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Development of 13m Cable Experiment

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SUMMARY

The safety and reliability of a cable-stayed bridge can be adversely affected by excessive vibration of its long, slender, and flexible cables. The purpose of this paper is to design a 13m cable experiment model to represent the behavior of a cable on a cable-stayed bridge. This paper determines the proper configuration of the cable based on a static computational analysis. The configuration of the cable is first described by a catenary curve. The computations are then simplified, and the assumption of a parabolic curve is proven accurate under the condition of small sag. The configuration of the cable model is determined based on the parabolic formulation. The design and assembly of a 13m cable experiment is completed based on these results. The as-built cable model is tested to verify that the behavior of the actual system corresponds to the analytical model. The results obtained show that the ideas presented in this paper can be used to effectively design cable systems.

INTRODUCTION

Cable stayed bridges have an inherent beauty that blends with their natural surroundings. Two examples are shown in Figure 1. The total design of these bridges is aesthetically pleasing and economical. The structure is economical because the towers and cables are relatively short and lightweight, making them easy to construct. As a result, there is no need to develop more complex erection techniques. The slender cables and small towers of a cable-stayed bridge also enhance the attractiveness of the bridge. The general appearance of slimness is the essence of this aesthetically pleasing structure. The overall structural form of the cable-stayed bridge possesses the unique ability to blend harmoniously with nature (Troitsky, 1988).

Figure 1. Cable stayed bridges.

The first modern-day version of a cable-stayed bridge, constructed in Germany in the year 1950, was not very successful. Preliminary designs lacked substantial theory. In addition, a lack of technical knowledge regarding the behavior of this statically indeterminate system resulted in inaccurate design and structural fatigue (Podolny, 1976). The behavior of a cable-stayed bridge should be analyzed by a complex static analysis, which was not completely understood when the bridge was first designed. Also, construction capabilities were limited by the adequacy of the materials available during this time. The strength of materials used for the initial construction of these bridges, such as timber, round bars, and chains, limited the structures load carrying capacity. None of these materials were sufficient to support the tension forces acting in the stays. As a result of these problems, this particular bridge design was not utilized in the United States until 1972 (Troitsky, 1988).

Modern methods of analysis, improved construction methods, and more reliable construction materials provided the ability to develop the present-day cable-stayed bridge. The development of computers enabled the creation of programs that could accurately analyze the statically indeterminate system. Other scientific advancements provided materials, such as high-strength steels, that were implemented in the construction of the bridge decks. Stronger materials significantly reduced fatigue and lessened the deformations resulting from asymmetrical loading. The development of computer programs and stronger materials are the underlying elements of technical progress that have lead to the widespread application of these beautiful structures (Podolny, 1976).

The slender stays of a modern cable-stayed bridge are beautiful, however their slimness is a point of concern. The slender cable stays are both lightweight and flexible. As a result, they are lightly damped and very prone to vibration. The vibration occurs when environmental excitations cause the cables to sway and gallop. Cable vibration can result in induced loads on the cables and cable fatigue. These factors are critical in order to ensure that the structure will support the intended tensile loads (Krenk). They are also important when considering the overall appearance of the bridge, defined in terms of attractiveness and perceived stability. A reduction in cable vibration raises public confidence, and increases the popularity of the bridge. Further analysis of cable fatigue, slack conditions and deck deformations is necessary to improve the strength and durability of the structure while maintaining its natural beauty.

This report describes the development and configuration of a 13m cable experiment used to examine smart damping cable vibration mitigation techniques. A 3m cable vibration study was performed during the fall of 1999 in the Structural Dynamics and Control / Earthquake Engineering Laboratory (SDC/EEL) at the University of Notre Dame. This experiment was important to develop an understanding of cable vibration and mitigation strategies. The purpose of the experiment was to analyze the addition of supplemental damping on a taut cable using a semi-active "smart" magnetorheological (MR) damper (Spencer et al, 1997). Initial testing of the 3m cable model provided positive results. However, a larger-scale cable experiment was necessary to model the behavior of the system more accurately. This paper describes the development of a 13m cable model that can be used to analyze cable damping strategies further.

The purpose of this paper is to design a 13m cable experimental model to represent the behavior of a cable on a cable-stayed bridge. This paper determines the proper configuration of the cable based on a static computational analysis. The configuration of the cable is first described by a catenary curve. The computations are then simplified, and the assumption of a parabolic curve is proven accurate under the condition of small sag. The configuration of the cable model is determined based on the parabolic formulation. The design and assembly of a 13m cable experiment is completed based on these results. The as-built cable model is tested to verify that the behavior of the actual system corresponds to the analytical model. The results obtained show that the ideas presented in this paper can be used to effectively design cable systems.

METHODS AND MATERIALS

The specific characteristics of the modeled structure are described in terms of frequency, weight per unit length, sag, angle of inclination, and tension. The configuration of the cable on a cable-stayed bridge is first analyzed by the equations of a catenary curve. This analysis describes the behavior of the cable under the distributed load of its own weight. The system is then resolved into four relationships that compare the arc length of the cable with the sag, tension, and distance to the points of support. A parabolic analysis of this cable system is proven to be an accurate approximation of the cable behavior, under the specified conditions of cable sag and arc length. The specific type of cable is selected based on material properties and yield specifications. Then, the configuration and orientation of the cable is determined. Finally, the 13m cable model is designed and built according to these results. The analytical solution is verified by comparing the numerical results to the parameters of the built model.

