Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Tensile force correction calculation method for prestressed construction of tension structures*

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Received Nov. 27, 2007; revision accepted June 2, 2008

Abstract: Factors such as errors during the fabrication or construction of structural components and errors of calculation assumption or calculation methods, are very likely to cause serious deviation of many strings' actual prestressing forces from the designed values during tension structure construction or service period, and further to threaten the safety and reliability of the structure. Aiming at relatively large errors of the prestressing force of strings in a tension structure construction or service period, this paper proposes a new finite element method (FEM), the "tensile force correction calculation method". Based on the measured prestressing forces of the strings, this new method applies the structure from the zero prestressing force status approach to the measured prestressing force status for the first phase, and from the measured prestressing force status approach to the designed prestressing force status for the second phase. The construction tensile force correction value for each string can be obtained by multi-iteration with FEM. Using the results of calculation, the strings' tensile force correction by group and in batch will be methodic, simple and accurate. This new calculation method can be applied to the prestressed correction construction simulation analysis for tension structures.

Key words: Tension structures, Prestressed construction, High precision
doi:10.1631/jzus.A0720090 **Document code:** A **CLC number:** TU3; TU7

INTRODUCTION

Tension structures, such as prestressed spatial grid structures and suspend-dome, etc., combine the rigid beams or rods with the flexible strings. The structural efficiencies of such new types of structural systems are enhanced because the structural rigidity is increased and the distribution of forces in the whole structure is improved by the string's prestressing force. Scholars have studied the analysis theories and calculation methods for this structure system (Saiton *et al*., 1993; Kawaguchi *et al*., 1993; Chen and Li, 2005; Zhang *et al*., 2004; 2005). However, the research topics concerning the mechanics analysis in the course of construction were just begun a few years ago. Some studies put emphasis on investigation of experiments (Tagawa *et al*., 1994; Yamagata *et al*., 1994; Kawaguchi and Abe, 1999; Miyasato *et al*., 1999). Some studies focus on the analysis theories and the calculation methods (Saiton *et al*., 2001; Dong *et al*., 2003; Zhuo and Ishikawa, 2004; Zhuo and Yuan, 2004; Zhuo *et al*., 2004; Lu and Shen, 2005). The key for constructing tension structures is the prestressed construction of many strings. It is unable to calculate accurately the string's prestressing force of tension structures in the structural design or construction simulation analysis, because such non-ideal factors as the errors of calculation assumption or calculation methods, the errors of fabrication or construction of structural components, the effects of construction or temperature loads, and the effects of the material deformation or friction of structural components, etc., are unavoidable. These non-ideal

* Project (No. 50678157) supported by the National Natural Science Foundation of China

factors are very likely to cause the actual prestressing forces of many strings deviating seriously from the designed values during a tension structure construction course or service period, and thus the safety and reliability of the structure would be threaten. In order to achieve high precision control of the prestressing forces of the tension structure, the work of construction correction is absolutely necessary.

The mechanics analysis of tension structures in the course of construction has been a hot research topic in recent years. Research has basically solved the issue of mechanics analysis and calculation method of tension structures in the course of introducing initial prestressing forces construction (Saiton *et al.*, 2001; Dong *et al.*, 2003; Zhuo and Ishikawa, 2004; Zhuo and Yuan, 2004; Zhuo *et al.*, 2004; Lu and Shen, 2005), but not the issue of analysis and calculation method of high precision controlling of prestressing forces for tension structures based on measured data during construction or service period. Aiming at the tension structures with big errors in prestressing force during construction or service period, a new calculation method, so-called "tensile force correction calculation method", is put forward in this paper. Based on the values of the strings' measured prestressing forces, the tensile force correction value, which means the string's tensile force control values in actual construction correction of each string, can be obtained by this calculation method. The calculation results showed that the string's tensile force correction construction work by group and in batch is methodic, simple and accurate.

