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Numerical Analysis of Long-Span Cable-Stayed Bridge in the Construction Phase

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Abstract: The fabrication and erection of cable-stayed bridges involve major changes in structure configuration through the addition and removal of structure components. In every stage of the construction process, adequate information on the constructed structure is important to determine the real structure situation for the analysis of errors and to verify construction requirements. The ultimate goals are to meet construction needs and identify the effects of modification in subsequent construction procedures. The final configuration of the structure is strongly dependent on the construction and fabrication procedures. In this regard, developing an FEA model to simulate the actual construction processes is necessary to determine the performance of a bridge under external loads. In this study, a general methodology for construction processes is presented to simulate a cable-stayed bridge. The stage-by-stage construction of the Sutong Bridge is simulated with ANSYS software package. The tensions of cables are realized with ANSYS parametric design language, element birth and death function, and mutliframe restart function. The objective of the construction stage simulation is to identify stresses and deformations of the steel box girder and the concrete towers, as well as the cable tension stress, to meet the design requirements. Results of the construction stage analysis showed that the temperature method could simulate the adjustment of the inclined cable force successfully, and the global stiffness of the Sutong Bridge was very small before closure. These findings served as the initial data for a dynamic research on the Sutong cable-stayed bridge.

Keywords: cable-stayed bridge, simulation analysis, finite element model, construction phase, inclined cable.

INTRODUCTION

A result of significant advancements in material and construction technologies, modern cable-stayed bridges have become increasingly popular worldwide in recent decades as an efficient solution for long-span crossing. Modern cable-stayed bridges consist of three components, namely, girders, towers, and inclined cables. The girder is supported by many inclined cables, so that it can span a much longer distance without any intermediate supports compared with those in other types of bridges. The loads on the girder, such as automobile load and crowd load, are transmitted to towers by inclined, high-strength cables that lead to high compression in the girder and tower.

In general, cable-stayed bridges can be fabricated with the cantilever erection method, which makes full use of segmental balanced cantilever techniques to build on both sides of the pylon simultaneously. For steel box girder cable-stayed bridges, the box girder segment produced in the factory is welded and suspended with inclined cables from the pylon. The construction of cable-stayed bridges includes a number of repetitive cycles of welding the steel box girder segments and mounting the inclined cables. During this process, a sequence of partial structures is developed. Temporary supports, transient displacement, and incline cable tensions are all provided during construction to avoid overstressing the components of the partial structures and to obtain the ideal final configuration. During the construction stage, the partial structures are more flexible before closure and are more sensitive to the construction loads than those during the completed stage.

Determining the internal forces and geometric configuration in the construction stages of cable-stayed bridges is important because the structure is very flexible and highly redundant. Its construction process is complicated and includes the nonlinear behavior of partial structures (*e.g.*, cable sag effect, beam–column effect, and large displacement), their continuous structural changes, and unforeseen erection variations. In the construction phase, large deviations from the design shape are inevitable, so the construction sequence needs to be simulated with a software program to determine the ideal state of each stage. One of the major objectives of construction stage analysis is to check the position control points of the partial structure in order to ensure that construction tolerances do not accumulate to the point in which the bridge fails to achieve its desired final configuration. The configuration of the completed bridge is related to the internal force distribution under the temporary load, the dead load, and the pretension forces in the inclined cables. An obvious characteristic of cable-stayed bridges is that the high tension forces in the inclined cables lead to high compression forces in the girders and towers. In other words, the internal forces of the girders, towers, and inclined cables are dependent on one another. If the tension force of one inclined cable changes, the girder shape and the internal force of towers simultaneously change. The completed stage must meet engineering design

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requirements, such as the configuration, girder stress, and tensions in the inclined cable. The interim and final stresses and deformations of the structure components depend directly on the construction method and the process used. Therefore, a numerical analysis of the actual construction process is an important task to determine the internal force and displacement under the action of external loads, such as live load and temperature load.

Nonlinear behavior is remarkable in that axial forces cause secondary moments to the structure and change the stiffness of structure components, particularly in the process of erection. Various simulation analyses have been proposed for cable-stayed bridges, such as linear analysis and nonlinear static analysis. Nonlinear analysis was also presented by Nazmy and Abdel-Ghaffar, who used a tangent stiffness iterative–incremental procedure [1]. Huu-Tai Thai and Seung-Eock Kim developed a spartial two-node catenary cable element for the nonlinear analysis of cable structures subjected to static and dynamic loadings [2]. Many researchers have focused on the construction stage analysis of cable-stayed bridges and emphasized that simulating the construction process in consideration of nonlinear behavior and the actual construction approach is important[3-5]. In the construction stage simulation domain, the use of simulation software has involved either a commercial simulation package (*e.g.*, ANSYS, Abaqus) or a professional simulation package (*e.g.*, Midas, Bsas) specifically designed to model the characteristics of construction projects. Dulcy used the MicroCYCLONE software to simulate two cable-stayed bridges and thus analyzed construction processes and the results of sensitivity analyses [4]. However, the simulation of the construction stage is associated with some computational difficulties, such as geometric nonlinearity, the connection between the cable and the girder, and the tension force of inclined cables. Some researchers have recommended the use of the backward analysis method or the forward analysis method to address these difficulties [6]. Huu-tai Thai used a multi-node element to simulate the long cable and thus consider the cable sag effect [2].

With the geometric nonlinearity effect considered, this study aims to simulate the construction stage of a cable-stayed bridge by using ANSYS software package. The construction stage simulation of the cable-stayed bridge is based on ANSYS parametric design language, the element birth and death function, and the multi-frame restart function [7]. To simulate the realistic behavior of an inclined cable accurately, the inclined cable is divided into several elements in order to consider the cable sag effect. The objective of the construction stage simulation is to identify stresses and deformations of the steel box girder and the concrete towers, as well as the cable tension stress, to agree the design requirements.

