Journal of Constructional Steel Research 129 (2017) 111–118

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Effects of temperature changes on the behaviour of a cable truss system

Arezki Sadaoui [a], Kamel Lattari [a], Amar Khennane [b,*]

[a] Université Mouloud Mammeri de Tizi-ouzou, Algeria
[b] UNSW Canberra, Australia

ARTICLE INFO

Article history:
Received 12 September 2016
Received in revised form 3 November 2016
Accepted 6 November 2016
Available online xxxx

Keywords:
Bi-concave cable truss
Closed form solution
Temperature change
Tensile structures
Continuous inextensible diaphragm
Relaxation forces
Finite element
Pre-stress

ABSTRACT

A previously published analytical solution for the analysis of a bi-concave cable truss structures under arbitrary vertical loads consisting of uniformly distributed and/or concentrated loads [A. Sadaoui, K. Lattari and A. Khennane, "A novel analytical method for the analysis of a bi-concave cable-truss footbridge", Engineering Structures 123 (2016) 97–107] is extended in the present to include the effects of temperature changes. A reference base temperature of 20 °C was considered as ambient. The material properties were assumed to be independent of temperature change, which is justified for small changes in temperature in the order of 50 °C. Positive and negative temperature increments were applied and their effects on the displacements and the forces developed in the elements were assessed. The obtained results were validated using finite element analysis. It was found that a temperature decrease intensifies the stresses, and susceptible of catastrophic failure because of certain structural steels exhibiting a shift from ductile to brittle behaviour if the temperature is lowered below a certain threshold. It was also found that a positive temperature change of 50 °C, which is not unusual in many parts of the world, results not only in increased deflections but also in increased relaxation of the tensile forces in the cables, which could affect serviceability. Most importantly, it was found that the loss of prestress is more severe (up to 58%) in the deck cable, which provides the stabilizing effect for the whole cable truss system.

1. Introduction

The use of cable systems in construction is not only architecturally appealing but constitutes also a significant technical achievement in the art of building. They offer the advantage of increasing the span while reducing self-weight, solving in a practical way the long-posed problem of achieving large spans over rivers, valleys and inlets. Being lightweight and high strength, these systems use the cable as the main structural element. Without bending or compression stiffness's, the system is only capable of carrying tensile forces. Hence, they are referred to as tensile structures. From this feature stems the necessity to apply a pre-tension to the cable before its use, the effect of which plays an extremely important role in the stability of the structure whose own weight is particularly low. This pre-tension or preload represents the initial load that needs to be applied so that in any case of overload none of the elements becomes compressed. However one cannot ignore the vulnerability of such structures to short and long term environmental effects. Environmental stresses due to temperature changes, be it daily or seasonal, constitute an important factor of aging of the cables, the hangers, and the stays, and in the long run may seriously affect the durability of the system. For instance, very low temperatures such as the ones prevalent in arctic regions can adversely affect the tensile toughness of many commonly-used engineering materials. Many types of structural steel experience a shift from ductile to brittle behaviour if the temperature is lowered below a certain threshold [2]. Higher temperatures on the other hand tend to cause thermal elongation and relaxation of stresses. Unlike failures at high temperatures, which can be noticed because of the accompanying large deformations, failures at low temperatures tend to be brittle and catastrophic. The disastrous accident of space shuttle Challenger because of low-temperature-induced failure of O-ring seals is a grim reminder of such problems [3]. It has become important therefore to identify or develop the right material that can be safely used in this regime. Studying the behaviour of tensile structures in order to estimate the stresses under the action of thermal effects is also equally important, particularly when these are combined with geometric nonlinearity, which plays a significant role in lightweight deformable systems.

There are many studies on the effect of temperature on tension structures, but the majority focussed on dynamic behaviour because temperature is known to affect vibration properties, such as frequencies, mode shapes, and damping [4]. Lepidi and Gattulli [5] studied the effect of temperature on the static and dynamic behaviour of suspended cables. They have found out that the linear frequencies of the cable are very sensitive to temperature change. Ni et al. [6] correlated modal properties to temperature changes for the Ting Kau cable-stayed Bridge in Hong Kong. Even, the event of accidental cable breakage has also been

* Corresponding author.
E-mail addresses: a_sadaoui@yahoo.com (A. Sadaoui), lattari_kamel@hotmail.fr (K. Lattari), a.khennane@adfa.edu.au (A. Khennane).

http://dx.doi.org/10.1016/j.jcsr.2016.11.013
0143-974X/

investigated [7,8]. Yet, coincidentally and despite its importance, there are very few studies addressing temperature effects on the static behaviour and/or the effect of cyclic loading. This topic is even more important for cable trusses whose structural rigidity and stability are ensured by the presence of prestressed deck and main cables. Indeed, it is well known that temperature changes, whether positive or negative, can result in relaxation or stress increase. This will have the negative effect of affecting the prestress in the stabilizing cables, and hence the stability of the whole structural system. Guo et al. [9] worked out an algorithm to calculate the feasible prestress but they did not include temperature. Kmet et al. [10,11] developed a closed form solution capable of taking temperature changes into account but they did not explicitly investigate their effects on the structural system. In the present work, the closed form solution developed by the authors [1] for the analysis of a bi-concave cable truss structures under arbitrary vertical loads is extended to include changes in temperature. The method is based on the fundamental assumption of approximating the hangers with a continuous inextensible diaphragm. The materials properties are those obtained at ambient temperature (20 °C), and they are further assumed to be independent of temperature for the range of temperatures considered; that is: from −30 to 70 °C, which is not unusual in many parts of the world.

