Research Article

Optimization Analysis Model of Self-Anchored Suspension Bridge

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The hangers of self-anchored suspension bridge need to be tensioned suitably during construction. In view of this point, a simplified optimization calculation method of cable force for self-anchored suspension bridge has been developed based on optimization theories, such as minimum bending energy method, and internal force balanced method, influence matrix method. Meanwhile, combined with the weak coherence of main cable and the adjacently interaction of hanger forces, a simplified analysis method is developed using MATLAB, which is then compared with the optimization method that consider the main cable's geometric nonlinearity with software ANSYS in an actual example bridge calculation. This contrast proves the weak coherence of main cable displacement and the limitation of the adjacent cable force influence. Furthermore, a tension program that is of great reference value has been developed; some important conclusions, advices, and attention points have been summarized.

1. Introduction

The self-anchored suspension bridge is a competitive bridge type often used for small and medium spans in urban areas. Because of its aesthetic appearance, efficient use of structural materials, good adaptability to a variety of terrain, and geological conditions, this type of bridge has been favored by more and more engineers. However, this kind of bridge is characterized as its complex mechanical state. Hangers need to be tensioned repeatedly as well as optimized during construction stage all the time and the rational order and level of hanger tension influence the structure's mechanical behavior and safety in completed state directly. There is great difference no matter in construction method or simulation from self-anchored to earth-anchored and the self-anchored one has its own particularity. During construction, the tension sequence and cable force determine the cable curve and the structure mechanical characteristics. So that the two points above must be one of the most important links in self-anchored suspension bridge design. Considering

the particular construction process, the hangers of self-anchored suspension bridge need to be tensioned several times to achieve the desired linear and cable force, rather than once optimization of hanger tension just like cable-stayed bridge. In order to ensure the structure safety of self-anchored suspension bridge and get the bridge into a rational complete state, engineers should develop right hanger tension levels and tension orders. Due to the similarity in terms of the mechanical behavior on the self-anchored suspension bridge with cable-stayed bridge that the stiffening girders of them are both compressed, we develop an optimization method of hanger tension of self-anchored suspension bridge which refer to the cable-stayed bridge optimization theory. Simultaneously, after the research of hanger tension levels and tension orders of self-anchored suspension bridge, we develop a legitimately optimized and simplified calculation method.

Several self-anchored bridges were built during the early 1900s, including the Seventh Street Bridge, Germany's Deutz bridge, and Mülheim Bridge. Before 1990, few self-anchored

suspension bridges were constructed. However, renewed interest in the self-anchored bridge design methodology began in the 1990s. Recently, several papers [1, 2] demonstrated the related researches of the self-anchored bridges. There have not been adequate documents related to the optimization theory of cable tension method of self-anchored suspension bridge, which seems not as mature as cable-stayed bridge is and tied arch bridge is. Qiu and Zhang [3] studied the complex nonlinear process of system transformation that hangers are tensioned to get the main girder separated from supporters during construction. This paper explores how to get the main girder away from the supported state and studies the optimization method of the stretching frequency and the number of prolonged rods. Based on the experimental data from a $1 = 10$ scaled model of the Liede Bridge in Guangzhou, China, Zhang et al. [4] studied the nonlinear behavior of a self-anchored suspension bridge during the process of structural system transformation. Based on employing the method of an equilibrium of internal forces, Jianhua et al. [5] researched hanger forces of completed self-anchored suspension bridges and finally put forward the hanger forces (due to dead load) design method of self-anchored suspension bridges. Zeng et al. [6] employ finite element analysis software ANSYS to simulate the completion process of Tianjin Fumin Bridge under three different conditions of the main cable initial tension. The influence on the performance of the completion structure by the initial tension of the main cable of the suspension bridge with space cable plane is studied. Moreover, the documents [7–15] and so forth all do the research on the scheme of hanger tension of self-anchored suspension bridge. However, the indefinite mechanical behavior of this kind of bridge makes it complex to solve these important points and a lot of relevant theories and experimental studies are still needed to make the mechanical behavior clear both in the construction stage and completed stage. Nowadays, optimization methods and the researches on it, in or abroad, are relatively rare. The relevant design methods have not been developed, meanwhile, there are still many theoretical and technical problems hard to be handled on this optimization theory as well as on the researches of tension orders and tension levels.