CONSTRUCTION STAGE SIMULATION

The addition and removal components of a structure comprise the construction consequence as internal forces and external loads change. For a cable-stayed bridge structure, the tower and the girder are subjected to a large axial compressive force together with the bending moment. Therefore, nonlinear behavior needs to be considered in construction stage simulation by activation and deactivation of elements in the appropriate stage. Nonlinearity includes the cable sag effect, beam–column effect, and large displacement, which significantly affect the deformation and internal force of a cable-stayed bridge. Nonlinear behavior is a key issue to be considered in simulating the construction consequence, so it can meet the actual state of the structure under load action. In a nonlinear finite element model, the geometric nonlinearity resulting from large displacements can be modeled by the updated Lagrangian method in Ansys software package, which is appropriate for changes in structure geometry as large deformation occurs. A known deformed configuration i is taken as the initial state for subsequent configuration $(i+1)$, and this is continually updated as the calculation proceeds. The stresses and strains in the configuration $(i+1)$ are transformed accordingly to refer to the updated configuration i .

The construction stage combined with the solution of the nonlinear formulation can be simulated to conduct the procedure of activating and deactivating the elements in ANSYS software package. All the elements of the bridge structure are considered present at all times in the finite element mesh. Corresponding to the new erected segments of the structure, such as the girder, tower, and inclined cable, some elements and external forces are assumed to be added at the n^{th} step. The new element group is activated through the contribution to the stiffness matrix. According to the erection process, the new elements are activated in the subsequent step, and a new stiffness matrix of the finite element model is developed. Some elements (*e.g.*, temporary support and equipment load) are removed from the structure at the m^{th} step, which is exactly opposite to the activated process. These elements will be omitted from the structure in the subsequent steps.

The methodology described in the preceding can be developed in the ANSYS software package used in this study. The death elements are not removed from the finite element model in the ANSYS program, but the structural stiffness matrix is multiplied by a small factor whose default value is 1.0E-6 and can also be assigned to other values. The load of the death element is zero, and it does not affect the load vector, but it still exists in the load lists. Similarly, the mass and damping of the death elements will be set to zero. The mass and energy of the death elements will not be included in the model solution results. The death element strain will also be set to zero. From the theory of element birth and death, death elements do not provide stiffness for the finite element model, but birth elements provide complete stiffness. Therefore, element birth and death technology can be applied to the simulation analysis of the construction process of cable-stayed bridges. Additional details on the theoretical formulation and the capabilities of the program can be found in the theoretical manual for the ANSYS program [7].

REALIZATION OF INCLINED CABLE TENSION

In the construction process of cable-stayed bridges, the inclined cables are tensioned by adjustment of the unstressed length of the inclined cable. Simulating the adjustment of the cable force through a direct change in the cable length in the

ANSYS program is difficult [8-10]. However, the initial strain method and the temperature method can simulate the adjustment of the inclined cable in the finite element model. The goal of the two former methods is to make the inclined cable force in the finite element model equal to the actual tension force. In this study, the temperature method will be used to adjust the inclined cable force.

Temperature change will result in temperature strain, and it will transfer to the cable force. The method of calculating the temperature strain is $\varepsilon = \alpha\Delta T$, where α is the expansion coefficient, and ΔT is the temperature change value. Obtaining the relationship between the cable force and the temperature because of the cable sag and the interaction of the inclined cable with the other components of the cable-stayed bridge is difficult. The inclined cable force increases as the cable temperature decreases, but an iterative solution is needed to obtain the inclined cable temperature, which is used to realize the actual tension.

In the finite element model, an iterative method is described as follows:

$$\Delta T^0 = T / (\alpha EA), \tag{1}$$

where E=modulus of the inclined cable, A=cross section area of the inclined cable, α= expansion coefficient, T =target cable force, and ΔT^0 =initial cable temperature.

The iteration method steps are as follows:

(1) The initial temperature ΔT^0 is assigned to the inclined cable in the finite model.

(2) The initial cable force is solved and picked up.

$$F^0 = f(\Delta T^0), \tag{2}$$

where F^0 = initial cable force.

(3) A precise temperature for the inclined cable is determined, as shown in Fig. (**1**).

$$\Delta T^n = \Delta T^{n-1} + k(T - F^{n-1}) / (\alpha EA), \tag{3}$$

where k=1～1.5; ΔT^n =the cable temperature of the nth iterative.

(4) The cable force is solved and picked up.

$$F^n = f(\Delta T^n). \tag{4}$$

(5) Whether the iteration reaches convergence is determined, and if not, step (3) is repeated.

$$T - F^n < \varepsilon, \tag{5}$$

where ε =allowable error.

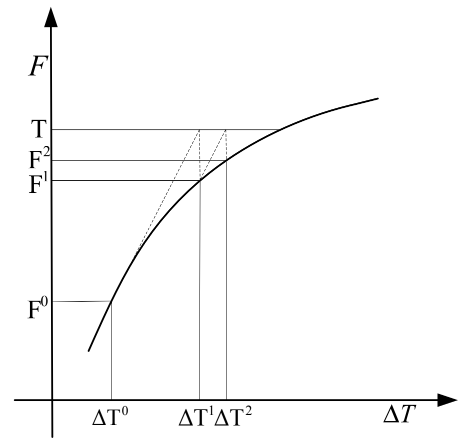


Fig. (1). Inclined cable tension iteration method.