Catenary Analysis of Cable Behavior

The catenary analysis provides the most accurate representation of the cables' structural behavior and configuration on a cable-stayed bridge. The cables are flexible supports that cannot be analyzed according to the underlying principles of more rigid bodies. The system is structurally indeterminate of a high order. This problem is the result of the changes in the cable sag and axial tension (Podolny, 1976). In a cable stayed bridge, the distributed weight of the inclined cable takes the shape of a catenary curve. This occurs because the cable is held between two supports with no intermediate anchorage (Podolny, 1976). Therefore, in order to describe the true configuration of a cable, the weight of the cable must be considered in a more complex evaluation of cable behavior. The most accurate approach to analyzing this problem is to describe the shape of the cable in terms of its slope, sag, and arc length using the equation of a catenary curve.

Figure 2 shows a cable that is loaded by its distributed weight. The catenary equations are used to analyze the curve created by a load distributed uniformly along its own length. A free-body diagram is drawn in order to calculate the forces along the inclined cable. The cable is cut at its lowest point and the origin of the x and y-axis is placed at this point. The tension at this point, T_o, is in the horizontal direction only. Figure 2 shows a load distributed along the cable's length.

The force acting on the length segment *ds* is *wds*, where *w* is the weight per unit length of the cable.

The sum of the forces in the x and y directions yield the equilibrium equations:

$$T \sin(\text{è}) = ws \tag{1}$$

$$T \cos(\text{è}) = T_o \tag{2}$$

Division of Eq.(1) by Eq.(2) yields the tangent:

$$\tan(\text{è}) = \frac{dy}{dx} = \frac{w}{T_o} s \tag{3}$$

The constant, $q = \frac{w}{T_o}$, is introduced and Eq.(3) is differentiated with respect to *x*:

$$\frac{d}{dx}\left(\frac{dy}{dx}\right) = q\left(\frac{ds}{dx}\right) \tag{4}$$

The differential length of the cable is described as:

$$ds^2 = dx^2 + dy^2 \tag{5}$$

$$\frac{ds}{dx} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \tag{6}$$

Let , $\zeta = \frac{dy}{dx}$, be the slope of the curve. Then, this relationship is combined with Eq.(6) to get the differential equation for the slope:

$$\frac{d\zeta}{dx} = q\sqrt{1 + \zeta^2} \tag{7}$$

By rearrange the equation, the following relationship is determined:

$$\frac{d\zeta}{\sqrt{1 + \zeta^2}} = q dx \tag{8}$$

The origin of the coordinate system is placed at the lowest point of the cable. The slope is zero at this point. Both sides of the equation are integrated:

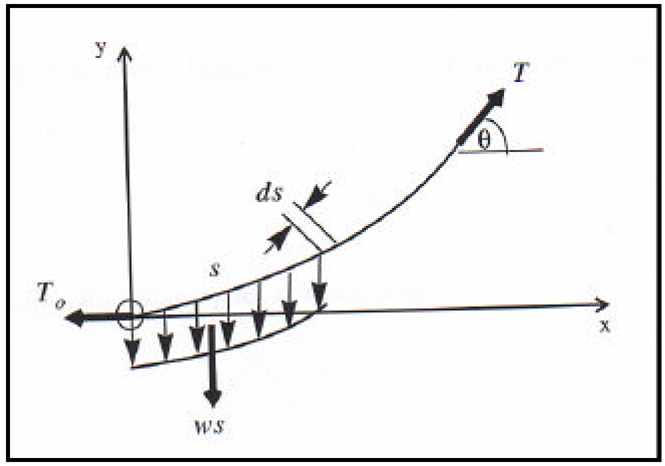

Figure 2. Catenary cable analysis.

$$\int_0^{\zeta} \frac{d\zeta}{\sqrt{1 + \zeta^2}} = \int_0^{x} q dx \tag{9}$$

$$\zeta = \frac{dy}{dx} = \frac{1}{2}\left(e^{qx} - e^{qx}\right) = \sinh(qx) \tag{10}$$

The equation for the curve the cable makes may be found by integrating the slope equation:

$$y = \frac{1}{q}\left[\cosh(qx) - 1\right] \tag{11}$$

This equation that describes the catenary now involves $\cosh(qx)$. The tension in the cable may be found by combining Eq.(2), Eq.(6), and Eq.(10) and employing the identity for the hyperbolic functions,

$$(\cosh(qx))^2 - (\sinh(qx))^2 = 1 \tag{12}$$

yielding:

$$T = T_o\sqrt{1 + [\sinh(qx)]^2} = T_o \cosh(qx) \tag{13}$$

This equation describes the length of the cable from its lowest point to any position *x*:

$$s = \frac{\zeta}{q} = \frac{[\sinh(qx)]}{q} \tag{14}$$

Eqs. (11) – (14) describe the cable as a catenary curve.