To solve these difficult issues mentioned above and to evaluate the impact on the bridge's structure mechanical performance using hanger tension, an optimized and simplified calculation method that is based on various optimization theories has been developed. A MATLAB program was developed and is described in this paper. Results obtained with our program are compared with those obtained with an ANSYS finite-element program to demonstrate the practicality and feasibility of our optimization program. A suitable tension order and tension level are determined, thereby bringing practical value to bridge engineering design.

2. The Optimized Calculation Model and the Reasonable Completed Bridge State

To make the method the most widely used, this paper chooses a three-cross twin towers model with just only a single

cable plane. The structure is assumed to meet the elastic requirement. The stiffening girder and the deck load are assumed to be distributed uniformly along the full bridge. The main cable shape is similar to parabola under all of the loads. For cable-force optimization at the completed stage, it is proposed to use a calculation model of ideal hanger tension (see Figure 1) in simplifying the calculation. The hanger force in completed stage is close to ideal cable force. The main cable is removed, and only hangers are remaining, while the horizontal components of the main cable force are added to the two ends of the stiffening girder. We just take the main girder as the calculation component. The original hangers' acting points are replaced with vertical supports. After the statistic calculation, the supporters reaction force in the location of the original hangers is proved to be approximate to the ideal cable force; the above three kinds of model of the optimization analysis are shown in Figure 1.

The reasonable completed bridge state of the self-anchored suspension bridge refers to the stress state and the geometry of a completed structure that is compact by the basic design parameter criterion and performance criterion. The mechanical characteristic of self-anchored suspension bridge shows that the stiffening girder force and the main cable line are mainly determined by the hanger's internal force apart from construction method and components' own characteristic. Combined with the mechanical property criterion of this kind of bridge, we could consequently develop a reasonable completed bridge state.

In accord with both the coordinates for the main cable and the stiffening and weight of elements, the horizontal components of the main cable force are obtained in a three-step iteration: (i) the initial loads, tensions, and cable forces are added to the ANSYS finite element model to form a geometry stiffness matrix from which a structure stiffness matrix is constructed; (ii) the moment and the vertical deformation of stiffening girder due to the dead load, the unbalanced horizontal component of the main cable force that exerts on the main tower, are observed and analyzed in the calculation results; the main cable's and the hanger's axial forces are extracted and converted to an initial strain endowed in the structure again. All the steps above are based on the completed bridge state, in accordance with a multiple iteration method including calculation, comparison, modification, and recalculation, until the analysis results meet the requirements such as the stiffening girder's minimum moments due to dead loads, the minimum deformation due to dead loads, and the minimum unbalanced horizontal components of cable force acting on the main towers.

The main cable has the characteristic of geometrical nonlinearity, and its cable curve guarantees a reasonable completed bridge state. The catenary method is used to calculate the cable curve of suspension bridge.

The suspension cable is divided into n segments in every vertical hanger point. The two ends of each segment are acted with a concentrated force separately, while vertically uniformly distributed loads are forced alongside the cable length. Consequently, after defining the boundary conditions, the main cable's curve could be developed. The main cable's coordinate is

FIGURE 1: Calculation model of hanger tension.

$$y = \frac{H}{q} \left[ch\alpha - ch \left(\frac{2\beta x}{l} - \alpha \right) \right], \quad (1)$$

where $\alpha = sh^{-1}(c\beta/lsh\beta) + \beta$, $\beta = ql/2H$, H is the horizontal component of the main cable force, q is the uniformly distributed loads alongside the arc length of the main cable, l is the main cable span, and c is the elevation difference between the two ends of the main cable. q^{i-1} , q^i are the boundary conditions of the main cable. In the beginning, some initial values will be assigned in the model, and then the precise cable curve can be developed by iteration. In the completed bridge stage, the horizontal component of the main cable force acted on the two sides of the tower are set to be equal, by which a reasonable finished bridge shape could diminish the tower's resisting moment. As long as the cable curve of one span is developed, the nearby span's horizontal force could be determined. So that we can work out another span's reasonable cable curve by iteration, making use of formulation (1). The unstressed cable length of the suspension bridge can be back calculated based on the stressed cable length in the reasonable completed bridge stage. The stressed cable length is

$$S = -\frac{H}{q} \left[sh \left(-\frac{q}{H}l + \frac{q}{H}t \right) - sh \left(\frac{q}{H}t \right) \right], \quad (2)$$

$$t = \frac{sh^{-1}(c\beta/lsh\beta) + \beta}{2\beta} l.$$

The unstressed cable length is

$$L_{us} = S + \frac{H^2}{4EAq} \left[sh \left(-\frac{2ql}{H} + \frac{2qt}{H} \right) - sh \left(\frac{2qt}{H} \right) \right] - \frac{Hl}{2EA}, \quad (3)$$

where EA is the axial stiffness.