To reach the target cable tension, an effective and efficient simulation of cable force in the construction process is important. In the ANSYS software package, the methodology described previously can be developed with the multi-frame restart method. Multi-frame restart means that users can set the restart point at any stage when the analysis is completed and then save the results as of the restart point as a reference for later stages of the analysis. Users can therefore continue the analysis from the restart point. In other words, the restart analysis is based on the specified restart point and includes its results.

CONSTRUCTION OF THE CABLE-STAYED BRIDGE

After the completion of the piers, pylons, and other associated works in the construction process, the steel girder erection and cable installation will be a typical repetitive cycle, as shown in Fig. (**2**). The lifting crane, which is mounted on the last erected segment, hooks up the segment from the transportation barge. This segment is lifted to the design level and is secured to the temporary support frame as a temporary fixing. It is welded to the preceding segment. Then, the inclined cable is installed on the segment. The cable is first anchored to the tower and the deck. After the anchorage work is completed, the cable is stressed by a heavy jack until the designed length is reached. To balance the bending acting on the tower, one back-span cable and one mid-span cable need to be stressed simultaneously. The first and the second cable tensions in the installed stage are shown in Table **1**. The typical erection cycle will be repeated

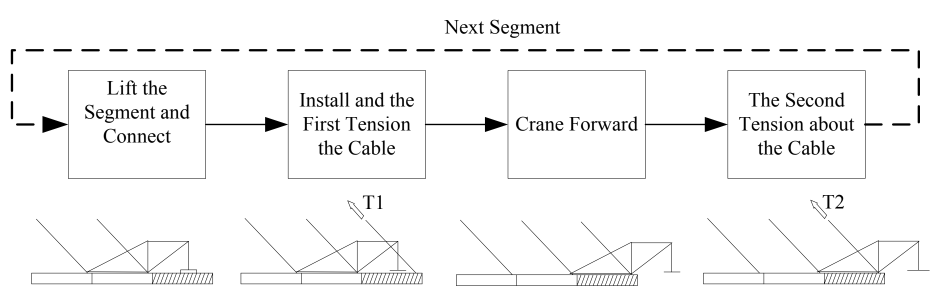


Fig. (2). Construction process of a standard girder.

Table 1. Parameters of the inclined cables.

No.	Cross section area (m2)	T1: First tension (kN)	T2: Second tension (kN)	No.	Cross section area (m2)	T1: First tension (kN)	T2: Second tension (kN)
A1	0.007197	1740	2702	J1	0.005811	2001	2618
A2	0.007197	1716	2766	J2	0.005811	1998	2614
A3	0.005811	1840	2755	J3	0.005349	2022	2477
A4	0.005349	1982	2679	J4	0.005349	1983	2579
A5	0.005349	2046	2796	J5	0.005349	1888	2661
A6	0.005349	2235	2805	J6	0.005349	1932	2657
A7	0.005349	2299	2805	J7	0.005349	2202	2691
A8	0.005811	2336	2974	J8	0.005811	2313	2997
A9	0.005811	2332	3044	J9	0.005811	2398	3097
A10	0.007197	2447	3406	J10	0.007197	2322	3257
A11	0.007197	2822	3521	J11	0.007197	2375	3373
A12	0.007197	2781	3507	J12	0.007197	2596	3455
A13	0.007197	3280	3827	J13	0.007197	2851	3655
A14	0.007197	3331	3860	J14	0.007197	2893	3679
A15	0.007658	3319	4010	J15	0.007658	3069	3752
A16	0.007658	3391	4147	J16	0.008582	3072	3890
A17	0.008582	3361	4186	J17	0.007658	2856	3832
A18	0.008582	3262	4135	J18	0.007658	2935	3853
A19	0.008582	3291	4180	J19	0.007658	3004	4019
A20	0.008582	3329	4216	J20	0.008582	2926	4306
A21	0.008582	3338	4180	J21	0.008582	3349	4221
A22	0.008582	3188	4231	J22	0.008582	3135	4222
A23	0.008582	3374	4218	J23	0.008582	3143	4485
A24	0.008582	3274	4233	J24	0.008582	3176	4507
A25	0.009275	3497	4548	J25	0.009275	3315	4786
A26	0.009275	3706	4558	J26	0.009275	3422	4871
A27	0.009275	3743	4655	J27	0.009275	3514	4842
A28	0.009275	3628	4694	J28	0.010891	3758	5278
A29	0.009275	3785	4741	J29	0.010891	3934	5343
A30	0.009275	3941	4756	J30	0.010891	4039	5338
A31	0.010891	4265	5369	J31	0.010891	4167	5330
A32	0.010891	4409	5357	J32	0.010891	4264	5341
A33	0.010891	4581	5333	J33	0.012046	4500	5511
A34	0.012046	4983	5822	J34	0.012046	4693	5752

until the last closure segment, which will be operated with a distinct method.

Based on the activating and deactivating elements, as well as on parametric design language features, the preceding ideas can be applied to the simulation analysis of cable-stayed bridge construction, as shown in Fig. (**3**).

DESCRIPTION OF THE SUTONG CABLE-STAYED BRIDGE

(1) Span Arrangement

The Sutong Bridge crosses the Yangtze River approximately 100 km upstream from Shanghai, China and connects the cities of Suzhou and Nantong located on the southern and northern banks, respectively. The bridge is a seven-span double-pylon and double-cable plane steel box girder cable-stayed bridge, with a span arrangement of 100+100+300+1088+300+100+100=2088 m, as shown in Figure 4. The Sutong Bridge is the second longest cable-stayed bridge in the world, with a record-breaking construction in the history of bridge building.

(2) Girder

The bridge girder is a streamlined closed flat steel box girder. The total width, including wind fairing, is 41.0 m, which accommodates eight traffic dual lanes. The cross section height is 4.0 m. The steel box is generally stiffened in the longitudinal direction with closed steel troughs. Transverse plate diaphragms are provided with a typical distance of 4.0 m. The characteristic yield strength of the steel box girder is 345 MPa. The standard cross section of the girder is illustrated in Fig. (**4**). The thickness of the skirts and stiffeners varies along the longitudinal direction of the bridge.