PRINCIPLE OF TENSILE FORCE CORRECTION CALCULATION METHOD

Many strings' measured prestressing forces in a tension structure have large errors, and should be carried out by group and in batch construction correction method. Here, the group, as a space parameter, refers to some strings tensioned at the same time, and the batch, as a time parameter, refers to the sequence of the strings tensioned. The groups and the batches should be decided on the distribution of the strings in the structure and the actual construction conditions.

The prestressed construction correction analysis is divided into two phases. In the first phase, the analysis is started at the "zero prestressing force status" of the structure, and ended at the "measured prestressing force status" of the structure with prestressing force errors. The subsistent tensile force calculation values of each string are forced to meet the measured values through structural finite element analysis. In the second phase, the starting point of analysis is the "measured prestressing force status", and the ending point is the ideal "designed prestressing force status" of the structure. The error status continuously approaches and finally reaches the ideal status through structural analysis and calculation, so the construction tension correction values of each string could be obtained.

The traditional concept of prestressing force should be changed and fractionized, because the construction correction of string's prestressing forces in a tension structure includes the factors of time and space. Assume n groups of strings in a tension structure tensioned in n batches. The parameters are defined as follows: (1) construction control tensile force $T_i^j(k,m)$—the prestressing force construction controlling value of the ith string in the jth batch tensioning construction; (2) subsistent tensile force $F_i^j(k,m)$—the prestressing force value of the ith string in the jth batch tensioning construction; (3) target tensile force $P_i(m)$—in the first analysis phase, it is the prestressing force measured value of the ith string after the structure construction completed or in the service period; in the second analysis phase, it is the prestressing force value of the ith string which should meet, i.e., the prestressing force design value of the string. Where m is the step of analysis phase, m=1, 2; k is the step of iteration, k=1, 2, 3, …; i refers to the ith string, i=1, 2, 3, …, n; j is the tension construction sequence number, j=1, 2, 3, …, n.

The tensile force correction calculation uses the iteration approximation methods. The second phase analysis is carried out after the first phase. The calculation principles and methods of the two analysis phases are basically the same. The analysis methods and the calculation procedures could be summarized as follows:

(1) For the first iteration, the structural geometrical nonlinear finite element method (FEM) analysis is performed in terms of the construction tensioning sequence. When calculating the strings of the jth group in the ith batch of tensioning, the construction

control tensile forces of strings are forced to be equal to the target tensile forces, i.e., $T_i^j(1,m)= P_i(m)$, and the subsistent tensile forces $F_i^j(1,m)$ of other strings which have been tensioned in structure are calculated at the same time. All of the subsistent tensile forces of each batch of strings have changed except that of the last batch strings when calculating the nth group of the last batch of the strings. The value of tension force change of each group of strings is $\Delta F_i^j(2,m)=T_i^j(1,m)-F_i^j(1,m)$.

(2) For the second iteration, the construction control tensile force value of each group of strings in the first iteration is modified by compensating the value of tension change. The construction control tensile force of the strings in the second iteration is $T_i^j(2,m)=T_i^j(1,m)+\Delta F_i^j(2,m)$.

The construction control tensile forces of the strings are forced to equal to $T_i^j(2,m)$ and the subsistent tensile forces of other strings tensioned in structure $F_i^j(2,m)$ are calculated at the same time. After calculating the nth group of the last batch of the strings, the tensile force change of each group of strings is $\Delta F_i^j(3,m)=T_i^j(2,m)-F_i^j(2,m)$.

The results of iterations k=3, 4, … can be obtained in terms of the same principle.

(3) At the end of the kth iteration, if $P_i(m)-F_i^n(k,m)\leq\varepsilon_0$, i.e., the difference between the actual value and the designed value of the string's tensile force is less than a certain value, the iteration could be terminated. The flowchart of calculation method is shown in Fig.1.

The results of the kth iteration in the first analysis phase are listed in Table 1. The subsistent tensile forces of the last row, $F_1^n(k,1)$, $F_2^n(k,1)$, …, $F_i^n(k,1)$, …, $T_n^n(k,1)$, equal the measured tension values of each string, $P_1(1), P_2(1), …, P_i(1), …, P_n(1)$.