The cable shape will be fixed in tension stage after the main cable erected completely. The deck geometrical shape is mainly controlled by the vertical hanger length which could be considered as the summation of the distance between the center of the main cable and the interanchor plate surface, the hanger length that has been amended in terms of curve and slope according to the outside diameter of the main cable, the size between cable clamp and the center of main cable, and the cutting of the elastic elongation of every segment.

The calculation method of the hunger force of self-anchored suspension bridge is similar to that of cable-stayed bridge that the calculation model is simplified as a continue

girder. Generally, the hunger force of suspension bridge is required to be uniform, which will enable the structure's moment and shear due to static loads uniform approximately. It is the most convenient and intuitive to calculate and analyze the structure's internal force that the main cable and the vertical hanger are replaced with forces. The girder's moment due to x_i is defined as m_i ; the basic structure's moment due to dead load is defined as M_p . Then the total bending moment of any section can be expressed as

$$M = M_p + \sum_{i=1}^n x_i m_i, \quad (4)$$

where n = the hanger number; the energy due to bending moment can be given by

$$U = \frac{1}{2} \left(\int \frac{M^2}{EI} \right) ds. \quad (5)$$

Substituting (5) for (4), then (6) can be obtained as follows:

$$U = \frac{1}{2} \int \frac{1}{EI} \left(M_p + \sum_{i=1}^n x_i m_i \right)^2 ds$$

$$= \frac{1}{2} \int \frac{1}{EI} \left(M_p^2 + \sum_{i=1}^n \sum_{j=1}^m x_i x_j m_i m_j + 2M_p \sum_{i=1}^n x_i m_i \right) ds. \quad (6)$$

Consider $\delta_{ij} = \int (m_i m_j / EI) ds$, $\Delta_{ip} = \int (m_i M_p / EI) ds$; then

$$U = \frac{1}{2} \left(\int \frac{M_p^2}{EI} ds + \sum_{i=1}^n \sum_{j=1}^m x_i x_j \delta_{ij} + 2 \sum_{i=1}^n x_i \Delta_{ip} \right). \quad (7)$$

The requirements for minimizing U are as follows:

$$\frac{\partial U}{\partial x_i} = 0, \quad \sum_{j=1}^n x_j \delta_{ij} + \Delta_{ip} = 0, \quad i = 1, 2, \dots, n. \quad (8)$$

There are n equations above to get out the cable force that can make the bending energy minimum, namely, minimizing the materials due to bending moments. It is noteworthy that " I " can be arbitrarily selected, and it can be completely fictional. For example, the ratio of the girder's to the tower's " I " value can be adjusted, or there is other alternatives of the side spans' " I " value and the middle span's " I " value, which are entirely

determined by the mechanical requirements. If we do the following conversion

$$\begin{aligned}\delta_{ij} &= \int \frac{m_i m_j}{EI} ds + \int \frac{N_i N_j}{EI} ds, \\ \Delta_{ip} &= \int \frac{m_i M_p}{EI} ds + \int \frac{N_i N_p}{EI} ds,\end{aligned}\quad (9)$$

where N_i = the axial force of the basic structure due to $x_i = 1$; N_p = the axial force of the basic structure due to static load; A = the element's section area. If A is defined as a large value, (8) is approximately deemed to be the force method equation. Then it is concluded that the structure's bending moment value will be smaller and distributed more uniformly when noncompressible and nonstretched elements are selected as the model to calculate the structural interforce. So we can manage to calculate conveniently by the method of displacement method. Therefore, the cable force x_i is formulated, and then the uniformly distributed loads q can be obtained as

$$q = w + \frac{\sum_{i=1}^n x_i}{l}. \quad (10)$$

The horizontal component of the main cable force of the main span due to dead load "Hg" can be obtained according to the optimization calculation model. The cable force obtained through the minimum bending energy can minimize the bending moment of girder and tower on the whole whereas it is found that some cable force cannot be in the most rational state, and some unreasonable cable force need to be optimized furthermore through the internal force balanced method, and so forth.