(3) Cables

The stay cables are arranged in double inclined cable planes with a standard spacing of 16 m in the central span and 12 m near the ends of the back spans along the girder. To reduce the effect of wind loads, the cable stay systems are made of a parallel wire strand consisting of 7 mm wires, each with a cross sectional area of 38.48 mm^2. The nominal tensile strength of the cables is 1770 MPa. Cable sizes range from a minimum of PES7-139 for the main span stays near the pylons to a maximum of PES7-313 for the longest backstay. The longest cable is about 577 m with a weight of 59 tons. The cable tension and cross section area of the cable-stayed bridge are listed in Table **1**. The cross section areas of the cables differ because each inclined cable consists

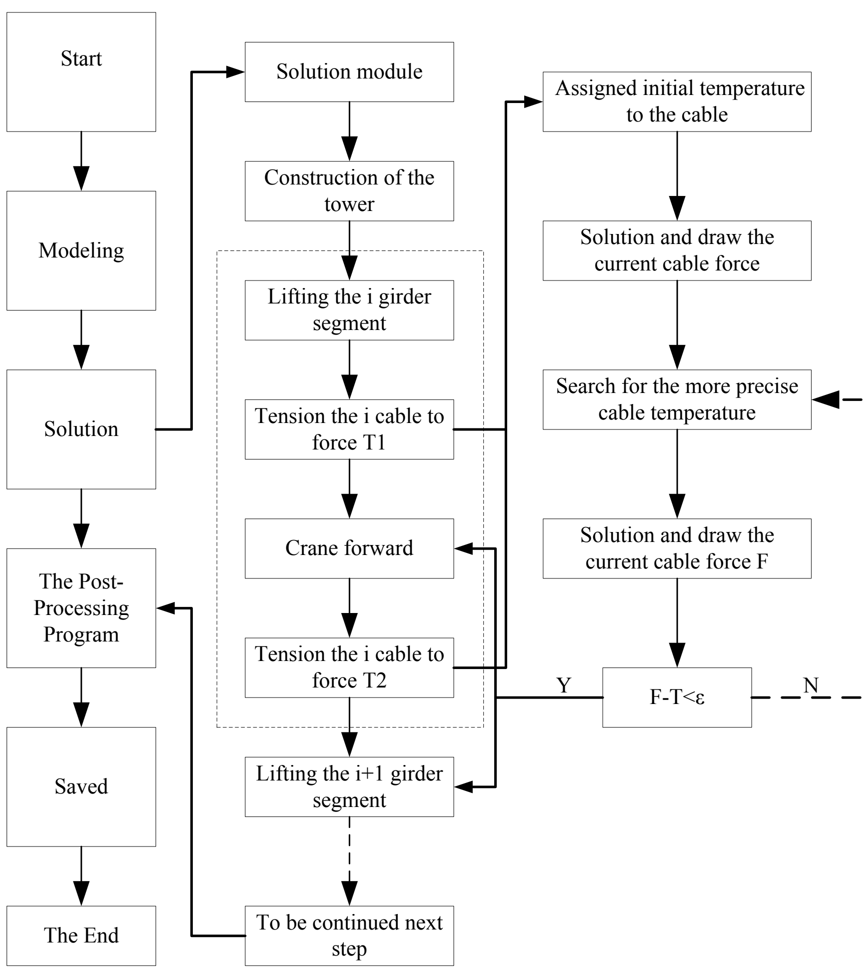
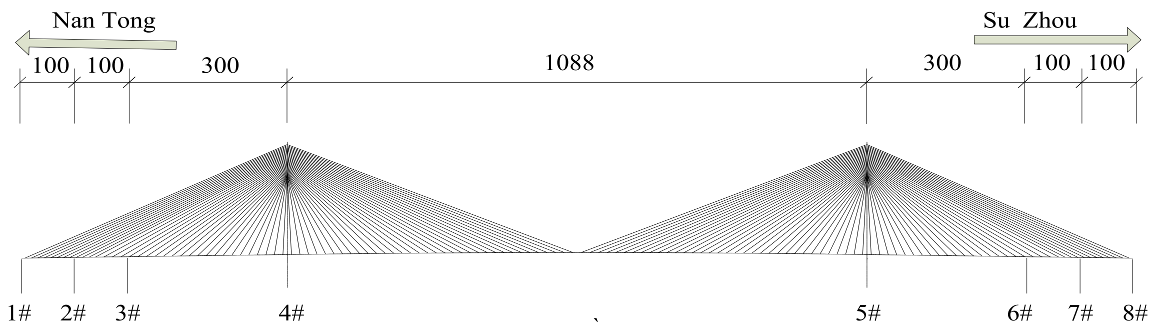
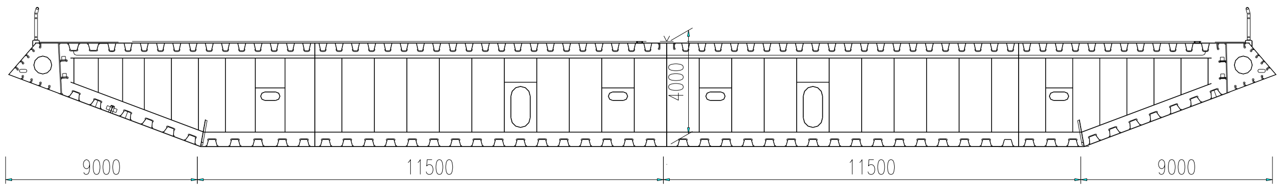


Fig. (3). Construction process simulation of a cable-stayed bridge.



