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Study on mechanical behaviors of cable-supported ribbed beam composite slab structure during construction phase

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Abstract. The cable-supported ribbed beam composite slab structure (CBS) is a new type of pre-stressed hybrid structure. The standard construction method of CBS including five steps and two key phases are proposed in this paper. The theoretical analysis and experimental research on a 1:5 scaled model were carried out. First, the tensioning construction method based on deformation control was applied to pre-stress the cables. The research results indicate that the actual tensile force applied to the cable is slightly larger than the theoretical value, and the error is about 6.8%. Subsequently, three support dismantling schemes are discussed. Scheme one indicates that each span of CBS has certain level of mechanical independence such that the construction of a span is not significantly affected by the adjacent spans. It is shown that dismantling from the middle to the ends is an optimal support dismantling method. The experimental research also indicates that by using this method, the CBS behaves identically with the numerical analysis results during the construction and service.

Keywords: cable-supported ribbed beam composite slab; pre-stress; hybrid structure; fabrication; construction; tensioning; dismantling

1. Introduction

The tensegrity is a high-efficient mechanical structural system put forward by Fuller and Snelson (Eleanor and Snelson 2009), and further developed by Pugh and Motro (Motro 2011), etc. It is still difficult to widely apply the tensegrity structure to actual buildings, however, based on the concept of tensegrity, some scholars have presented other advanced structure patterns which are introduced as follows. The cable dome structure was proposed and applied to the actual building first by Geiger. With Geiger's research extended, Geiger dome was deeply investigated (Wang *et al*. 2010, Ouni and Kahla 2014) and some new types of cable dome structures, such as Levy dome,

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Kiewitt dome, etc., were put forward and studied (Wei *et al*. 2015, Kmet and Mojdis 2015). With the upper cable net replaced by rigid latticed shell in the cable dome structure, Kawaguchi presented the suspend-dome structure, which inherits the merits of the cable dome and is easier to construct (Dai *et al*. 2013, Chen *et al*. 2015). The beam (truss) string structure was put forward systematically by Masao. The cable supported system is introduced to the beam or truss, as a result, the mechanical features of the beam and truss structure system are significantly improved (Zhao *et al*. 2015). Moreover, Chen *et al*. (2012) and Sun *et al*. (2013) introduced struts and cables to the cylindrical grid shell structure and presented the cable-supported barrel vault structure. The out-plane stability of cylindrical grid shell structure can be improved and the horizontal thrust at the supports can be reduced significantly due to the action of struts and strings. The highlight of the cable-supported barrel vault structure is that the horizontal thrust of the supports can be almost eliminated through optimization design. It means that this kind of grid vault can be used without the giant thrust balancing elements. Qiao (2010) summarized the common features of these structures including cable dome structure, suspend-dome structure, beam (truss) string structure and cable-supported barrel vault structure, etc. and proposed the concept of cable-supported structure, which assembles the merits of both the rigid structures such as shell, grid structure and the flexible structures such as cable network structures, and can form a self-balanced system because of the action of pre-stressed cables. Subsequently, in order to calculate the friction in cable-strut joints, Yan *et al*. (2015) carried out a deep research on cable-supported structures and introduced a new equivalent friction element to the traditional numerical model. The analysis results indicate that this method can simulate the real mechanical situation of the practical cable-supported structures precisely. Due to high-efficiently mechanical features, elegant configuration, long span availability and cost-saving, cable-supported structure system has been one of the most popular structure patterns for engineers and architects.

The support system of the floor and roof such as columns and walls will affect the utilization efficiency of the indoor space. Sometimes, the column-free or wall-free indoor space is preferred in some public buildings such as gymnasiums, airline terminals, special workshops, etc. With this background and based on the concept of the cable-supported structure, Chen and Qiao (2010) proposed the cable-supported ribbed beam composite slab structure (CBS). The CBS consists of the upper concrete slabs, middle struts and lower cables. The lower pre-stressed cables can act on the upper ribbed beams and slabs system through the struts. As a result, the struts behave as the flexible supports of the upper system. With this configuration, CBS can span a long distance when used in the floor and roof and the utilization efficiency of the indoor space is enhanced significantly. Moreover, Chen *et al*. analyzed the static characteristics of the initial CBS prototype theoretically, put forward the design method, and investigated some factors that affect the mechanical properties.