Model Assumptions: Catenary verses Parabolic Analysis

The actual shape of a cable in a cable-stayed bridge is a catenary curve. However, the behavior of cable systems can be approximated by a simplified equation for the shape of the cable. The equation of a parabolic curve does not describe the cable configuration of a cable- stayed bridge exactly. However, for small sag, the approximation of a parabolic curve provides very accurate results. When defined according to specified model assumptions, a parabolic curve analysis is an acceptable approximation of the cable behavior. Three specific conditions must be met in order for the approximation to maintain minimal error. The sag ratio, $n = f / l$, must be less than or equal to 0.15, the horizontal component of the length must be large, and the angle of inclination of the cable chord to the horizontal cannot exceed 70° (1.22 radians) (Podolny, 1976).

This criterion was determined by comparing the cable lengths of a catenary and a parabola curve assuming a typical cable design with a span of about 90.0-100.0 m and a support height of about 40 m for different horizontal tensions. The difference in lengths between a catenary and a parabolic curve is controlled by Eq.(15) and Eq.(16). Figure 3 is the free-body diagram of the cable represented and analyzed by the same two equations. L is the arc length of the cable, l is the length of the cable along the x-axis, b is the support height along the y-axis, T_0 is the horizontal tension, and w is the weight per unit length (Podolny, 1976).

The length of the parabolic curve is determined by,

$$L^2 = b^2 + \left(\frac{T_o}{w}\right)^2 \left(\sinh\left(\frac{lw}{2T_o}\right)\right)^2 \qquad (15)$$

$$L = \frac{1}{\cos(\theta)}\left[1 + \frac{8}{3}\left(\frac{wl}{8T_o}(\cos\theta)^2\right)^2\right] \qquad (16)$$

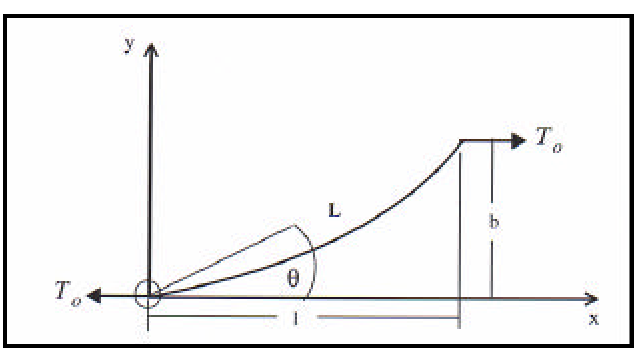

Figure 3. Catenary vs. Parabolic arc length.

The length of the catenary curve, determined by evaluating Eq. (13) along $x : L$ is,

$$L = \frac{T_o}{w}\sinh\left(\frac{w_o}{T_o}L\right) \qquad (17)$$

Table 1 describes the resulting comparison between the parabolic and catenary curves. L_C is the arc length of the catenary curve and L_p is the arc length of the parabolic curve. According to Table 1, the error remains less than 0.5% at the worst condition specified. Therefore, the parabolic curve appears, within reasonable error, to be adequate to model a cable with small sag. The parabolic analysis is described in the next section and the error between the static profile of catenary and parabolic curves for the proposed cable is examined later in this paper.

Table 1. Percent Error: Catenary vs. Parabola. (Podolny, 1976)

T_0 (kN)	L_c (m)	L_p (m)	D$L = L_c - L_p$ (m)	DL / L_c (%)
222.40	109.77	109.30	0.47	0.42
444.80	101.65	101.62	0.03	0.03
667.30	100.21	100.20	0.01	0.01
889.70	99.70	99.70	0.10×10^{-3}	0.01
222.40	99.18	99.16	0.02	0.01

Parabolic Analysis of Cable Behavior

Rather than considering the weight distribution along the cable's length, the parabolic curve assumes the weight to be distributed as a uniform load per unit length along a horizontal projection of the cable (Podolny, 1976). Figure 4 describes the simplified analysis of cable behavior. According to the assumption of a parabolic curve, the weight is distributed uniformly along a horizontal line. The tension in the cable is always tangent to the curve at any point along its length. In order to analyze the forces acting on the cable, a free-body diagram is drawn with the cable cut at its lowest point. The origin of the coordinate system is designated at the low point of the cable, and the equilibrium equations are defined from this point. The tension at the lowest point of the inclined cable is defined as T_0. The tension is only horizontal at this point because the tangent to the curve is equal to zero. The weight per unit length of the cable, w , and the tension, T , is defined at any point, x , along the curve.

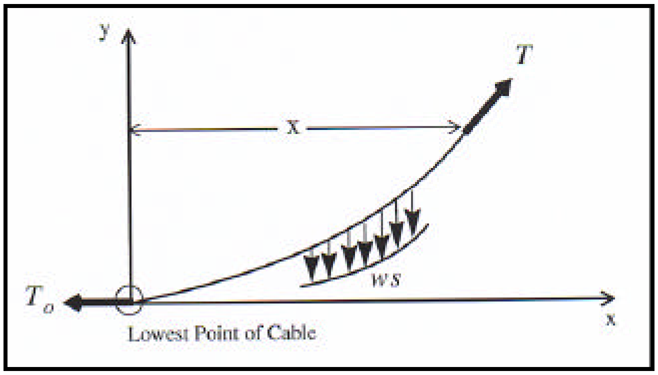

Figure 4. Parabolic Cable Analysis.