The cable system of interest consists of a bi-concave cable truss as shown on Fig. 1. The system consists of two major cables anchored at their ends, a series of pin-ended hangers attached to the cables supporting a lightweight deck whose stiffness can be neglected.

2. Nonlinear analytical model

Fig. 2 shows the system of two bi-concave cables and closely spaced hangers at rest subject to its own weight ω' and the pre-tension forces H_0 and H_1. For simplicity, the ends of the both cables are assumed to be anchored to rigid supports which are at the same level. It is also assumed that the cables are parabolic and perfectly flexible, and when tensioned, they have a sag/rise over the span of about 1/10 or less. Additionally, the hangers are supposed to be so close to each other that they can form an extensible diaphragm.

The parabolic profiles of the main and deck cables are given as:

$$n_0 = \frac{4\,f_0}{L^2}x(L-x) \tag{1 – a}$$

$$n_1 = -\frac{4\,f_1}{L^2}x(L-x) \tag{1 – b}$$

The pre-tension force H_1 in the deck cable gives rise to a uniformly distributed action ω_1 in the diaphragm. If ω' is the weight per unit length of the cable truss, the distributed action ω_0 acting on the main cable is obtained as the sum:

$$\omega_0 = \omega_1 + \omega' \tag{2}$$

Taking a cut distance x as shown in Fig. 3a, the force $T_{C'}$ in the deck cable can be decomposed into the thrust horizontal force H_1 and $V_{C'} = \frac{\omega_1 L}{2}$, which represents the vertical reaction due the uniformly distributed load ω_1.

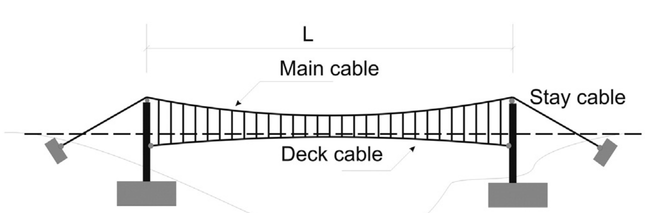

Fig. 1. Bi-concave cable truss footbridge.

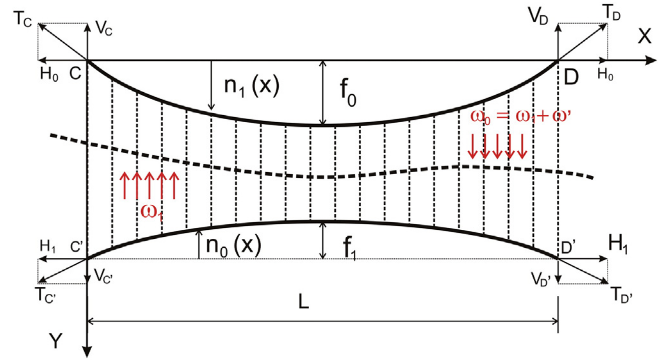

Fig. 2. Cable truss at initial conditions.

Considering moment equilibrium and taking into account the hypothesis stating that the cable is flexible, and the bending moment is equal to zero at any point x, $M(x) = 0$, it follows that:

$$H_1 n_1 = -\mu_1 \tag{3}$$

where $\mu_1(x) = \frac{\omega_1 x}{2}(x-L)\mu_1 = \frac{\omega_1 x}{2}(x-L)$, represents the moment created by the uniformly distributed action ω_1 on a uniformly loaded and simply supported beam as shown on Fig. 3b. Note that n_1 is by definition a negative quantity.

Using Eq. (1-b) yields;

$$H_1 = \frac{\omega_1 L^2}{8 f_1} \tag{4}$$

Similarly for the main cable, it follows:

$$H_0 n_0 = \mu' + \mu_1 \tag{5}$$

WHERE μ' is the moment caused by the self-weight ω'. Using Eq. (1-a) yields:

$$H_0 = \frac{\omega_0 L^2}{8 f_0} \tag{6}$$

Now, consider that there is a change in the external loads applied on the deck and/or a change in temperature. This change in loads creates an additional moment, which in turn gives rise to a uniformly distributed action ω_υ in the hangers, which will act generally upwards on the deck cable and downwards on the main cable and will create a moment υ. The horizontal components of the forces developed in the cables become $(H_0 + h_0)$ and $(H_1 + h_1)$ by analogy as shown in Fig. 3. Furthermore, the cables undergo changes in deflections v_0 and v_1 given by the following equations akin to Eqs. (3) and (4):

$$(H_1 + h_1)(n_1 + v_1) = -\mu_1 + \mu - \upsilon \tag{7 – a}$$

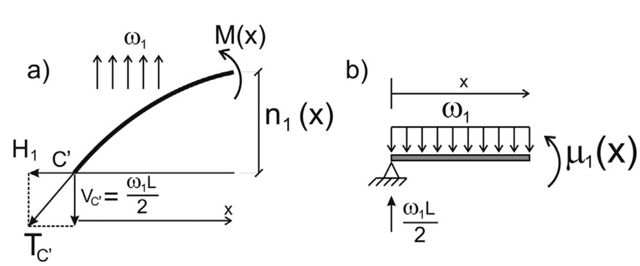

Fig. 3. Bending moment in the deck cable.