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© А. М. Масленников, д-р техн. наук, профессор

© Б. О. Рагех, канд. техн. наук

(Санкт-Петербургский государственный
архитектурно-строительный университет)

E-mail:aleksmaslennikov@yandex.ru,

eng_basem85@mail.ru

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© A. M. Maslennikov, Dr. Sci. Tech., Professor

© B. O. Rageh, PhD in Sci. Tech.

(Saint Petersburg State University of Architecture
and Civil Engineering)

E-mail:aleksmaslennikov@yandex.ru,

eng_basem85@mail.ru

COMPARISON BETWEEN TWO ALGORITHMS FOR EVALUATING OF THE OPTIMUM INITIAL TENSION OF CABLES IN CABLE-STAYED BRIDGES

СРАВНЕНИЕ ДВУХ АЛГОРИТМОВ ОПТИМИЗАЦИИ ПЕРВОНАЧАЛЬНОГО НАТЯЖЕНИЯ ВАНТ ВАНТОВЫХ МОСТОВ

Optimal tension of cables in cable-stayed bridges is one of the main problems in the design of bridges. The article compares two algorithms developed for this purpose. The first proposed algorithm developed by M. M. Hassan in 2010 uses spline functions, and the second algorithm is proposed by B. O. Rageh. This algorithm minimizes the total potential energy with the conjugate gradient method. It is programmed in FORTRAN language. The comparison is made on the specific models of cable-stayed bridges from the action of stationary loads. As parameters of comparison, the deflections of the beam of rigidity and deflection of pylons are accepted. The article shows certain advantages of the second algorithm.

Keywords: cable stayed bridges, optimum initial tension, minimization of potential energy, dead load analysis.

Сравниваются два алгоритма оптимизации первоначального натяжения вант вантовых мостов. Первый, разработанный М. М. Хасаном в 2010 году, использует сплайн-функции, а второй предложен Б. О. Рагехом. Этот алгоритм минимизирует общую потенциальную энергию, используя метод сопряжённых градиентов. Он запрограммирован на языке FORTRAN. Сравнение производится на конкретных моделях вантовых мостов, находящихся под действием неподвижной статической нагрузки. В качестве параметров сравнения приняты прогибы балки жёсткости и отклонения пилонов. В статье показаны определённые преимущества второго алгоритма.

Ключевые слова: вантовые мосты, оптимизация натяжения вант, минимизация потенциальной энергии, расчет на неподвижную нагрузку.

Introduction

Determining the optimum distribution of initial tension in cables is considered one of the most difficult tasks in the design of cable-stayed bridges. The initial tension forces control the distribution of internal forces and affect the overall design of the bridge. Several design optimization algorithms for cable-stayed bridges are available in the literature [1], [2], [3]. In the optimization method developed by J. H. J. O Negro and L. M. C Simoes [1997] and L. M. C Simoes and J. H. J. O Negro [2000], the post-tensioning cable forces are determined by minimizing a convex scalar function. This function combines dimensions of cross-sections of the bridge, overall structural geometry, and post-tensioning cable forces. Maximum and minimum allowable

stresses in stay cables and deflections of the deck are the three constraints imposed in the method. The unit load method (ULM) is suggested by Janjic D., et al. [2003]. The method takes into account the effect of the three sources of geometric nonlinearities. In this method, a desired bending moment distribution at specific degrees of freedom (cable-deck connections) is used to obtain the optimum cable forces. The bending moments at these specific DOFs are first calculated due to a unit load case for each stay cable. The bridge is analyzed under the action of the dead load. A system of linear equations can be established with one equation for each DOF. This system of equations can be directly solved for the unknown cable forces that can be applied to achieve the desired moment distribution. Selection of DOFs

is one of the most critical precautions of this method, as it may lead to singularities in the equation system. The new algorithm developed by M. Hassan [4] obtained for evaluation the optimum initial tension forces in cables under the effect of the deck dead load using finite element method and B-spline function. A suggested algorithm for selecting the best initial tension in cables depending on an iterative scheme to give the minimum deformations of the bridge based on the minimization of the total potential energy of structural elements, via conjugate gradient technique, is carried out [5].

Algorithm using B-spline function for evaluation of the optimum initial tension in cables

M. M. Hassan [2010] developed a new algorithm using B-spline function, and the mathematical model of the bridge is analyzed by finite element method. The flow chart, which describes the algorithm, is shown in Fig.1. In this technique, B-spline curves are selected to represent the post-tensioning forced in each cable shown in Fig. 2. A p^{th} degree B-spline curve $C(u)$, is defined as follows:

$$C(u) = \sum_{i=0}^n N_{i,p}(u) p_i, 0 \leq u \leq 1, \quad (1)$$

where u is the independent variable, and p_i , are the control points. The polygon formed by the control points p_i , is called the control polygon. $N_{i,p}(u)$ are the p^{th} degree B-spline basis functions given as:

$$N_{i,0}(u) = \begin{cases} 1 & \text{if } u_i \leq u \leq u_{i+1} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u). \quad (3)$$

According to the previous algorithm, in order to obtain the optimum initial tensioning in cables, five cases obtained by M. M. Hassan [2010] in the analysis, which every case produced the initial tension forces in cables depending on the choice of the control points p which are taken as a percent of maximum breaking load of cable.

