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The Long-term Monitoring of the Stress in the Structural Components of a Tension Fabric Roof

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Abstract. This paper deals with the long-term monitoring of the stress in some selected structural components of the tension fabric roof which covers the tram stop “K Barrandovu” in Prague. Meanwhile three times the experiment was performed and it was always focused on three types of structural components – support cables anchored to the ground, edge cables placed in a fabric pocket and fabric membranes. The non-destructive experiment is based on the geometrical nonlinearity and the frequency method. The dependence of cable forces on temperature changes can be found out from the obtained results.

Introduction

Today Czech building investors prefer traditional building materials due to better knowledge about their properties and durability. There are a lot of new buildings from bricks, concrete, steel and wood in the Czech Republic presently.

The most widespread opinion on the tension fabric structures is that the fabric structures are short-term solutions only. However the behavior of Czech Architects was changed recently. They designed a few unusual and original structures of airy roofs by using of the tension fabric roof. The advantages of these structures are lower acquisition costs, an easy potential replacement of a fabric membrane and various roof shapes. The disadvantages are limited usage, a complicated structural design theory and high production requirements.

Building companies, which are specialized in tension fabric structures, are small. Their competitiveness does not permit to check the prestress forces in the support and edge cables during the construction of a tension fabric roof and to inspect the changes of the cable prestress forces after some years. Another problem is the influence of temperature changes to stress in roof structural components.

The team of authors of the paper developed the measurement system for the non-destructive experimental determination of the stress in support cables, edge cables and a fabric in the last few years [1, 2, 3, 4]. At first, its verification took place in a laboratory and then it was used on a real structure.

The Description of the Experiment

The roof structure of the tram stop “K Barrandovu” in Prague was observed by the described long-term experiment. The investigated structure is shown in Fig. 1. A stop was built in 2002 and the maintenance of prestress in the support cables was carried out in 2004.

Fig. 1 The overview of the tension fabric roof of the tram stop “K Barrandovu” in Prague.

Fig. 2 The observed points of the investigated tension fabric roof.

The experiments took place three times on 21st March 2009, on 22nd March 2012 [1] and on 22nd March 2013. Although the experiments were carried out in the same time of year practically, the air temperature was significantly different at each stage of the experiment. The air temperatures were about 4°C in the year 2009, 14°C in the year 2012 and 0°C in the year 2013.

The prestress forces were determined experimentally on the four support cables, in three points on the edge cables and in three points on the fabric membranes. The observed points on the cables are shown in Fig. 2.

The second order theory was used for the basic results evaluation of the nondestructive experiment focused on the prestress forces of the cables. If the mathematical model of a cable is considered as perfectly flexible, then the axial force N can be calculated from the measured transverse displacement Δw and the measured transverse force F_p on the basis of the simple relations between N, Δw and F_p

$$N = \frac{F_p}{2}\sqrt{\left(\frac{L}{2\cdot\Delta w}\right)^2 + 1} \tag{1}$$

$$N = \frac{F_p}{2}\sqrt{\left(\frac{L}{2\cdot\Delta w}\right)^2 + 1} - \frac{E\cdot A}{2}\cdot\left(\sqrt{\Delta w^2 + L^2/4} - L/2\right)/L_c \tag{2}$$

where L is the original length of the cable used by the experiment and L_c is the original total length of the cable. The meaning of quantities in equations (1) and (2) is evident from Fig. 3. The formula (1) can be used for the structure, where one joint is free, and the relation (2) for both fixed joints.

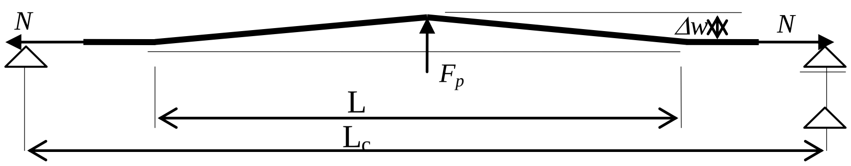

Fig. 3 The principle of measurement of a cable force.