The equilibrium equations can be found according to the free-body diagram in Figure 4:

$$\sum F_x = 0 \tag{18}$$

$$T\cos(\text{è}) - T_o = 0 \tag{19}$$

$$\sum F_y = 0 \tag{20}$$

$$T\sin(\text{è}) - wx = 0 \tag{21}$$

Divide Eq. (21) by Eq. (19) to form the tangent and the following relationship:

$$\frac{T\sin(\text{è})}{T\cos(\text{è})} = \frac{wx}{T_o} \tag{22}$$

The tangent of a point on the curve is equal to the slope at that point:

$$\tan(\text{è}) = \frac{dy}{dx} = slope \tag{23}$$

$$\frac{dy}{dx} = \frac{wx}{T_o} = qx \quad \text{where} \quad q = \frac{w}{T_o} \tag{24}$$

Separate variables and integrate:

$$dy = qxdx \tag{25}$$

$$\int dy = \int qxdx \tag{26}$$

The following equation describes the curve of the cable as a parabola:

$$y = \frac{1}{2}qx^2 \tag{27}$$

The expression for T_0 describes the horizontal tension at the lowest point of the cable:

$$T_o = \frac{w}{q} \tag{28}$$

The tension in the cable at any point can be found in terms of by the use of Eq. (28) and Eq. (27):

$$T_{\max} = T_o\left(\sqrt{1+q^2x^2}\right) \tag{29}$$

RESULTS

The following results describe a cable system that is similar to the experimental system designed at the Hong Kong Polytechnic University by Yong Chen and Gang Zheng. The orientation and cable characteristics are specified in their report, "Vibration Testing of Stay Cable Connected with Wire-Cable Damper," February 2000. The cable system presented by Yong Chen and Gang Zheng is consistent with the cable system formulated in the conclusion of this report (Chen et al, 2000).

The analytical results presented describe the process of cable design based on the requirements of low sag, large horizontal length, and a small angle of inclination. The parabolic assumptions are re-examined and verified, then the selection of the cable is made based on the required cable weight and strength. Finally, the analytical results are compared with the parameters that define the actual built model. The model assumptions and methodology are proven to be accurate.

Analytical Results

The parabolic formulation and analysis of cable behavior is used to describe a specific experimental cable system. The purpose is to determine the necessary orientation of the cable, and the specific characteristics of the cable properties based on the established parameters. All calculations are performed under the model assumptions of a parabolic inclined cable. The parabolic assumption was described previously in the *Model Assumption* section of this report. According to this assumption, three specific conditions must be met in order for the approximation to maintain minimal error. The formulation of this particular cable system maintains that the following criteria are met: the sag ratio is less than 1%, the horizontal length is greater than 120 m, and the angle of inclination is less than 45°. After the calculations are made, the resulting shape of the parabolic curve is compared to the shape of the catenary curve to illustrate that the resulting error is negligible.

Selection of Cable Configuration

Figure 5 illustrates the orientation of the cable with respect to the equation variables. The equations used to solve for the specific cable orientation are described by Eq. (30) - Eq. (39).

For these calculations, the nominal arc length, L_0 , of the cable is set equal to 12.0 m, and θ = 18°.

The variables q and y_L are defined according to the original derivation by Eq. (30) and Eq. (31).

$$q = \frac{\left(2L_o \sin \grave{e}\right)}{\left({x_R}^2 + {x_L}^2\right)} \qquad (30)$$

$$y_L = \frac{q}{2} {x_L}^2 \qquad (31)$$

The arc length of the entire cable, evaluated at x_R and x_L, is shown by Eq.(32) and Eq.(33). Then, according to Eq.(34), the arc length at x_L is subtracted from the arc length at x_R to define the section of the cable under consideration.

$$S_R = \frac{1}{2q}\left(x_R q \sqrt{(x_R q)^2 + 1} + \ln\left(x_R q + \sqrt{(x_R q)^2 + 1} \right)\right) \qquad (32)$$

$$S_L = \frac{1}{2q}\left(x_L q \sqrt{(x_L q)^2 + 1} + \ln\left(x_L q + \sqrt{(x_L q)^2 + 1} \right)\right) \qquad (33)$$

Therefore, for this orientation, the arc length, L_{arc} , is defined by S_R - S_L.

$$L_{arc} = S_R - S_L \qquad (34)$$

The next four equations, Eq.(35) - Eq.(38) , are used to calculate the sag, ∂ , at the midspan. The location of the midspan is found along the horizontal axis and defined

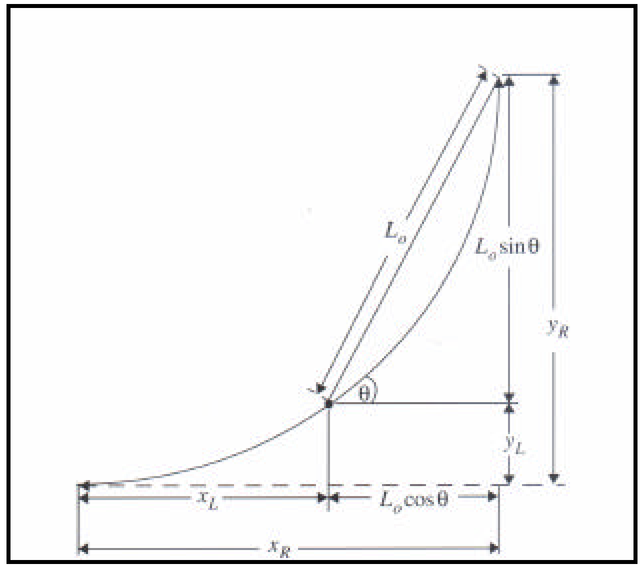

Figure 5. Cable Orientation.