Suggested algorithm for evaluation of the optimum initial tension in cables using conjugate gradient method to minimize energy [6, 7]

Fig. 1. Algorithm for evaluation of the optimum initial tension cable forces: where: $\delta_1, \delta_2, \dots$ — vertical deflection of the nodes of the deck spine, $\delta_{1p}, \delta_{2p}, \dots$ — lateral deflections of the pylons' tops, $\epsilon = 1.5 \times 10^{-4}$, l — main span of the bridge model.

Coordinates of B-spline control points

Case1	$(0, 0.5T_{\max}), (0.25l, 0.5T_{\max}), (0.75l, 0.5T_{\max}), (l, 0.5T_{\max})$
Case2	$(0, T_{\max}), (0.25l, T_{\max}), (0.66l, T_{\max}), (l, T_{\max})$
Case3	$(0, T_{\max}), (0.4l, T_{\max}), (0.8l, T_{\max}), (l, T_{\max})$
Case4	$(0, 0.5T_{\max}), (0.4l, 0.5T_{\max}), (0.8l, 0.5T_{\max}), (l, 0.5T_{\max})$
Case5	$(0, 0.5T_{\max}), (0.25l, 0.5T_{\max}), (0.66l, 0.5T_{\max}), (l, 0.5T_{\max})$

Suggested algorithm for selecting the best initial tension in cables depending on an iterative scheme to give the minimum static response is presented in Fig. 3. The energy method based on the minimization of the total potential energy of structural elements via conjugate gradient technique is used. All previous parameters were described in details in literature [8, 9, 10].

Description of the Bridge

The geometry of the cable-stayed bridge chosen for this study is similar to that of the Quincy Bayview

Bridge, located in Illinois, USA. The original bridge has 56 cables, however, in the current example, this number is increased to 80 cables in order to demonstrate the efficiency of the new method for a large number of stay cables. The total length of the main channel span is 285.6 m, with two side spans of 128.1 m. Therefore, the total length of the bridge is 541.8 m, as shown in Fig. 4, 1.

The deck superstructure is supported by double planes of helically wrapped stay cables in a semi-fan type arrangement. The cross-section of the bridge deck consists of a precast concrete deck having a thickness of 0.23 m and a width of 14.20 m. Two steel main girders are located at the outer edge of the deck. These girders are interconnected by a set of equally spaced floor steel beams. The distance between each pair of floor steel beams is 9.0 m. The vertical moment of inertia (I_{dv}), the transverse moment of inertia (I_{dh}), the cross-section area (A_d), and the modulus of elasticity (E_{ds}) of the deck are 0.704 m^4 , 14.2 m^4 , 0.602 m^2 , and $2 \times 10^8 \text{ kN/m}^2$, respectively. All the deck section properties are based on transferring the concrete slab to an equivalent steel plate. The

Fig. 2. Representation of the cable forces by B-spline curves

Fig. 3. Suggested algorithm for evaluation of the optimum initial tension cable forces us here: T_0 — Initial tension in cables, T_f — Final tension in cables, $\varepsilon = 10^{-4}$

cables are assumed to have constant cross-sectional areas of 0.0176 m. The modulus of elasticity (E_{cs}), the ultimate tensile strength (T_c cable), and the weight per unit length (w_{cs}) of the cables are 2.1×10^8 kN/m², 1.6×10^6 kN/m², and 1.36 kN/m, respectively.

The pylons consist of two concrete legs 4.20×2.20 m with thickness 0.6 m, interconnected with a pair of struts. The upper strut cross beam connects the upper legs, and the lower strut cross beam supports the deck. The lower legs of the pylon are connected by a 1.22 m thick wall, which is placed

as a web between the two legs, cross section of the upper legs and lower legs, the modulus of elasticity for the concrete (E_c) is 2.5×10^7 kN/m².

Results and discussion

The nonlinear static analysis of the bridge is carried out. The bridge is analyzed under the action of the dead load using the energy method, based on the minimization of the total potential energy of structural elements, via conjugate gradient technique. The main results are shown in Fig. 5, 6. The optimum initial tension forces in each cable

Fig. 4. Cables number and geometry of the bridge

Fig. 5. Initial tension forces in cables

are illustrated in Fig. 5 obtained by using the 2-x algorithms which are described in Fig. 2, 3. Values of independent variables for initial search points used in B-spline function (Table) in cases from 1 to 4. The vertical deflection of the deck and lateral deflections of the pylons' tops are illustrated in Fig. 6 (a, b). Fig. 6 (a, b) show the effect of applying the optimum initial tension in cables using the 2-x algorithms on the deck and pylon responses where a significant decrease in a the vertical deflection of the deck and lateral deflections of the pylons' tops can be noticed, also a good agreement was figured between the finite

element method (FEM) and the energy method results for the analysis of the bridge.

Conclusion

1. Results obtained by using energy method have a good comparison with those by finite element method.

2. Suggested algorithm gives a predicted value for the allowable deflection of the deck under the dead load effect with the optimum initial tension in each cable, a significant decrease in a the vertical deflection of the deck and lateral deflections of the pylons' tops can be obtained.

Fig. 6. (a) vertical deflection of the deck (b) lateral deflections of the pylons' tops

3. Suggested algorithm can be easily applied in the analysis more than the other algorithm which was obtained by M. M. Hassan [2010] due to carrying out a lot of cases to get a suitable B-spline curve, which gives the optimum initial tension in each cable. Furthermore, the suggested algorithm gives very close results with those obtained by B-spline curve's results.

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