(a) Elevation (unit: m)



(b) Cross section of the steel box girder (unit: mm)

(c) Construction stage

Fig. (4). Configuration of the Sutong Bridge.

of different numbers of strands.

4) Foundations

Bored friction piles support the piers and pylons from P1 to P8, with diameters from 2.8 m near the pile-head to 2.5 m away from the top along the piles. Each of P1–P2 and P7–P8 has 19 piles. Thirty-six piles are driven by P3 and P6 separately. Each pylon of P4 and P5 is supported by 131 piles. The pile lengths vary from 108 m to 116 m.

The connection between the girder and the pylons is accomplished by nonlinear dampers. These dampers do not confine the displacement of the steel girder induced by temperature, moderate wind, and vehicle traffic. However, they transfer the loads from the girder induced by gust, earthquake and other forces from specific load combinations to an alternative pylon.

GLOBAL ANALYTICAL MODEL

The finite element model of the Sutong cable-stayed bridge is developed with ANSYS software package, which uses beam elements (beam 44) to model the towers and girders, as well as space truss elements (link 10) to model the cable. The sectional properties of the typical components of the Sutong cable-stayed bridge listed in Table **2** are required to develop the 3D finite element model. The entire finite element model illustrated in Fig. (**5**) comprises 1,541 nodes and 2,393 elements. The structural modeling is in accordance with the planned construction scheme.

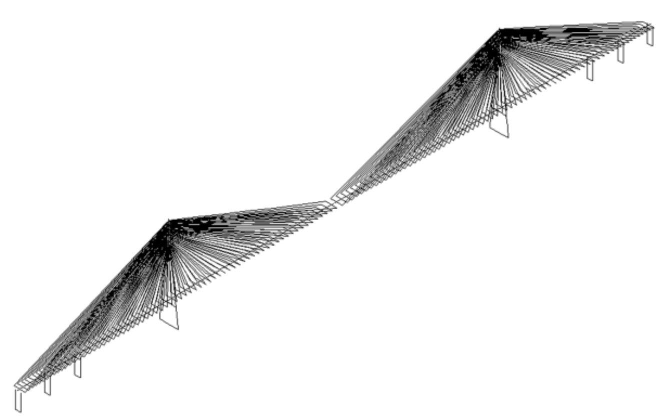


Fig. (5). Finite element model of the Sutong cable-stayed bridge.

Table 2. Sectional property of the Sutong cable-stayed bridge.

Properties	Girder	Pylons	Pier
A (m2)	1.74–2.81	35–119	13.00
Ixx (m4)	224.33–334.90	335–2194	50.23
Iyy (m4)	4.67–7.78	185–1917	121.69
Izz (m4)	12.47–22.29	500–1705	113.4

Note: A=cross section area; Ixx, Iyy, Izz=moments of inertia.

In the 3D full-scale structural model, the pylon, girder, and pier are modeled with a linear elastic beam element (beam 44) with six degrees of freedom at each node. The inclined cables are modeled in ANSYS with the use of 3D tension-only truss elements (link 10) without bending stiffness, as well as stress-stiffening capacity. Fig. (**6**) depicts a line diagram of the finite element model geometry at several construction stages of the Sutong cable-stayed bridge. The cable tensions reach the design forces through applying the temperature loading on the truss elements detailed in the Fig. (**1**). The cable sagging effect can be incorporated with the stress stiffening capability. To consider cable sag effects, each of the stay-cables is divided into 50 meter-long elements rather than the use of the effective module of elasticity. Other interacting nonlinear effects, such as the P-delta effect, large displacements, and shear displacements, are also considered in the calculation. Creep and shrinkage effects are computed according to Chinese code. The connection between the girder and both pylons is treated as a nonlinear static spring element. The temporary static loads are simulated with equivalent distributed forces, which are applied on the beam elements.

RESULTS OF THE CONSTRUCTION STAGE SIMULATION

Each stage of the construction process requires detailed information on the existing partial structure to determine the actual structure state, investigate the deflection, and thus meet design guidelines. For the Sutong cable-stayed bridge, some criteria in the construction stage were based on the design specification and construction scheme. Specifically, a zero allowable tension for the concrete tower was guaranteed in the construction stages; each cable tension stress needed to be less than 0.4 times the cable design stress. These limitations played an important role in the construction stages to ensure that the erected structure was in a safe state.

The results of the Sutong cable-stayed bridge under dead loads, including the lifting crane weight and some temporary loads acting on the superstructure in the construction stage, are shown in Figs. (**7** to **9**). The internal force and stress of the superstructure were drawn according to the construction sequence previously detailed. The results, including the stress analysis of the girder and the tower during the erection, as well as the cable tension stress in each stage, were important to control the geometry profile of the steel deck and the concrete tower and evaluate the behavior of the actual structure.

Fig. (**7**) shows the distributions of the internal force and compressive stresses in the steel box girder at various stages of the construction. The construction stage analysis for the Sutong cable-stayed bridge indicates that the maximum double cantilever stage (no. 103 stage), the maximum single cantilever stage (no. 309 stage), and the completed stage (no. 326 stage) correspond to the most detrimental and important construction stages. The maximum compressive stress at the top flange (bottom flange) of the box girder is 29.39 MPa (18.80 MPa) in the maximum single cantilever stage. Some

