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Technical Note

Preliminary static analysis of self-anchored suspension bridges

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1. Introduction

Nowadays with the development of computer technology, suspension bridges are designed by making extensive use of the nonlinear finite element method. Based on the finite displacement theory and advanced computation technique, it is so far the most accurate and mature computational method for suspension bridge. However, this method normally leads to analysis with a large number of variables involved, difficult to verify and tend to obscure the influence of key parameters on the overall behavior of the bridge. Any parametric variance will cause readjustment of the computation model, and the status that any model describes usually needs experienced designers to repeat the process of try for many times.

In this paper the dimensionless form of the deflection theory of self-anchored suspension bridges was derived, and a concept of composite axial stiffness coefficient of stiffening girders was introduced. This paper also studied the relationship between the mechanical properties of self-anchored suspension bridges and Irvine's parameter, Steinman's stiffness coefficient and so on.

2. Dimensionless equations of the deflection theory of self-anchored suspension bridges

According to Ochsendorf's theory(1999), the deflection equation of self-anchored suspension bridges can be expressed as

$$EI\frac{d^4w}{dx^4} - h\frac{d^2z}{dx^2} = p \tag{1}$$

Mechanical behavior of self-anchored suspension bridges is not only related to spans, but also stiffness of the main cables, stiffness of the stiffening girder, the amount of dead load and so on. Therefore a comprehensive consideration of the influence of the above factors is necessary in the analysis process of bridge mechanical properties. Assume that the cable slides at the top of the

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pylon so that the horizontal force in the cable can be assumed constant. Perform the transformations

$$\bar{x} = \frac{x}{l},\ \bar{h} = \frac{h}{H},\ \bar{w} = \frac{H}{q_0 l^2}w,\ \bar{F} = \frac{p}{q_0 l},\ \bar{p} = \frac{p}{q_0},\ \bar{M} = \frac{M}{q_0 l^2} \tag{2}$$

the deflection theory of self-anchored suspension bridges can be written in dimensionless form as

$$\alpha^2 \frac{d^4\bar{w}}{d\bar{x}^4} + \bar{h} = \bar{p} \tag{3}$$

$$\bar{M} = -\alpha^2 \frac{d^2\bar{w}}{d\bar{x}^2} \tag{4}$$

$$\bar{h} = \lambda^2 \int_A^B \bar{w} d\bar{x} \tag{5}$$

The mechanical behavior of a self-anchored suspension bridge is thus described by parameters λ^2, α^2, γ given as

$$\lambda^2 = \left(\frac{q_0 l}{H}\right)^2 \frac{l}{\left(\frac{HL_e}{E_c A_c} + \frac{l}{\gamma}\right)},\quad \alpha^2 = \frac{EI}{Hl^2},\quad \gamma = \frac{E_s A_s}{H} \tag{6}$$

Parameter λ^2 has been first interpreted by Irvine in the study of conventional suspension bridges. It accounts for the relation between geometric and elastic stiffness. It is small for taut flexible cables and it approaches infinity for an inextensible suspended cable.

Parameter α^2 is Steinman's stiffness factor. It measures the ratio between the elastic stiffness of the beam and the gravity stiffness of the cable. In long span self-anchored suspension bridges $\alpha^2 \ll 1$, and it's the same for earth anchored suspension bridges.

This paper derived dimensionless equations of the deflection theory of self-anchored suspension bridges and redefined λ^2 so that it can include the effect caused by the axial compression of the stiffening girder. And γ indicating the composite axial deformation stiffness was introduced into the dimensionless parameters of self-anchored suspension bridges. The dimensionless parameters of several typical self-anchored suspension bridges are given in Table 1.

It can be seen in Table 1 that α^2 is larger than that of earth anchored suspension bridges and λ^2 smaller. According to D. Cobo del Arco's theory (2001), α^2 ranges from 10^{-5} to 0.01 and λ^2 from 90 to 230 for earth anchored suspension bridges. The main cause for this difference lies on that the span usually exceeds 1000 m for most earth anchored suspension bridges, but is usually under 400 m for self-anchored suspension bridges. The dimensionless parameter is not a simple function of any single structural factors such as spans, stiffness of the main cables, stiffness of the stiffening

Table 1 Dimensionless parameters of self-anchored suspension bridges

	Golden Bay Bridge	Kangji Bridge	Beiguan Bridge	Jinghang Canal Bridge	Wanxin Bridge	Lanqi Bridge scheme
Main span (m)	60	100	118	132.5	160	240
α^2	0.531	0.769	0.191	0.743	0.218	0.084
λ^2	421	616	203	381	189	223
γ	18933	4253	6818	12372	6118	4429

girder, the amount of dead load and so on, but a composite function of all of these parameters. Therefore studies on these dimensionless parameters can reflect the essential characteristics of self-anchored suspension bridges with higher accuracy.