The results of the kth iteration in the second analysis phase are listed in Table 2. The results on the diagonals, $T_1^1(k,2)$, $T_2^2(k,2)$, …, $T_i^j(k,2)$, …, $T_n^n(k,2)$, are the construction control tensile force values of the strings of groups 1, 2, …, n. These values are the construction tension correction values of actual construction correction tensioning by group and in batch, which are the major results that the new calculation method in this paper seeks for. The last row, $F_1^n(k,2)$, $F_2^n(k,2)$, …, $F_i^n(k,2)$, …, $T_n^n(k,2)$, presents the final subsistent tensile force values of the strings which are equal to their designed tension values, $P_1(2), P_2(2), …, P_i(2), …, P_n(2)$, respectively, with the construction correction tensioning method by group and in batch. This is the final target of the calculation method in this paper as well as the high precision control of prestressed construction for tension structures.

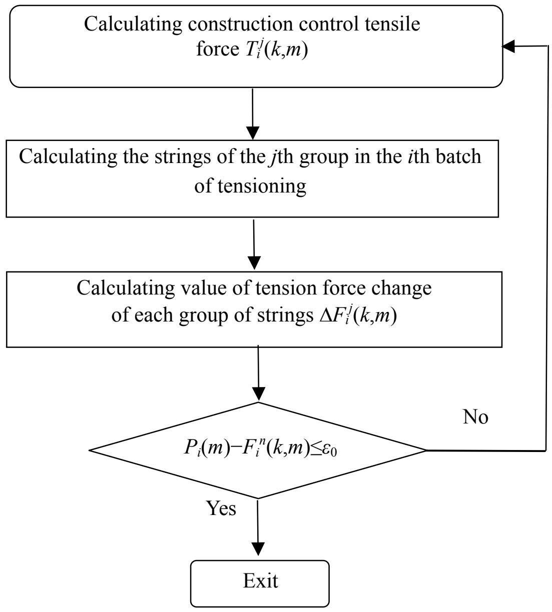

Fig.1 Flowchart of tensile force correction calculation method

Table 1 Results of the first analysis phase

Tension construction sequence number	String number					
	1	2	…	i	…	n
1	$T_1^1(k,1)$	0	…	0	…	0
2	$F_1^2(k,1)$	$T_2^2(k,1)$	…	0	…	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
j	$F_1^j(k,1)$	$F_2^j(k,1)$	…	$T_i^j(k,1)$	…	0
⋮	⋮	⋮	⋮	⋮	⋮	0
n	$F_1^n(k,1)$	$F_2^n(k,1)$	…	$F_i^n(k,1)$	…	$T_n^n(k,1)$

Table 2 Results of the second analysis phase

Tension construction sequence number	String number					
	1	2	…	i	…	n
1	$T_1^1(k,2)$	$F_2^1(k,2)$	…	$F_i^1(k,2)$	…	$F_n^1(k,2)$
2	$F_1^2(k,2)$	$T_2^2(k,2)$	…	$F_i^2(k,2)$	…	$F_n^2(k,2)$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
j	$F_1^j(k,2)$	$F_2^j(k,2)$	…	$T_i^j(k,2)$	…	$F_n^2(k,2)$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	$F_1^n(k,2)$	$F_2^n(k,2)$	…	$F_i^n(k,2)$	…	$T_n^n(k,2)$

ILLUSTRATIVE EXAMPLE AND DISCUSSIONS

Overview of the project

A prestressed spatial grid structure project with 27 m span, 24 m length and 24 m height is shown in Fig.2. The distances to the first quarter plane and the last quarter plane are both 2 m. The nodes are of bolt spherical node type. The rods are two types of steel tubes with 216.3 mm×7.0 mm and 114.3 mm×6.0 mm circular hollow sections (CHSs), and the Young's modulus of the steel was 200 GPa. Wall strings of groups 1~6 with maximum prestressing force of 500 kN, symmetrically distributed at two sides of the structure, are to potentiate the side walls of the spatial grid structure. Strings connected to the lower node of the grid structure are for tensioning in construction. Roof strings of groups 7~12 with maximum prestressing force of 650 kN, are to reinforce the top of the structure. The string's group numbers are shown in Fig.2a.