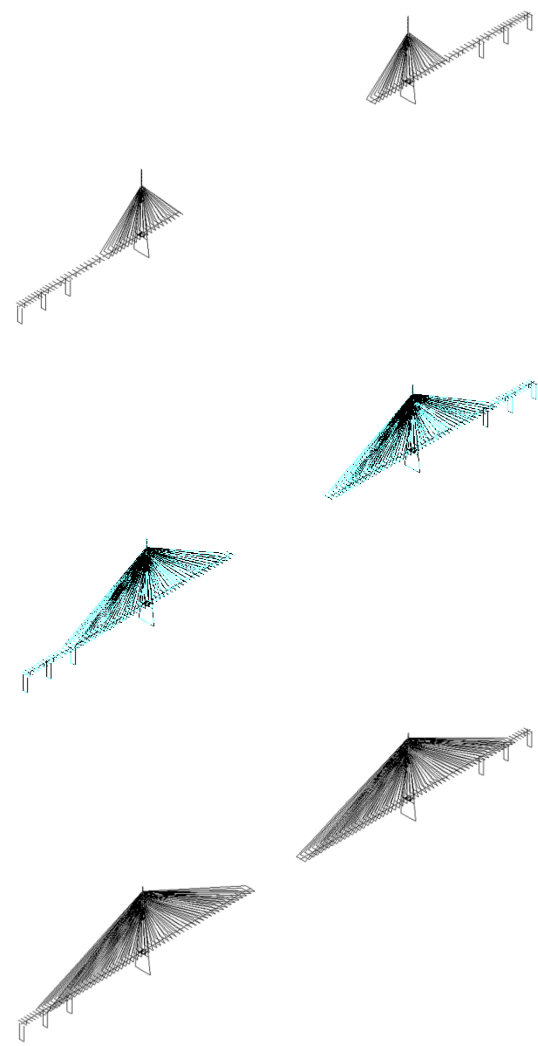
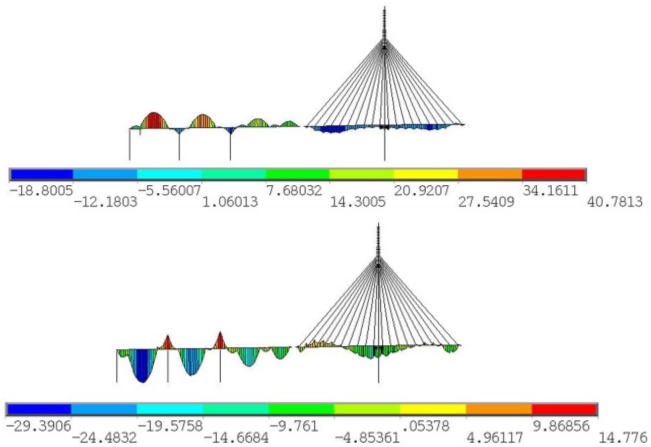
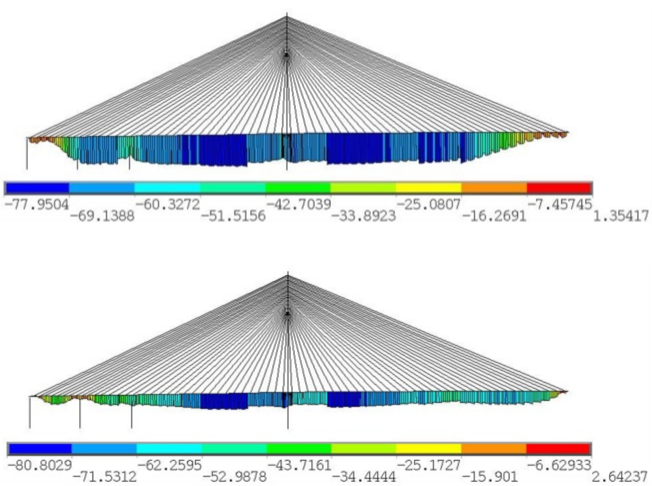


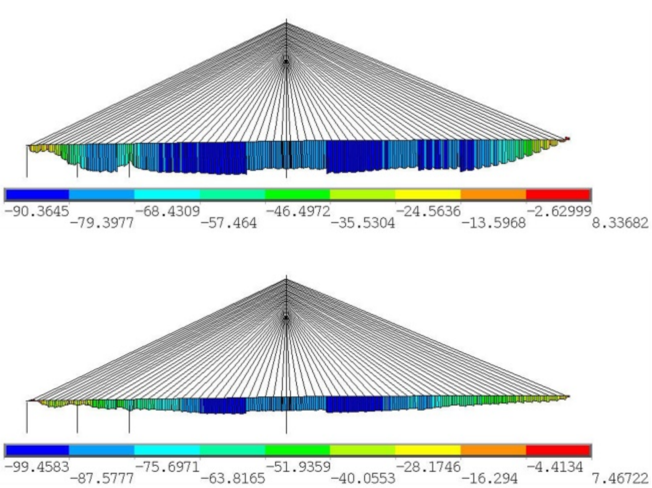
Fig. (6). FEA model of the construction stage.



(a) Maximum double cantilever stage (no. 103 stage)



(b) Maximum single cantilever stage (no. 309 stage)



(c) Completed stage (no. 326 stage)

Fig. (7). Stress distribution (top and bottom flanges) of the girder at various stages of construction (MPa).