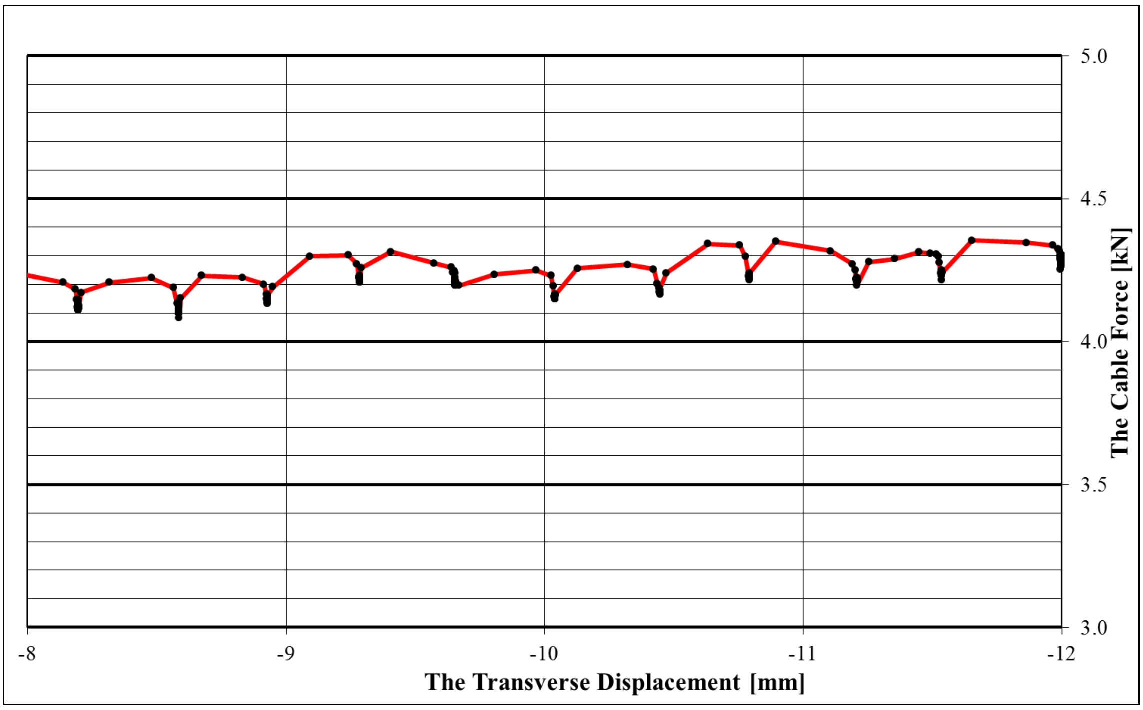

Fig. 4 The edge cable placed in a fabric pocket (the point No. 1) – the dependence of the evaluated cable force on the transverse displacement.

The special equipment is connected to the investigated cable by the experiment (Fig. 2). The equipment laterally deflects the investigated cable. The values of the transverse displacement Δw and the transverse forces F_p are measured continually (Fig. 4 and 5). The small force transducer and two inductive displacement transducers are used for measuring of F_p and Δw.

In reality the actual bending stiffness of the investigated cable (especially for cables with diameter bigger than 10 mm) has an influence on the evaluated cable force. This effect can be eliminated by a trial test. The calibration experiments for the developed equipment were