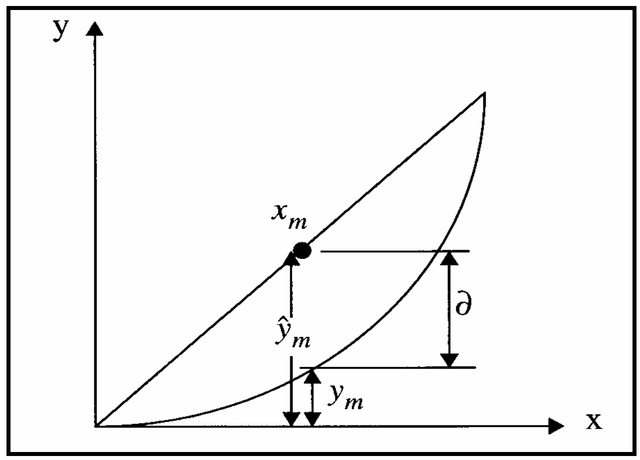

Figure 6. Sag Calculation.

by x_m. Figure 6 describes the relationship between $\hat{y}_m$ and y_m. The sag, ∂ , is calculated by subtracting, $\hat{y}_m$ - y_m .

$$x_m = \frac{L_o}{2}\cos \grave{e} \qquad (35)$$

$$\hat{y}_m = \frac{L_o}{2}\sin \grave{e} + \mathrm{y_L} \qquad (36)$$

$$y_m = \frac{q}{2}\left(\frac{L_o}{2}\cos \grave{e} + \mathrm{x_L}\right)^2 = \frac{q}{2}{x_m}^2 \qquad (37)$$

$$\partial = \frac{L_o}{2}\sin \grave{e} + \mathrm{y_L} - \frac{q}{2}\left(\frac{L_o}{2}\cos \grave{e} + \mathrm{x_L}\right)^2 \qquad (38)$$

The sag ratio, S , is defined by the sag, ∂ , divided by the horizontal span of the cable, as shown by Eq.(39).

$$S = \frac{\partial}{\left(x_R - x_L\right)} \qquad (39)$$

The equations above are solved with respect to the changing length of x_L. An array is defined for x_L beginning at a length of 135 m and spanning a distance of 5 m to a maximum length of 140 m. The variables required to define the orientation of the cable are S, x_R , y_L , y_R , L, and q. Each variable is graphed with respect to the array, x_L , for a particular *S*. The results are shown below in Figures 7 - 12.

Using the relationships illustrated in the graphs, Figures 7-12, the value of each variable is determined with respect to a specified sag ratio. In order to create the desired cable system, a sag ratio of 0.321% was used to evaluate each variable. Table 2 displays the calculated parameters at 0.321% sag.

First, Eq. (40) is used to evaluate T_{max} with respect to *w*.

$$T_{\max} = \left(\frac{w}{q}\right)\sqrt{1 + q^2 x_R{}^2} \qquad (40)$$

The frequency, *f*, is then evaluated in three modes according to Eq. (41) and (42):

The natural frequency for the first symmetric mode (for small sag) is approximately,

$$f_{symm} = \frac{\eth}{L}\sqrt{\frac{g}{q}} \qquad (41)$$

The natural frequency for the first anti-symmetric mode is,

$$f_{anti} = \frac{2\eth}{L}\sqrt{\frac{g}{q}} \qquad (42)$$

Table 2. Calculated Values for a Sag Ratio of 0.321%.

x_L	138.6987 m	y_L	21.6426 m	L	13.0003 m
x_R	150.1114 m	y_R	25.3508 m	q	0.0023 m^{-1}

Re-examination of Parabolic Assumption

The values listed in Table 2, x_L , x_R , y_L , y_R , *q*, and *L*, are used to re-evaluate the accuracy of the parabolic assumption. These values, which were solved calculated by the parabolic equations, are re-evaluated by the catenary equations. The characteristics of the cable are also described in terms of the desired arc length, $L_{arclength}$ = 12.05 m. Eq.(43) and Eq.(44) are combined with the general derivation of a catenary curve to determine three relationships. These relationships are presented by Eq.(45), Eq.(46), and Eq.(47). They completely describe the shape of the cable in terms of the angle of inclination, θ = 18° , and the arc length of the cable, $L_{arclength}$ = 12.05 m.

$$x_R = x_L + L_o \cos(\text{è}) \qquad (43)$$

$$y_R = y_L + L_o \sin(\text{è}) \qquad (44)$$

$$y_L = \frac{\cosh(qx_L) - 1}{q} \qquad (45)$$

$$y_R = \frac{\cosh(qx_R) - 1}{q} \qquad (46)$$

$$\frac{\sinh(qx_R)}{q - L} = \frac{\sinh(qx_L)}{q - L} \qquad (47)$$

The graph presented in Figure 13 compares the results of the cable analysis for the parabolic and catenary equations. This graph plots the solutions of both the catenary and parabolic derivations across the horizontal span of the cable, x_L to x_R. As shown in Figure 13, the two curves are so similar that they are indistinguishable. Although the true characteristics of a cable in a cable-stayed bridge are described by a catenary curve, the graph shows that the error resulting from the parabolic approximation is minimal.