After the internal force tests of the structure carried out the prestressed construction, large errors between the actual prestressing forces and the designed values were found in many strings, and construction correction on the prestressing forces of the strings should be carried out. The actual values $P_i(1)$ and the designed $P_i(2)$ values of the prestressing forces of active wall strings and roof strings are shown in Table 3.

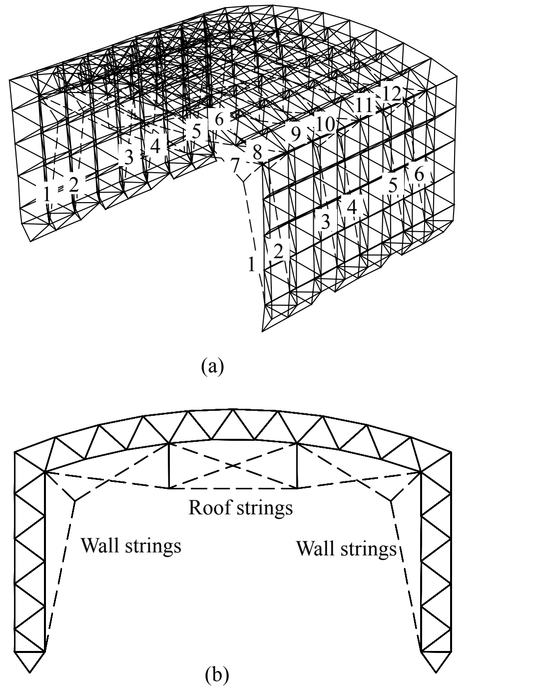

Fig.2 Structural sketch and string. (a) Perspective view; (b) Front view

Table 3 Target tensile force values of strings

i	$P_i(1)$ (kN)	$P_i(2)$ (kN)	i	$P_i(1)$ (kN)	$P_i(2)$ (kN)
1	123.00	300	7	323.00	450
2	209.26	300	8	209.26	450
3	325.67	300	9	425.67	450
4	340.58	300	10	409.58	450
5	292.50	300	11	492.50	450
6	243.00	300	12	343.00	450

Note: i is the string's number; $P_i(1)$ is the measured value of the prestressing force of the ith string after the structure construction is completed or in the service period; $P_i(2)$ is the design value of the prestressing force of the ith string.

Analysis of calculation results

When applying the tensioning construction correction method by group and in batch, the tensioning sequence number was set the same as the string group number. Two symmetrical wall strings constituted one group and were tensioned in sequence from 1 to 6, and roof strings were tensioned in sequence from 7 to 12. The construction simulation analysis of the structure applied the tensile force correction calculation method submitted in this paper, and four iterations were done in terms of the calculation procedure and formulae of the first and the second analysis phases. Due to the limited space of this paper, only the strings' calculation results of four iterations in the first and second analysis phases were listed in Table 4 and Table 5, respectively, showing that:

(1) At the end of the first analysis phase, the calculation values of prestressing forces of all strings in Table 4 have met their measured values in the structure status with the prestressing force errors. And, at the end of the second analysis phase, the calculation values of prestressing forces of all strings in Table 5 have met their designed values in the ideal structure status without any errors.

(2) The initial subsistent tensile forces of all strings listed in Table 3, 123.00, 209.26, 325.67, 340.58, 292.50, 243.00, 323.00, 209.26, 425.67, 409.58, 492.50, 343.00 kN, are the measured tensions in Table 4 when k is 4. The subsistent tensile forces of all strings meet their target tensile forces after analysis and calculation by applying the calculation method described in this paper. According to the sequence from 1 to 12 which is identical to the calculation, applying the calculation results of