3. To Implement the Calculation Method of the Optimizing Cable Force

Optimization is aimed to adjust the cable force that is determined according to the minimum bending energy method initially, whereas the moment state of the main girder and the tower still needs to be the same as the original. Partial nonrational cable force will be optimized by balancing internal forces balanced method or quadratic programming method to get all of the cable force, the main girder, and the tower's bending moment into the completion state. At the same time, the cable force of the full bridge will be adjusted according to the result of the second step. Namely, the target value of cable force adjustment will be adjusted. Through artificial dressing evenly while the moment will be adopted from the second 12 step directly. The completion state optimized is characterized as uniform cable force and small girder moment. Above all, before the optimization calculation, the structure must be simplified and all of the calculation parameters, including the section characteristics of the stiffening girder and density, must be initialized.

The program implementation process based on the software MATLAB is shown in Figure 2, where M_{d1} and M_{d2} are defined as the control internal force. The cable force calculation program based on the minimum bending energy

FIGURE 2: Flow chart of global analysis.

method is optimized by the software MATLAB 6.5 and the secondary adjusting program based on the quadratic programming method and internal force balanced method, and the nonlinear least squares method has been compiled, making use of the toolbox owned by the MATLAB 6.5. In order to accelerating the running speed, the calculation object is the simplified abstract model. The principle part of the program is for plane frame structure, combined with the modules, such as the linear coordinate calculation of the segmental catenary, the calculation towards axial force due to dead load, the axial force in completion state, and the cable.

4. Verifying the Optimization Program towards the Cable Force

In order to verify the correctness and reliability of this calculation program, an example analysis that compared this one with an optimization program with the software ANSYS is given as follows.

4.1. The Model for Verification Introduction. The structure model's span arrangement is 60 + 120 + 60 m. It has a clear rise of 15 m, giving a rise to span of 1/8. One group of hungers is set on the side span and five groups of hungers are set on the main span. The optimization model and the hunger number are shown in Figure 3. The section area of stiffening girder is 0.486 m², of which the moment of inertia is 0.274 m⁴; the section area of tower is 5.84 m², of which the moment of inertia is 1.872 m⁴; the section area of main cable is 0.08824 m²; the section area of hunger is 0.007 m². Apart from the bridge tower, which is made of concrete, the rest of the structure is assumed to be made of steel. A point to note is that the cable cross-sectional area and moment of inertia have been calculated on the basis of a double-cable plane; hence, the cross-sectional area is twice the original cross-sectional area of the main cable. The

FIGURE 3: Sketch of optimize model.

model mentioned above is used to verify the correctness and reliability of this calculation program and to make a comparative analysis between the results with the software ANSYS and the optimization program elaborated in this paper. At first, we define that Stage 1 is tensioning the number 4 hunger; Stage 2 is hanging the number 3 hunger; Stage 3 is hanging number 1 hunger; Stage 4 is hanging number 2 hunger. The hungers' tensioning order is as follows: Stage 1: tensioning the number 4 hunger; Stage 2: tensioning the number 3 and number 4 hungers; Stage 3: tensioning the number 1 hunger; and Stage 4: tensioning the number 2 and number 3 hungers. Meanwhile, the initial hunger strain in every stage is defined as the design variable DV, of which the upper limit is up to 3.5×10^{-5} , the lower limit is down to 2.5×10^{-5} , and the tolerance is 0.0001. The hunger's internal force in the completion state (Stage 4) is defined as the controlled stress variable SV, of which the upper limit is up to 2×10^6 N, the lower limit is down to 3×10^6 N, and the tolerance is 0.01. The square of stiffening girder's moment is defined as the objective value OBJ (its tolerance is 1). The subproblem approximation method of ANSYS is preliminary utilized to optimize the cable force and then the equal step-search method is used to complete the scan analysis in the design space.

4.2. The Contrast Analysis of the Two Optimization Methods.

The results of cable force optimization in tension stage are given in Table 1. Through the calculation, the cable force in completion stage obtained with the optimization program

developed and that with the nonlinear and optimizing function in the software ANSYS are basically the same. In the software ANSYS, we can find initial stress in every tension stage rather than make trail repeatedly artificially based on a given tension order. Furthermore, what should be noted is that the number of variable and object value is limited and in the ANSYS optimization module, it is available only to define not more than 60 design variables, 100 control variables, and 1 object value (only minimum value obtained). So that it is of great importance to diminish design variables, simplify control variables, and determine object value. Many control variables need to be defined in the detailed analysis, such as saddle offset, cable internal force, displacements of control points of stiffening girder and main cable, stress of top and bottom flange of stiffening girder, and bottom stress of tower. These variables can be replaced with one kind of variable that is related to some of the others, by which the number of variables will drop down rapidly. Since only one object value can be optimized in the optimization module of ANSYS, it is significant to determine an object value that can describe the essence of ideal completion state. In terms of self-anchored suspension bridge, the bending moment of stiffening girder in tensioning is an important reference factor. So the square of stiffening girder's moment is selected to be the object value.