3. Mechanical properties of self-anchored suspension bridges

Structural parameters of self-anchored suspension bridges include shape parameters like spans, sag to span ratio of the main cables, and mechanical parameters like stiffness of the main cables, stiffness of the stiffening girder, the amount of dead load and so on. For self-anchored suspension bridges, there exist three dimensionless parameters λ^2, α^2, γ, and the selection of which will affect the displacement and bending moment under live loads. Studies on this influence can help us select appropriate structural parameters during the design process, and therefore optimize the design.

Results for the displacement and bending moment in the middle of the span under the action of a concentrated load ($F = 0.025q_0l$) are shown in Figs. 1-6. The analyses have been performed for a given $\alpha^2 = 0.769$ as a function of λ^2 (see Fig. 1 for displacement and Fig. 2 for bending moment), for a given $\lambda^2 = 400$ as a function of α^2 (see Fig. 3 for displacement and Fig. 4 for bending moment), and for a given $\lambda^2 = 770$, $\alpha^2 = 0.77$ as a function of γ (see Fig. 5 for displacement and Fig. 6 for bending moment).

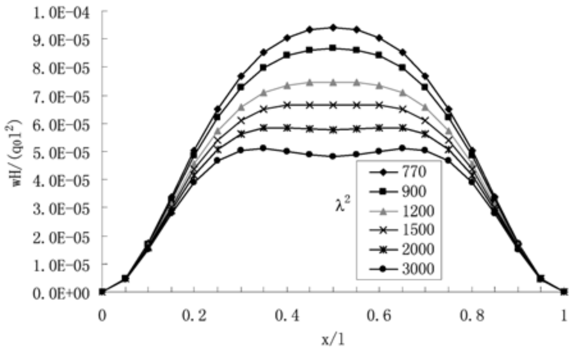

Fig. 1 Displacement under the position of a concentrated load ($\alpha^2 = 0.769$)

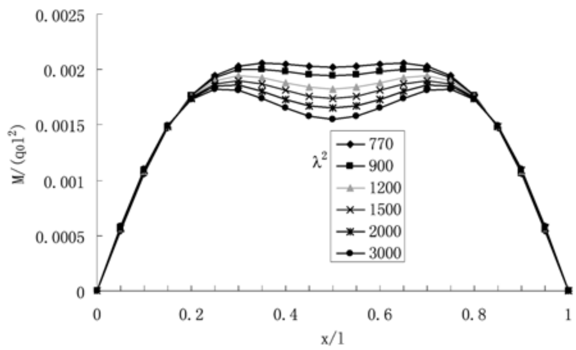

Fig. 2 Bending moment under the position of a concentrated load ($\alpha^2 = 0.769$)

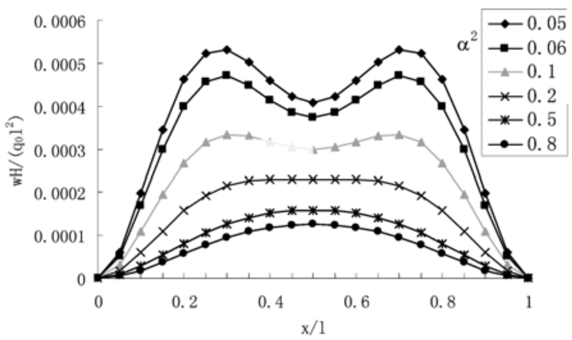

Fig. 3 Displacement under the position of a concentrated load ($\lambda^2 = 400$)

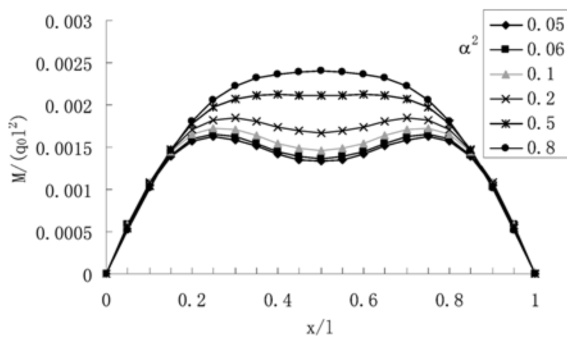

Fig. 4 Bending moment under the position of a concentrated load ($\lambda^2 = 400$)