Table 4 Calculation results in the first analysis phase

k	*j*	String's tension (kN)											
		i=1	2	3	4	5	6	7	8	9	10	11	12
1	1	123.00											
	2	110.15	209.26										
	3	103.07	200.40	325.67									
	4	99.41	194.42	311.29	409.58								
	5	102.80	195.46	306.67	401.11	292.50							
	6	108.05	198.06	304.09	395.44	277.16	243.00						
	7	127.58	214.18	311.01	398.51	274.01	236.31	323.00					
	8	138.28	218.75	315.96	401.66	273.76	234.27	301.62	209.26				
	9	146.19	227.09	322.76	410.33	279.99	239.17	288.85	189.67	425.67			
	10	148.99	231.86	330.71	416.93	288.93	248.66	285.06	180.42	401.72	409.58		
	11	143.38	230.74	338.28	429.32	301.84	276.64	295.60	184.62	388.73	384.30	492.50	
	12	137.58	227.95	341.00	435.60	317.41	294.57	305.95	190.96	384.56	373.12	457.17	343.00
2	1	108.42											
	2	96.72	190.57										
	3	89.97	182.13	310.34									
	4	86.55	176.53	296.86	383.56								
	5	89.64	177.48	292.59	375.81	267.59							
	6	93.78	179.53	290.59	371.33	255.48	191.43						
	7	114.34	196.50	297.88	374.57	252.16	184.39	340.05					
	8	126.00	201.47	303.27	378.00	251.89	182.17	316.80	227.56				
	9	134.67	210.63	310.73	387.51	258.72	187.53	302.80	206.09	466.78			
	10	137.73	215.83	319.38	394.69	268.46	197.87	298.66	196.01	440.72	446.04		
	11	131.72	214.63	327.50	407.96	282.28	227.84	309.96	200.51	426.79	418.96	527.83	
	12	125.92	211.84	330.22	414.23	297.83	245.71	320.29	206.82	422.63	407.79	492.56	343.00
3	1	105.51											
	2	93.95	188.00										
	3	87.30	179.68	305.78									
	4	83.92	174.14	292.47	378.90								
	5	86.96	175.07	288.28	371.31	262.24							
	6	91.04	177.09	286.31	366.89	250.32	188.72						
	7	111.77	194.20	293.67	370.15	246.97	181.62	342.78					
	8	123.55	199.23	299.11	373.62	246.69	179.38	319.26	230.01				
	9	132.27	208.44	306.61	383.20	253.57	184.78	305.17	208.39	469.82			
	10	135.34	213.67	315.31	390.40	263.35	195.16	301.02	198.28	443.66	447.82		
	11	129.33	212.46	323.42	403.67	277.17	225.12	312.31	202.77	429.74	420.75	527.76	
	12	123.54	209.68	326.14	409.94	292.71	242.99	322.64	209.08	425.57	409.58	492.50	343.00
4	1	104.18											
	2	92.71	186.48										
	3	86.13	178.24	302.88									
	4	83.36	173.71	292.00	378.53								
	5	86.39	174.64	287.81	370.95	262.05							
	6	90.47	176.66	285.84	366.53	250.12	188.76						
	7	111.22	193.79	293.20	369.80	246.77	181.66	343.15					
	8	123.01	198.81	298.65	373.27	246.49	179.42	319.63	230.19				
	9	131.73	208.03	306.15	382.85	253.37	184.82	305.54	208.57	469.91			
	10	134.80	213.25	314.83	390.05	263.15	195.19	301.38	198.46	443.75	447.81		
	11	128.79	212.05	322.95	403.32	276.96	225.15	312.67	202.95	429.84	420.74	527.74	
	12	**123.00**	**209.26**	**325.67**	**409.58**	**292.50**	**243.00**	**323.00**	**209.26**	**425.67**	**409.58**	**492.50**	**343.00**

Note: Data with underline represent construction control tensile forces; data in bold represent measured values of the prestressing force of the strings; *k* is the step of iteration; *i* is the string's number; *j* is the sequence number of the tension construction

construction control tensile forces, 283.35, 286.24, 289.13, 293.95, 299.04, 299.81, 473.82, 451.20, 453.16, 451.72, 460.31, 450.00 kN, in Table 5 at *k*=4, the actual tensions of each string would meet their designed tensions at the end of the 12th string tensioned during actual prestressed construction correction.

