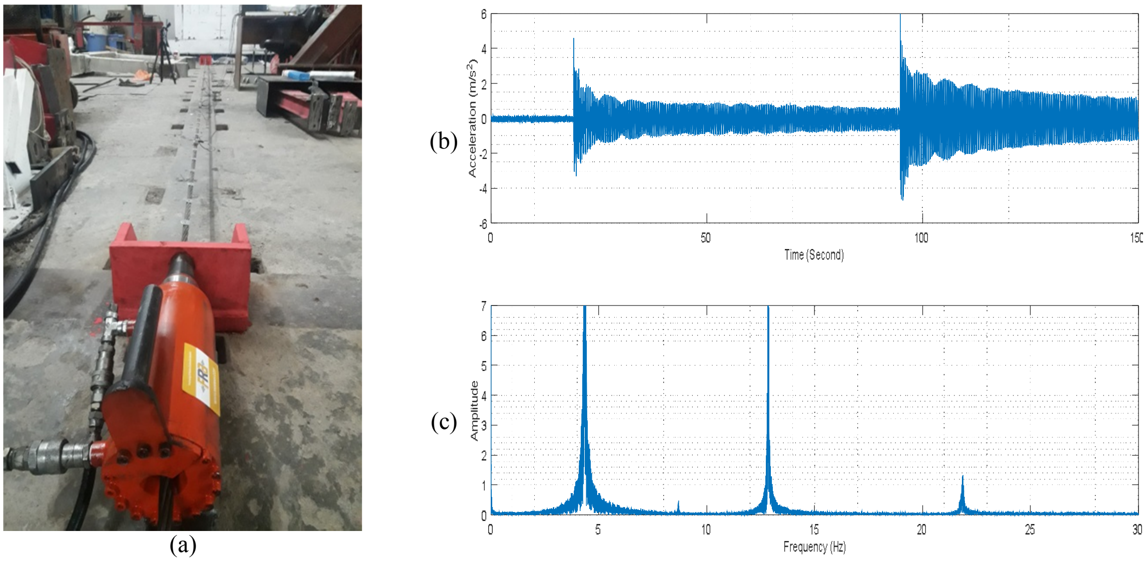

Figure 1. View of external tendon experimental test setup (a); acceleration time history in impact test at tension force 10 kN (b) and FFT of signal (c).

Table 1. Estimated tendon tension using string theory.

Tendon Tension (kN)	**10**	**50**	**70**	**80**	**90**	**100**	**120**
Estimated Tension (kN)	9.48	47.45	66.34	75.91	85.29	95.53	113.39
Accuracy (ratio)	0.948	0.949	0.948	0.949	0.948	0.955	0.945

CONCLUSION

This paper presented vibration based method for tension estimation of a tendon in box girder post-tensioned concrete bridges. All three identification methods successfully detect the lower natural frequencies and show very good performance in accuracy with minimal difference, but SSI method also identify higher natural frequencies which is suitable for long tendons in cable stayed bridges, because derivation of lower order frequencies is difficult in those cases. Finally the results from different method have been compared to the exact amounts of tension in tendon at experiment and string theory with approximately 95 percent of accuracy, shows compromising compares to the other.

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