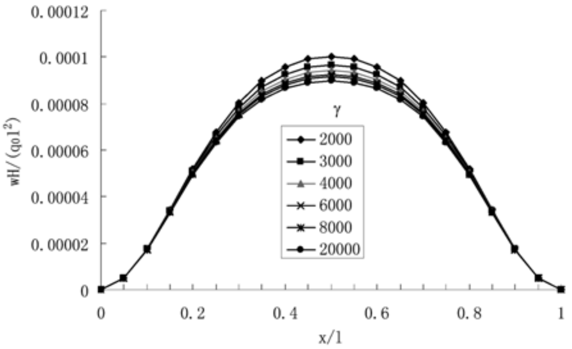

Fig. 5 Displacement under the position of a concentrated load ($\lambda^2 = 770$, $\alpha^2 = 0.77$)

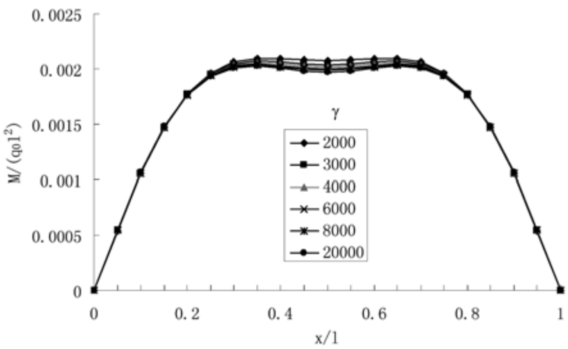

Fig. 6 Bending moment under the position of a concentrated load ($\lambda^2 = 770$, $\alpha^2 = 0.77$)

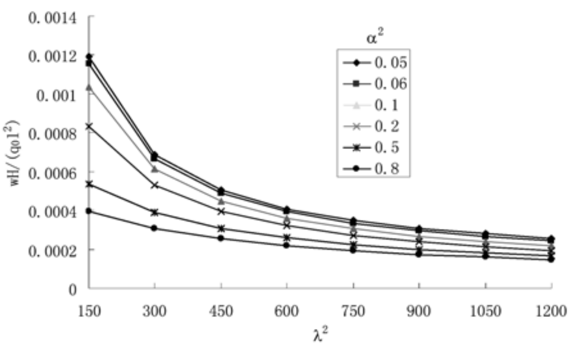

Fig. 7 Maximum displacement under distributed load ($q = 0.1q_0$)

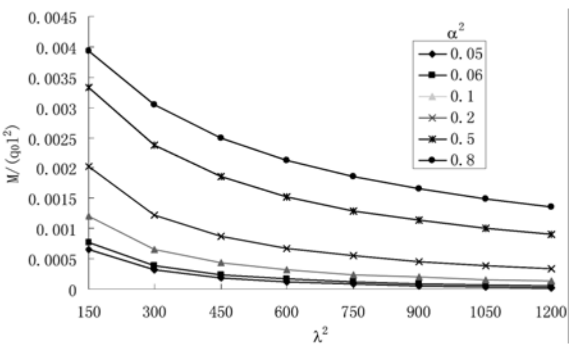

Fig. 8 Maximum bending moment under distributed load ($q = 0.1q_0$)

Finally, the maximum displacement and the maximum bending moment in the middle of the span obtained for a distributed load ($q = 0.1q_0$) are shown in Figs. 7 and 8. The analyses have been performed for a given λ^2 ranged from 150 to 1200 as a function of α^2.

The study shows that larger composite axial stiffness coefficient of the stiffening girder γ can decrease the dimensionless displacement and bending moment, but the influence is not remarkable. α^2 and λ^2 decrease while the span increases. Moreover α^2 ranges from 0.06 to 0.80 and λ^2 from 180 to 800 for self-anchored suspension bridges with a small span, when the vertical stiffness of the deck has a great influence on the displacement and bending moment. For a given $\alpha^2 < 0.06$, a great decrease of the vertical stiffness of the deck will not cause a substantial increase in the displacement and almost superposition appears in both the displacement and bending moment curve. This indicates that there is not necessity to increase the girder height, but the cross-sectional area of the stiffening girder should be enlarged to resist the huge axial compressive force.

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