(3) From the calculation results at *k*=4 in Table 5,

Table 5 Calculation results in the second analysis phase

k	j	String's tension (kN)											
		i=1	2	3	4	5	6	7	8	9	10	11	12
1	1	300.00	199.72	322.41	408.15	294.00	245.94	336.88	222.96	431.00	411.86	489.93	338.52
	2	294.77	300.00	320.01	406.83	294.23	246.76	343.45	226.08	433.96	413.74	489.72	337.35
	3	295.12	300.47	300.00	407.45	294.49	246.91	342.93	225.42	433.53	413.17	489.31	337.13
	4	295.95	301.86	303.37	300.00	297.01	248.80	341.72	223.18	430.50	410.83	485.74	334.35
	5	295.97	301.87	303.33	299.93	300.00	248.64	341.69	223.17	430.55	410.92	485.83	334.54
	6	296.83	302.30	302.92	298.98	297.22	300.00	340.39	222.43	431.22	412.46	489.80	338.58
	7	302.67	307.36	304.95	299.86	296.31	298.12	450.00	211.04	427.60	411.11	491.84	341.91
	8	314.84	312.47	310.48	303.33	295.98	295.84	425.90	450.00	416.25	405.14	493.39	346.23
	9	315.47	313.12	310.97	303.96	296.39	296.11	424.88	448.48	450.00	403.23	492.59	345.85
	10	315.85	313.69	311.84	304.63	297.29	296.99	424.35	447.37	447.35	450.00	490.48	344.43
	11	316.23	313.74	311.26	303.70	296.42	294.93	423.61	447.11	448.36	451.92	450.00	348.51
	12	314.49	312.91	312.08	305.58	301.11	300.34	426.71	449.00	447.11	448.57	439.46	450.00
2	1	285.51	200.51	322.68	408.27	293.88	245.70	335.75	221.86	430.56	411.67	490.14	338.89
	2	280.99	287.09	320.61	407.12	294.08	246.41	341.42	224.54	433.13	413.30	489.97	337.88
	3	281.57	287.86	287.92	408.15	294.50	246.66	340.57	223.45	432.41	412.37	489.28	337.51
	4	282.44	289.33	291.49	294.42	297.17	248.65	339.29	221.08	429.20	409.89	485.51	334.57
	5	282.45	289.34	291.47	294.38	298.89	248.56	339.27	221.08	429.24	409.94	485.56	334.68
	6	283.31	289.77	291.06	293.43	296.12	299.66	337.97	220.33	429.89	411.48	489.51	338.69
	7	290.52	296.02	293.57	294.53	295.01	297.34	473.29	206.27	425.43	409.81	492.03	342.82
	8	302.97	301.24	299.23	298.07	294.67	295.01	448.62	451.00	413.80	403.70	493.61	347.24
	9	303.71	301.99	299.80	298.80	295.14	295.32	447.43	449.24	452.89	401.48	492.69	346.79
	10	304.11	302.60	300.73	299.52	296.10	296.26	446.86	448.06	450.06	451.43	490.43	345.27
	11	304.39	302.64	300.29	298.83	295.46	294.74	446.32	447.86	450.81	452.84	460.54	348.29
	12	302.65	301.80	301.12	300.72	300.16	300.16	449.42	449.76	449.55	449.49	449.98	450.00
3	1	282.86	200.65	322.73	408.29	293.85	245.65	335.54	221.65	430.48	411.64	490.18	338.96
	2	278.44	285.29	320.71	407.17	294.05	246.35	341.08	224.27	432.99	413.22	490.00	337.97
	3	279.04	286.09	286.81	408.24	294.49	246.61	340.20	223.14	432.25	412.27	489.30	337.59
	4	279.92	287.57	290.40	293.70	297.18	248.61	338.91	220.76	429.02	409.77	485.50	334.63
	5	279.93	287.57	290.38	293.66	298.74	248.53	338.89	220.75	429.05	409.82	485.55	334.73
	6	280.78	288.01	289.97	292.72	295.98	299.51	337.60	220.01	429.70	411.35	489.49	338.73
	7	288.04	294.29	292.50	293.82	294.85	297.17	473.87	205.85	425.20	409.67	492.02	342.88
	8	300.53	299.53	298.18	297.38	294.51	294.83	449.13	451.25	413.55	403.54	493.61	347.31
	9	301.28	300.30	298.75	298.12	294.99	295.15	447.92	449.45	453.34	401.29	492.67	346.86
	10	301.69	300.91	299.70	298.85	295.97	296.15	447.35	448.25	450.47	451.94	490.38	345.32
	11	301.97	300.96	299.26	298.16	295.33	294.58	446.81	448.06	451.21	453.35	460.56	348.33
	12	300.23	300.12	300.09	300.05	300.02	300.00	449.90	449.95	449.96	450.00	450.00	450.00
4	1	283.35	200.58	322.69	339.27	293.86	245.67	335.60	221.68	430.50	411.64	490.17	338.94
	2	278.88	286.24	320.64	338.14	294.06	246.37	341.21	224.35	433.03	413.25	489.99	337.94
	3	279.44	286.98	289.13	339.13	294.47	246.61	340.39	223.30	432.35	412.36	489.34	337.59
	4	279.78	287.56	290.55	293.95	295.53	247.41	339.89	222.36	431.07	411.38	487.84	336.42
	5	279.81	287.57	290.50	293.87	299.04	247.22	339.84	222.35	431.14	411.48	487.95	336.65
	6	280.69	288.02	290.08	292.89	296.19	299.81	338.51	221.59	431.81	413.06	492.01	340.78
	7	287.90	294.26	292.59	293.98	295.07	297.49	473.82	207.52	427.35	411.39	494.53	344.90
	8	300.30	299.46	298.23	297.52	294.73	295.16	449.25	451.20	415.77	405.31	496.11	349.30
	9	301.00	300.18	298.77	298.21	295.18	295.47	448.12	449.51	453.16	403.19	495.22	348.88
	10	301.39	300.77	299.67	298.91	296.12	296.38	447.57	448.36	450.41	451.72	493.03	347.40
	11	301.70	300.82	299.20	298.16	295.42	294.71	446.98	448.15	451.22	453.27	460.31	350.70
	12	**300.00**	**300.00**	**300.00**	**300.00**	**300.00**	**300.00**	**450.00**	**450.00**	**450.00**	**450.00**	**450.00**	**450.00**