Selection of Cable

The purpose of this analysis is to determine the proper configuration of a scaled cable that models the structural behavior of a cable on a cable-stayed bridge. The model consists of an aircraft cable of approximately 13 m in length. Figure 14 describes the orientation of the cable. It also describes the relationship between the angle of inclination, the arc length, the distance along the x-axis to the base of the support, and the distance along the y-axis to the top of the tower. Specific characteristics of several cables are found in Table 3. For this particular system, the 7 x 19 stainless steel cable, 4.0 mm (5/32 in) diameter, will be used. The

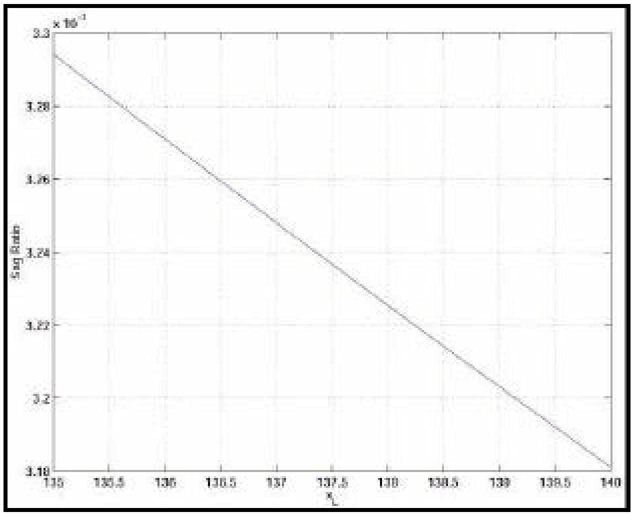

Figure 7. x_L vs. Sag Ratio.

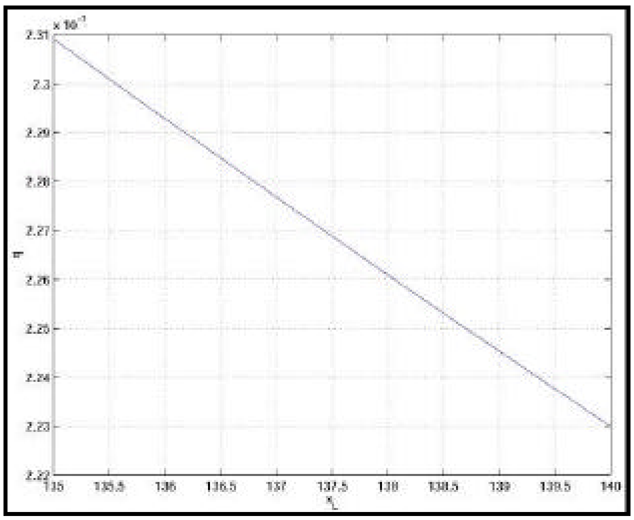

Figure 8. x_L vs. q .

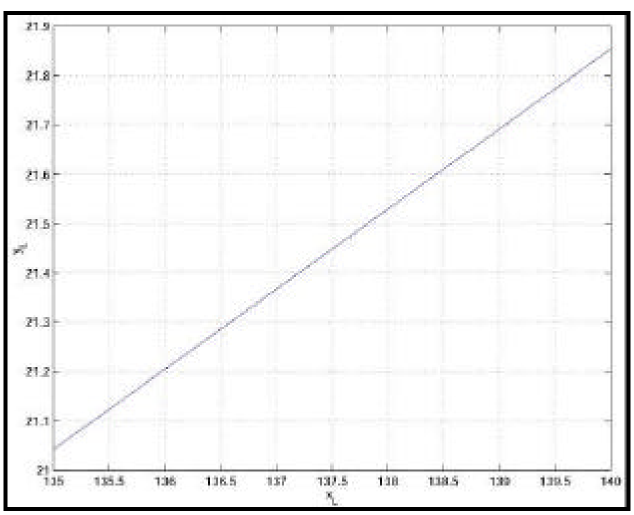

Figure 9. x_L vs. y_L .

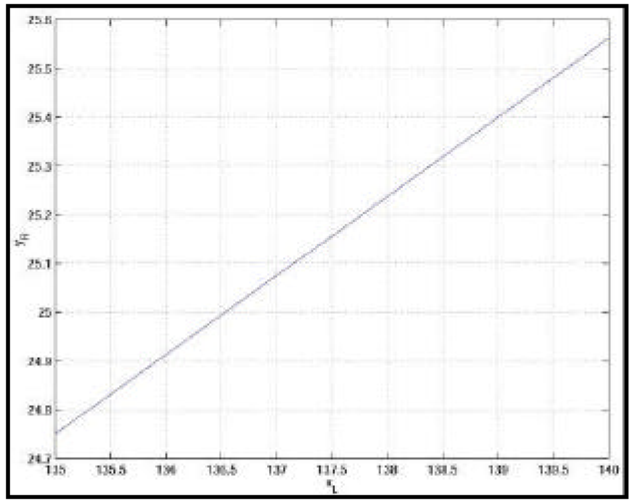

Figure 10. x_L vs. y_R .