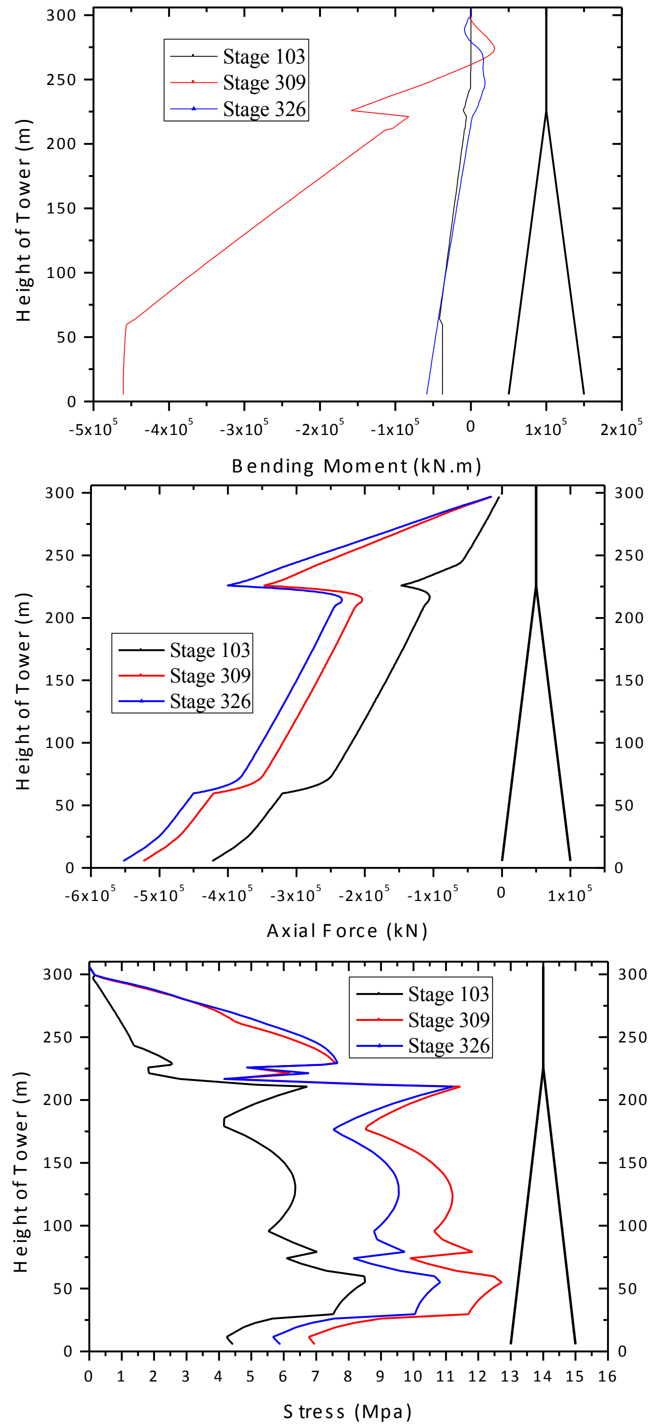


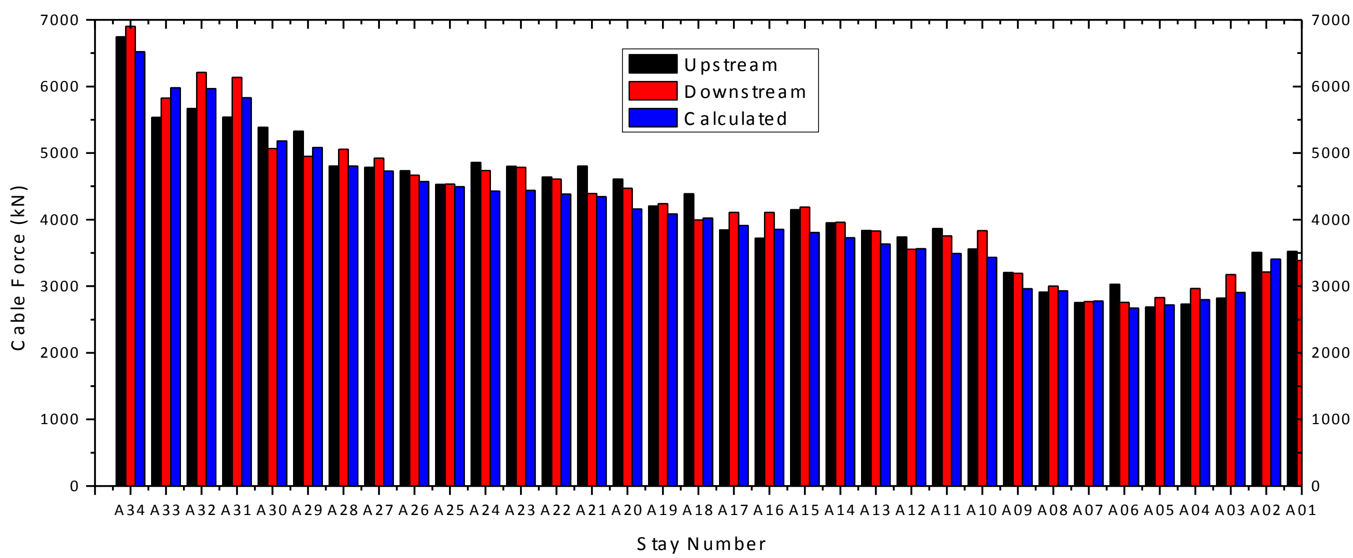
Fig. (8). Results of the tower at various stages of construction.

segments of the box girder at the side span were erected with the scaffold construction method, and they were held by many temporary supports, as shown in Fig. (**4c**). In the maximum single cantilever stage and the completed stage, the maximum compressive stress at the top flange (bottom flange) of the box girder is 77.95 MPa (80.80 MPa) and 90.36 MPa (99.45 MPa), respectively, which are within the acceptable steel box girder range during construction.