Note: data with underline represent construction control tensile forces; data in bold represent design values of the prestressing force of the strings; *k* is the step of iteration; *i* is the string's number; *j* is the sequence number of the tension construction

it is shown that the maximum tensions on wall strings in groups 1~6 have ever reached 339.27 kN and the maximum tensions on roof strings in groups 7~12 ever reached 496.11 kN during prestressed construction correction. These values are all less than the maximum allowable prestressing forces, though higher than the designed tensions. Likewise, the calculation results have also shown that no rod in the structure has been overstressed during prestressed construction correction. Therefore this construction correction plan is feasible. If calculation results indicate that the subsistent tensile forces of some strings exceeds the allowable values or the internal forces of some rods exceed the allowable values during the prestressed construction correction, it could be solved by optimizing tensioning sequence or increasing the tensioning grade quantity.

(4) It is obvious that the increasing number of iterations will lead to more precise results. But it is good enough to do compensation three times for real projects in general.

CONCLUSION

The correction of prestressing forces in actual construction should follow the sequence determined by the calculations, and tensioning the strings of each group one by one at the controlling values of actual prestressed construction which are the construction correction values. When the tensioning of the last string is done, the internal forces of all strings would meet the respective designed values of the prestressing force.

The calculation method in this paper is a high-efficiency step-by-step approximation. Theoretically, it needs many iterations to achieve the final result. But, for the actual engineering application, the result obtained from 2 or 3 iterations is good enough to reach the required precision.

The calculation method could obtain not only the construction tension correction values of the strings, but also the internal force values and the node displacement values of all structural components in each batch of tensioning. Therefore, using the calculation method illustrated in this paper and with the aid of structural analysis software, the construction correction simulation analysis on tension structures could be carried out easily.

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