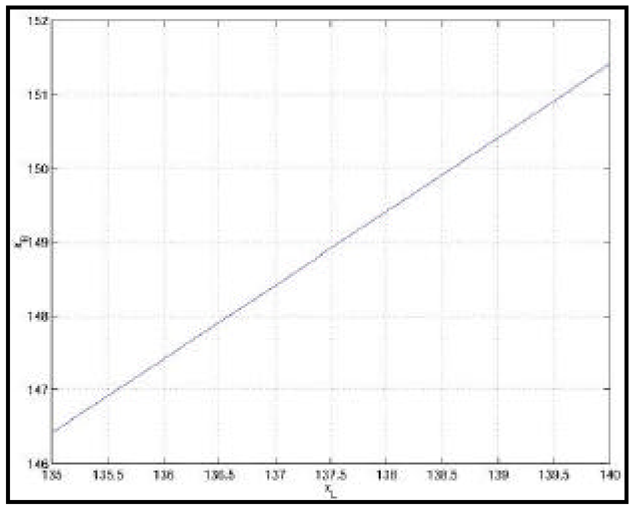

Figure 11. x_L vs. x_R .

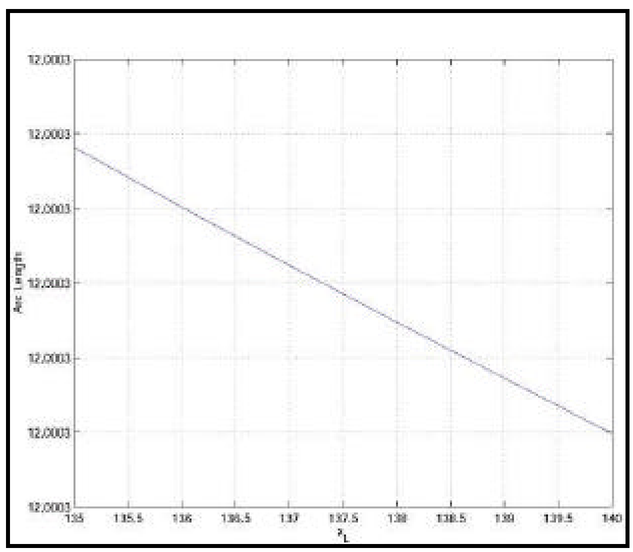

Figure 12. x_L vs. Arc Length.

approximate weight per unit length, w, is 0.6573 N/M (6.70kg/100m). The breaking strength listed for each wire rope applies to new, unused rope under the stress of a straight-line pull. The minimum load required to break the cable is 11 kN (2400 lbs). The rope's maximum safe working load, T_{max}, is considered to be 20% of the minimum breaking strength, L_{min}. (Wire Rope Industries) Therefore, according to Eq. (45), the maximum tension used in this analysis 1800 N.

$$T_{\max} \geq 0.02(L_{\min}) \qquad (48)$$

The weight per unit length of the cable is approximated at T_{max} = 1800 N. An array is defined for w ranging from 0-15 N/m. The graph in Figure 15 describes the relationship between T_{max} and w. From this graph, it is determined that for $T_{max} = 1.7961 \times 10^3$ N, w = 3.8287 N/m.

For the values of q and L listed in Table 2, and g = 9.81 m/s^2, the frequency is calculated in each of the three modes:

The natural frequency for the first symmetric mode, Eq.(41), is f_{symm} = 2.7512 Hz.
The natural frequency for the first anti-symmetric mode, Eq.(42), is f_{anti} = 5.5023 Hz.

The horizontal span is determined by Eq.(49)

$$x_R - x_L = 11.4127 \text{ m} \qquad (49)$$

The vertical height is determined by Eq.(50)

$$y_R - y_L = 3.7082 \text{ m} \qquad (50)$$

A specific amount of mass must be added to the cable in order for the total weight of the cable to equal the desired weight per unit length, w. Eq. (51) is used to determine the amount of weight that must be added to the cable.

$$w = w_{cable} + w_{added} \qquad (51)$$

The weight of the 1/8 in galvanized cable is determined by Table 3, w_{cable} = 0.6573 N/m. According to Eq.(51), w_{added} = 3.17143 N/m. The spacing between each of the weights will be 10 cm along the entire length of the cable. Therefore, the equivalent distributed weight is 0.317143 N/.1m.

This results in a cable with 0.321% sag.