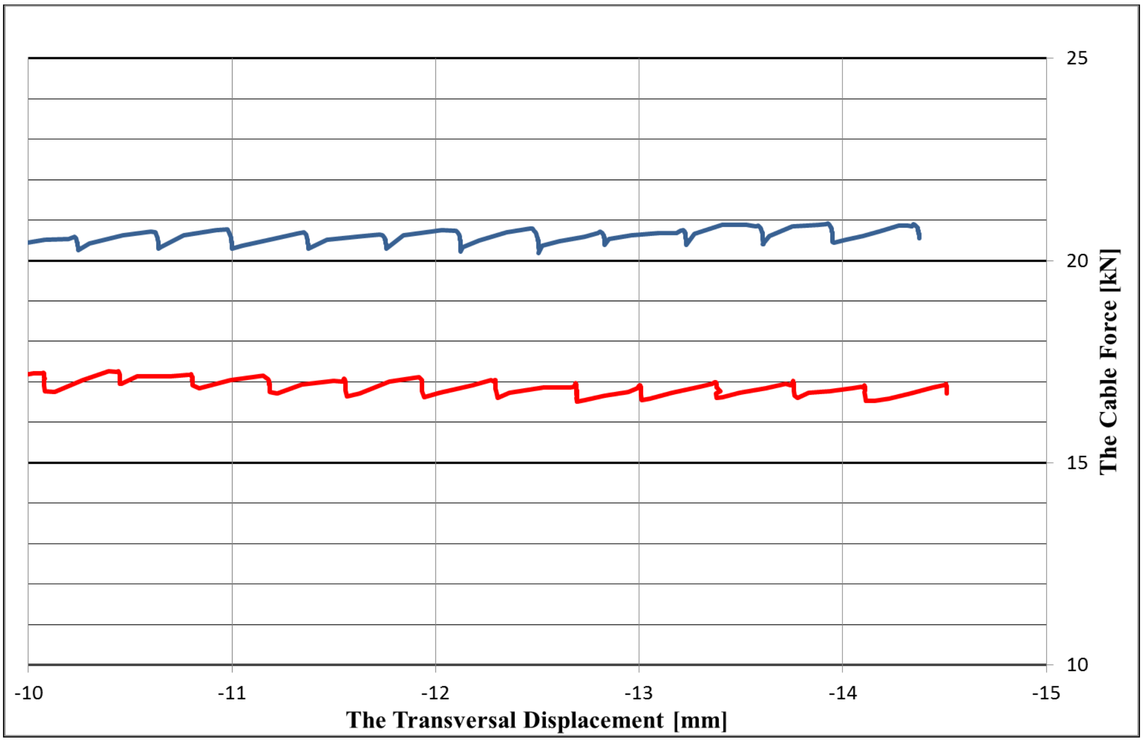

Fig. 5 The support cables No. 2 (blue) and 3 (red) – the dependence of the evaluated cable force on the transverse displacement.

Tab. 1 The evaluated prestress forces in the edge cables placed in a fabric pocket.

Cable No.	Observed point No.	The prestress force evaluated in the year		
		2009 [kN]	2012 [kN]	2013 [kN]
1	1	4.00	3.87	4.42
1	2	4.03	3.79	4.26
2	3	4.48	4.50	5.39
The air temperature [^{o}C]		4	14	0

Tab. 2 The evaluated prestress forces in the observed support cables.

Cable No.	The prestress force evaluated in the year		
	2009 [kN]	2012 [kN]	2013 [kN]
1	13.79	11.96	15.16
2	18.34	17.10	20.48
3	14.51	13.26	16.77
4	x	6.25	8.23
The air temperature [^{o}C]	4	14	0

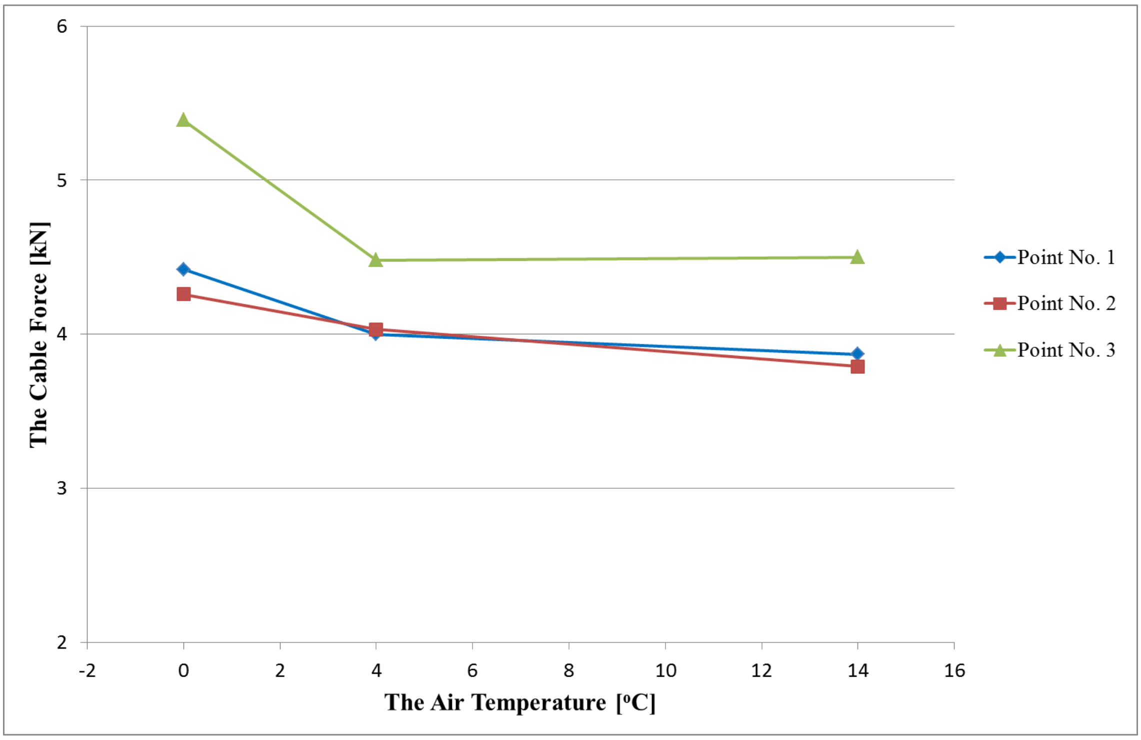

Fig. 6 The dependence of the evaluated edge cable forces on the air temperature.