5. To Implement the Calculation Method of Optimizing the Cable Force

Compared with the cable force optimization in completion stage, the difficult points of that in construction stage include the main cable's geometric nonlinearity in construction, the interaction of the hunger forces, the uncertain tension sequence, and some factors that it influences. In this section, we will optimize and simplify the method of cable force tension in construction, in the premise of meeting the optimizing results' accuracy.

5.1. Simplified Calculation in Construction. In the construction stage of self-anchored suspension bridge, many factors need to be controlled. Because the unloaded cable is of great difference with that in completion stage, hungers need to endure not only the stiffening girder's weight but also the intension force. Besides, since the initial location of stiffening girder supports is the same as the deck elevation in completion stage, generally the hunger length is shorter than the distance between cable clamp to the main girder. In construction, cable saddle should be pushed to diminish the tower moment due to cable tension. Yet in order to simplify the optimization calculation, the interforces of stiffening girder and main cable are mainly considered while the effects brought about by cable saddle pushing are ignored temporarily. It is assumed that all of the materials are within the linear elastic range; the stiffening girder is uniform continuous beam; the vertical curve of stiffening girder is not considered; the stiffening girder is in stress-free state due to dead load. So that we can obtain approximately one hunger's interforce interacted by the hunger tension nearby as well as obtain the cable force and longitudinally axial force acted

TABLE 1: Result of optimization hanger tension in stretching stage (unit: N).

Tensioning stage	Cable numbers	Optimization	ANSYS	Relative error
Initial stage	4#	3.04×10^6	3.39×10^6	-10.3%
Second stage	3#	4.62×10^6	5.35×10^6	-13.6%
	4#	2.76×10^6	3.26×10^6	-15.3%
Third stage	1#	5.41×10^6	6.45×10^6	-16.2%
	3#	4.42×10^6	5.40×10^6	-18.2%
	4#	2.68×10^6	3.24×10^6	-17.3%
Fourth stage (completed bridge phase)	1#	2.83×10^6	2.96×10^6	-4.4%
	2#	2.62×10^6	2.76×10^6	-5.1%
	3#	2.27×10^6	2.32×10^6	-2.2%
	4#	2.25×10^6	2.15×10^6	4.7%

TABLE 2: Hanger tension order.

Initial tension order	Cable number	Second tension order	Cable number
1	13	1	13
2	14	2	12
3	15	3	14
4	16	4	11
5	17	5	15
6	18	6	10
7	19	7	16
8	20	8	9
9	21	9	17
10	22	10	8
11	23	11	18
12	24	12	7
13	25	13	19
14	26	14	6
15	27	15	20
16	28	16	5
		17	21
		18	4
		19	22
		20	3
		21	23
		22	2
		23	24
		24	1
		25	25
		26	26
		27	27
		28	28

on the stiffening girder directly, meanwhile, we can calculate the displacement performance during the hunger tension. Finally, the interforce situation of stiffening girder in every hunger tension stage and the cable force will be controlled.

5.2. Implementation of Optimization Program. The cable force optimization program of self-anchored suspension bridge is based on MATLAB program platform, which mainly considers the interactivity among the hungers in tension stage and calculates the changes of stiffening girder's axial force immediately to obtain the internal force state in every stage; the program implementation process based on the software MATLAB is carried out.

6. The Contrast Analysis of the Two Methods of Cable Force Calculation Optimization

For the purpose of verifying the application effect of the calculation method of hanger force optimization, a self-anchored suspension bridge with a span length of 476.15 m is utilized to make the contrast analysis of the two methods of cable force calculation optimization. The general arrangement of the Bridge is shown in Figure 4. The main bridge is double-cable planes, self-anchored concrete suspension bridge, with the main span of 160 m, the side span of 70 m, and the anchor span of 15 m. The main girder has width of 41 m and height of 2.5 m at the beam center. It is a five-span continuous reinforced concrete box beam of which the standard cross-section is 5-cell single box. The center distance of main cables reaches to 26.5 m and hangers are placed throughout the entire bridge at 5 m intervals. A detailed finite element model (Figure 5) of the example bridge is developed using the software ANSYS. The cable force in completion stage is computed by the hanger optimization program in ANSYS and the optimization module in MATLAB, respectively. The contrast analysis results of vertical displacement in the different stages have been shown in Figure 6.