Based on the previous research of CBS, the mechanical behavior of CBS during construction phase is investigated in this study. For the cable-supported structure, the shaping during the construction is more difficult than that of the traditional structures because of the existence of flexible elements. Nie and Li (2011) analyzed the mechanical behaviors of one-way beam string structure with the consideration of the supporting structure. Meanwhile, the influence of factors on the mechanical properties including grouting, support form and corrosion were investigated. The results of Nie and Li's study provide reference for the construction of beam string structure. Wang *et al*. (2011a) introduced a temporary support frame, segment lifting and high altitude splicing construction method for Chiping gymnasium suspend-dome structure. Wang and Guo *et al*. (2011b) carried out a series of measurements of internal forces in the cables, struts and some other key elements during the construction of a suspend-dome structure. The monitoring results were used to adjust the construction details to achieve the original design. In the research of Guo *et al*. (2008), the lifting installation of upper latticed shell, the installation and tension of lower pre-stressed cables are introduced in detail. Strut-adjustment method is innovated and applied successfully in the construction of a long-span suspend-dome structure for the first time.

This study will bring together previous construction methods of the cable-supported structures and propose a feasible construction method for CBS including five steps and two key phases. The remainder of this paper is organized as follows: Section 2 describes the basic fabrication of CBS and the whole constructional process. Section 3 introduces the research prototype of CBS. In Section 4, the study on tensioning phase is performed by both theoretical and experimental methods. Continuing the research in Section 4, the study on the dismantling phase is implemented in Section 5.

2. Basic elements and construction

The fabrication of a standard unit of CBS is shown in Fig. 1. The upper reinforced concrete slab, the rib beams, the middle steel struts, and the lower cable are all prefabricated and then assembled together on site. Most of the connections are traditional and simple except for two special connections. Fig. 2 shows the special connection between the strut and the beam, which includes two rotation axes in different directions. The lower pin is used to adjust the angle of strut so that it can be connected to another strut or cable easily, and the upper one can rotate about the longitudinal direction of the cable, which will help in transmitting the cable force from one end to the other. The two ends of each cable are connected with the beam. The anchorage of cable end is shown in Fig. 3.