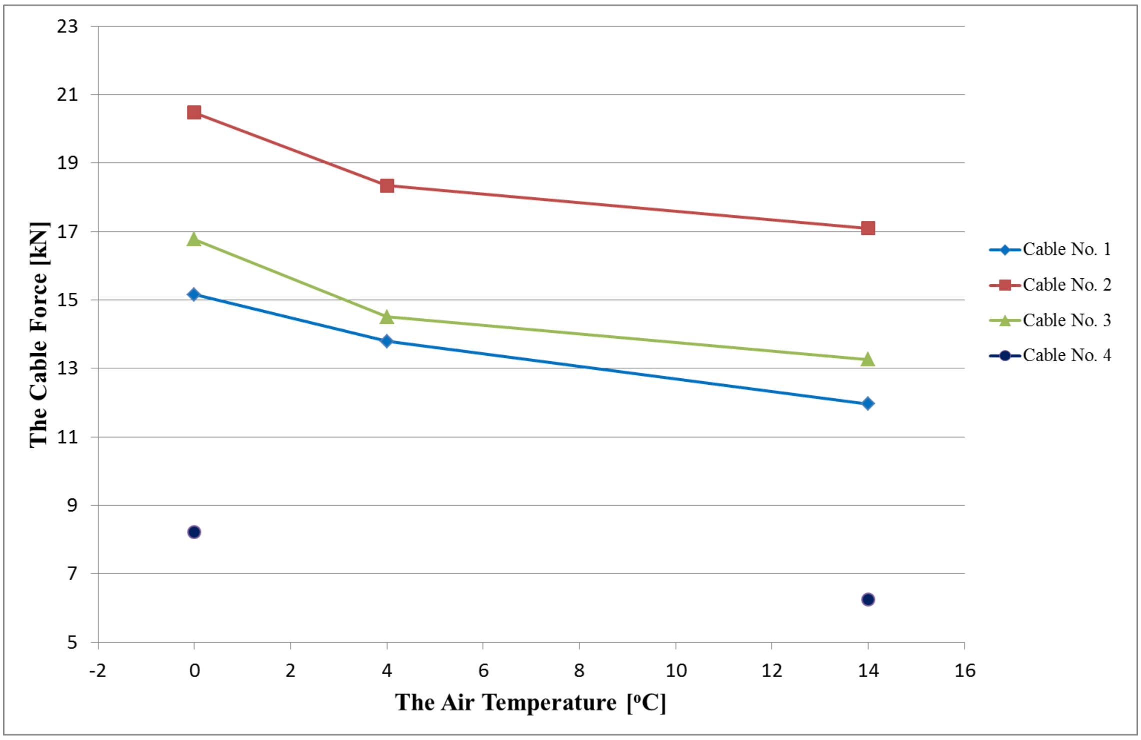

Fig. 7 The dependence of the evaluated support cable forces on the air temperature.

provided on the Faculty of Civil Engineering in the experimental laboratory. Obtained dependencies among the type of cable (especially its diameter) N, F_p and Δw were used during the evaluation of the described experiment. In compliance with expectations the cable forces evaluated on the base of the calibration experiment results were smaller than the theoretical forces calculated from the relations (1) or (2). The difference was about 8.8%. The evaluated forces are shown in Tab. 1 and Tab. 2.

The vibration frequency method was used for control determination of forces in the selected support cables. The results of this method can be made more precisely using the detail analysis of the measured natural mode shapes of the cables [2].

Summary

The non-destructive experimental method designed for cable forces measurement is simple and sufficiently accurate. The cable force error without calibrating is about 8 % with calibrating 2 %.

The dependence of cable forces on the temperature changes can be found out from the obtained results. The air temperature decreasing about 14°C caused cable forces increasing about 20%.

The temperature during the erection of the observed tension fabric roof in the year 2002 was approximately 24°C. It means that the corresponding cable forces were very small and it is suitable to tighten ones at a next maintenance.

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