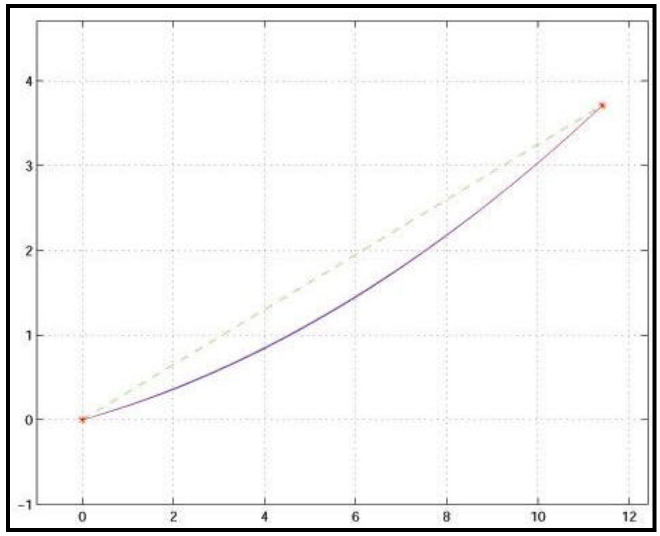

Figure 13. Parabolic vs. Catenary Curve.

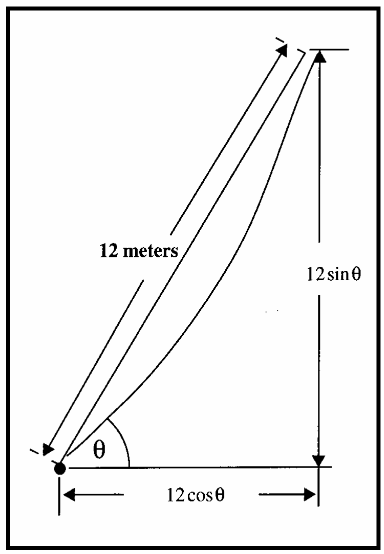

Figure 14. Cable Configuration.

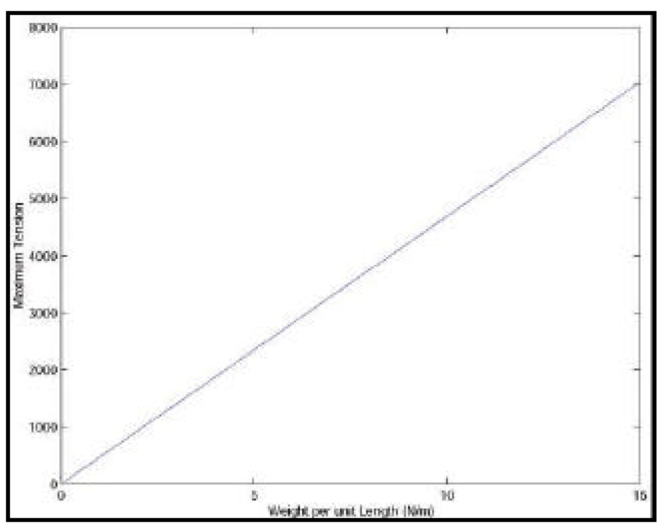

Figure 15. T_{max} vs. w .

Analytical Verses Experimental Results

The analytical results are used to establish target values that define the ideal orientation and configuration of the 13 m cable model. These values had to be modified slightly as a result of limitations imposed by the laboratory dimensions. Table 4 provides a comparison between the analytical results using the target parameters of the system and the experimental results using the actual size and shape of the built cable model. These results verify the consistency of the analytical and experimental results and validate the accuracy of the numerical solution.

Table 3. Aircract Cable (7X7 Commerciala Quality) (7X19 Stainless Steel Type 302/304). (Wire Rope Industries)

Diameter (mm)	Diameter (in.)	Rope Construction	Weight (kg/100m)	Weight (lb/100ft)	Minimum Breaking Load (kN)	Minimum Breaking Load (lbs.)
1.6	1/16	7 x 7	1.21	0.75	2.0	480
2.4	3/32	7 x 7	2.38	1.60	4.0	920
3.2	1/8	7 x 19	4.32	2.90	8.0	1760
4.0	5/32	7 x 19	6.70	4.50	11.0	2400
4.8	3/16	7 x 19	9.67	6.50	16.0	3700
6.4	1/4	7 x 19	16.37	11.00	28.0	6400
7.9	5/16	7 x 19	25.74	17.30	40.0	9000
9.5	3/8	7 x 19	36.16	24.30	53.0	12000

Table 4. Analytical Results verses Experimental Results using Target Parameters

	Target Parameters – Analytical Results	Model Parameters – Experimental Results
L	13.00 m	12.56 m
θ	18.00°	22.53°
w	3.83 N/m	3.99 N/m
T_0	1665 N	2172 N
q	0.0023 m^{-1}	.0018 m^{-1}
f	2.75 Hz	2.89 Hz

DISCUSSION

The purpose of this paper was to develop an analytical model that accurately described the behavior of a cable on a cable-stayed bridge and could be used to design and assemble a 13m cable experiment. This paper determined the proper configuration of the cable based on a static computational analysis. The configuration of the cable was first described by a catenary curve. The computations were then simplified, and the assumption of a parabolic curve was proven accurate under the condition of low sag. The size and shape of the cable model was determined based on the parabolic formulation. The design and assembly of a 13m cable experiment was completed based on these results. The 13m cable model was tested to verify that the behavior of the actual system corresponds to the analytical model. The results obtained show that the ideas presented in this paper can be used to effectively design cable systems.

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