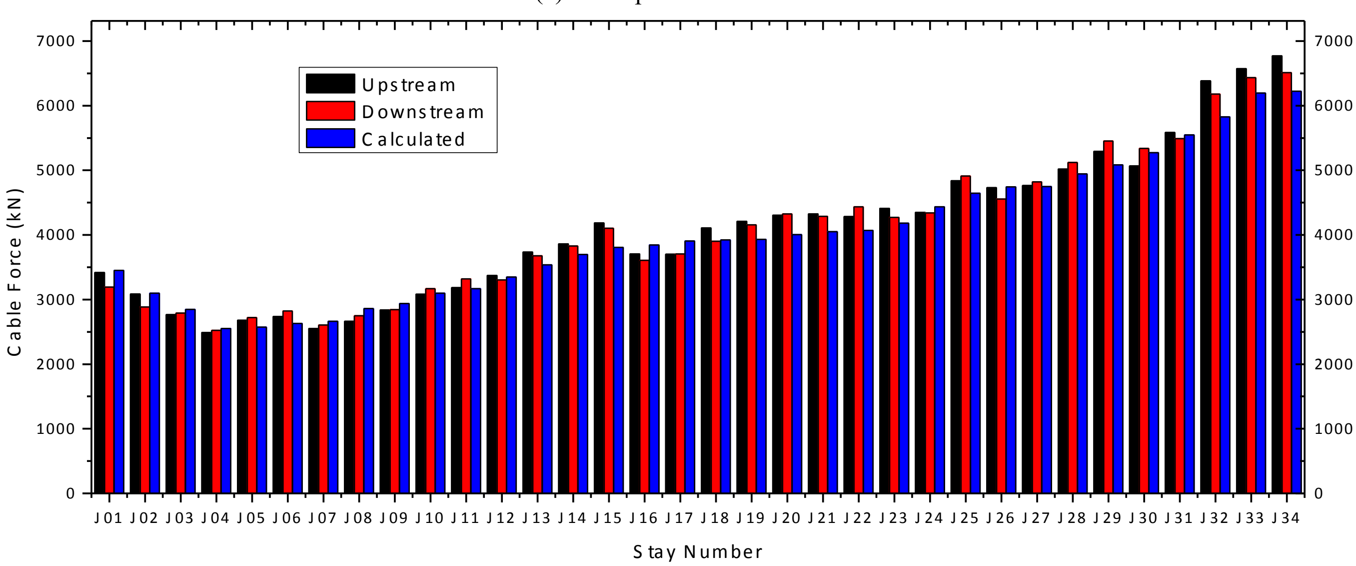
The construction stage simulation was based on the actual construction scheme and design requirements. Fig. 8 shows that the maximum compressive stresses of the concrete tower are 11.22 Mpa in the completed stage and 8.73 and 12.73 MPa in the maximum single cantilever and the maximum double cantilever stages, respectively. These values are appropriate in terms of design stress and are well within China code limits. During the construction simulation, no tension stress exists in the concrete tower to meet the zero tension criterion for the concrete structure. In the completed stage, the bending moment of the tower is minimized compared with those in the other construction stages under permanent loads.

The results of primary interest for the concrete tower are compressive stress, deformation of the tower, and the longitudinal bending moment in each construction stage. After the completion of the stage-by-stage construction simulation, the top of the towers was observed to have swayed 0.028 m toward the side span. As the construction progressed, the deformation of both the main span and the side span girder was evenly distributed from the tower to the end of the cantilever girder in the double cantilever stages. Furthermore, the vertical displacements in the two cantilevered girders were nearly equal until the side span was closured with the steel box girder segment supported by the temporary scaffold. After the side span was closed, the vertical deflection of the cantilevered girder was increased in the single cantilever stage because of the constraint from the long span girder segments.

Fig. (**9**) shows the cable force in the completed stage. The deformation of the girder and the tower is sensitive to the cable force. In the construction, the cables forces were usually adjusted to change the internal force and the displacement of the girder and the tower. Furthermore, the cable force is a key factor to determine the actual geometry profile in the completed stage. The tensions in the cables were changing during the construction because every cable was stressed initially in the installation stage and re-stressed subsequently in a passive manner during the construction stage. To meet the design requirement and some limits for the Sutong cable-stayed bridge, some cables forces were adjusted in the construction stage. Fig. (**9**) shows that the cable force distribution is smooth and does not involve non-mutation, and the tensions in the cable are in an ideal state. The cables forces from the stage-by-stage analysis are in good agreement with the field measurements, as depicted in



(a) Side span cables forces



(b) Main span cable forces

Fig. (9). Inclined cable force at the completed stage (kN).

Fig. (**9**). The upstream and downstream cable forces were measured in the field after the Sutong cable-stayed bridge was completed. A comparison of the calculated and measured results shows that little difference exists between them, and the cable tension stress is in the range of Chinese design standards.

CONCLUSION

A finite element methodology is presented for the construction simulation analysis of the Sutong cable-stayed bridge. To meet the design requirements, an effective and efficient stage-by-stage simulation of the construction process is necessary. The simulation analysis can determine the tension force in the cable at each construction stage and identify the consequent deformation of the structure. The commercial software ANSYS package is developed and applied in the simulation of the construction process, including the realization of inclined cable tension. This study presents the most extensive construction process simulated with the use of the finite element method. One of the important tasks involved is to realize the cable tension in the finite element model. During the construction of the Sutong cable-stayed bridge, extensive field measurements have been made to monitor the geometry of the deck and tower, as well as the cable force. These field measurement results are compared with the calculated results to evaluate the behavior of the actual structure.

The finite element simulation details can be used to: (1) monitor the geometry shape and internal force distribution of each partial structure at each stage; (2) set the pre-camber of the girders segment as a basis for the final configuration in the completed stage; (3) determine some possible effects of adjusting the construction process to meet design requirements, and (4) identify the initial stresses from the stress distribution for use in structure health monitoring.

This research is a part of an ongoing study to examine the seismic performance of cable-stayed bridges. Possible research directions include studies on the dynamic behavior and inclined cable vibration of cable-stayed bridges. The results obtained from the construction simulation analysis will serve as the initial data for the main research.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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