In the actual construction, four-point synchronous symmetrical tension method is adopted: hangers are tensioned successively from the main tower to the middle point of midspan; by the way of pushing saddle and hanger tension in midspan, hangers among the full bridge are tensioned by 6 times; in construction, hanger is tensioned at 200 kN per step, and the displacement of the top of tower and hanger tension force are set to be the control parameters; hangers of the side span are not tensioned at the first tension step but at the second one. It is the moment when the tension forces of hangers adjacent to the tower are of huge difference, which

TABLE 3: Hanger tension order after optimization.

Tension order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17~20
Cable	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Part adjust cable force
	12	11	10	9	8	7	6	5	4	3	2	1

FIGURE 4: Perspective view of a three-span self-anchored suspension bridge.

FIGURE 5: Analytical model of a three-span self-anchored suspension bridge.

leads to big displacement of the saddle in the top of tower. Meanwhile, the hangers of side spans have nearly reached to the design tension force so that starting from the third step, mainly hangers of the midspan area of the main span will be adjusted, of which the control tension force is 2750 kN. The detailed tension order is shown in Table 2; the moment of stiff girder in the different three stages is shown in Figure 7.

Seeing Figure 5 and the contrast analysis towards vertical displacements of the nodes of main cable in three steps, the hanger forces of the midspan are quite not uniform, of which the difference between the maximum and the minimum reaches to 2500 kN. Moreover, the hanger forces adjacent to tower vary greatly, which is very detrimental to the stability and the safety of the overall structure. So this tension method should be optimized. In view of its three-span symmetrical structure, this bridge's hangers should be tensioned symmetrically as well in order to ensure the whole bridge safety. We advise that hangers both the side span and the middle span should be tensioned simultaneously around the main towers. Thus, the whole bridge safety can be ensured and the significant cable force relaxation due to nonsimultaneous tension can be diminished. Document [16] has been managed to analyze and verify the tension order in actual construction and that optimized. The tension method 2, namely, tensioning simultaneously from the main towers to the side span and the middle span, respectively, is developed in this paper (the method mentioned in the previous paragraph is called method 1). The detailed tension order is summarized in Table 3.

FIGURE 6: Vertical displacement in different three stages.

FIGURE 7: Moment of stiff girder in different three stages.

In the actual construction, after tensioning with method 1, hanger forces are quite nonuniform: the number 13 cable force near the main tower is the minimum one (174 kN); the number 20~No.27 cable forces in the midspan are the maximum ones (approximately reach to 2700 kN). After tensioning with the first step of method 2, hanger forces (most of which are more than 2000 kN) are uniform relatively. Yet the number 5 is the minimum one (600 kN), the number 12 is the maximum one (4194 kN), and the number 13 reaches to 2960 kN. These forces might well lead to cracking and destroy the main girder. After the first step of method 1, the biggest hanger force change lies in number 20 (1/4 of the midspan) while the minimal one lies in number 13. In the method 2, the biggest one is number 20 while the minimal ones are number

6-number 11 and numbers 12–27, meanwhile, tensile force relaxation emerges in the number 5 hanger [16].

In accordance with the results of [16], both hangers numbers 13 and 14 are slack after tensioning hanger number 17 when employing method 1 and some hangers are slack while hangers numbers 14–26 are being tensioned when employing method 2. In spite of great difference between the methods 1 and 2, the tension force of number 12 hanger (the side span side of the main tower) is also up to a high value, the same as that with method 1, which has already exceeded the limited control range. So we can abandon number 12 hanger tension at the first step and it is available not to tension the hangers near the towers at the initial stage. Besides, we can see from the analysis towards hanger tension in construction of the bridge that the results obtained with the simplified analysis program (on the basis of adjacent hangers affect) is of great difference with the actual hanger force. It cannot reflect the rule of hanger force changing.

7. Conclusion

A new optimization analytical model of cable force of self-anchored suspension bridge is developed and solved by the optimization analytical method. From optimization analysis model of the cable force of a self-anchored suspension bridge, by comparison, the cable force computed with the optimization method is approaching to that with the finite element model of software ANSYS, which basically meets the accuracy, and the completion cable force can be obtained promptly with this method. Combined with actual construction data, an optimized tension method was developed through the analysis of tension order of the suspension bridge. If possible, a symmetrical tension method should be applied to reduce the interaction of cable forces and allow hanger relaxation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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