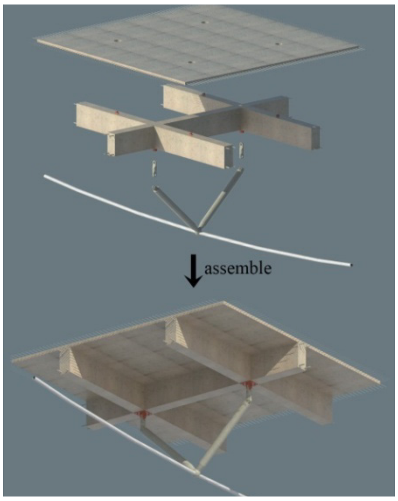

Fig. 1 Model Fabrication of unit

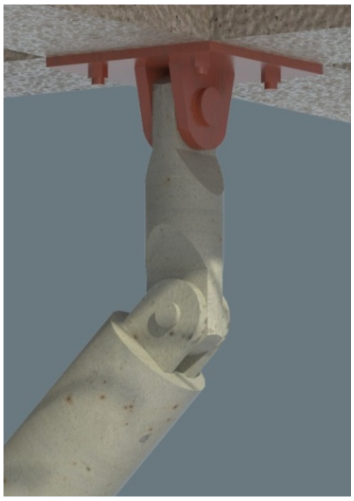

Fig. 2 Strut junction

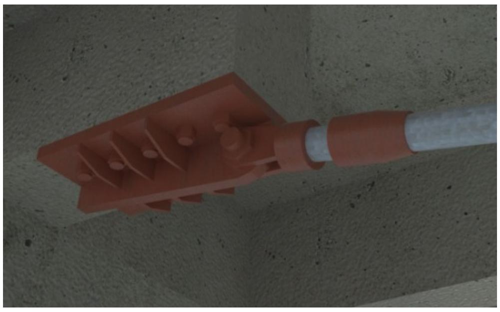

Fig. 3 Mesh grid of topographic model

Considering the construction methods of other cable-supported structures and also the features of CBS, three important aspects of the CBS construction are highlighted. First, the standard slabs, beams, struts, cables and joints are prefabricated, then assembled on spot. Secondly, casting concrete between the prefabricated slabs and beams is performed so that they can be connected firmly. Finally, one end of the span of CBS is fixed and the other end is slidable along the span. By this configuration the cable force can act on the upper slabs through struts efficiently, and the horizontal force can be released as well.

Furthermore, as shown in Fig. 1, the prefab elements are assembled together as one integrated structure. The four shear connectors made of angle steels on beams are inserted into the four holes

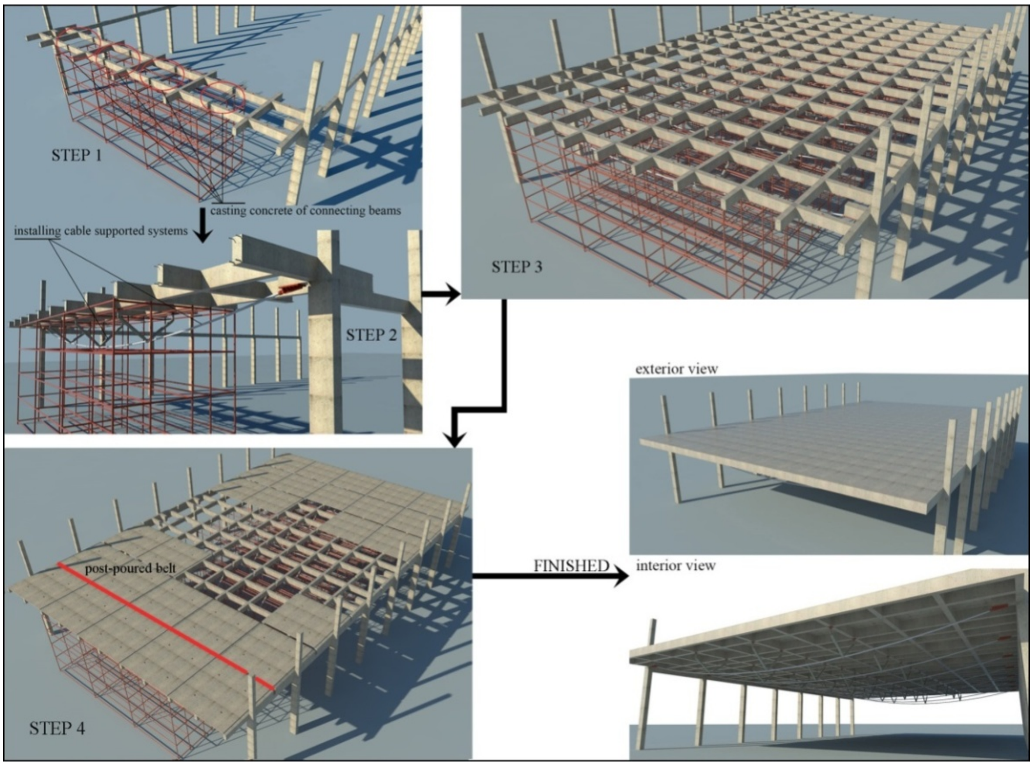

Fig. 4 Constructional process

in the slab, then concrete are cast into the holes. This fabrication method can deal with the shear forces between beams and slabs.

The major construction process of CBS are illustrated as follows:

Step 1. The first span CBS construction. The beam elements are assembled firstly, and the scaffold will support the current span CBS. The steel bar cages are set up among prefab beam elements, which are marked red circles shown at the left top of Fig.4.

Step 2. Cast concrete into the steel bar cages, and the prefab beam elements are connected firmly. The struts and cables under the upper beams are installed, then the cables are pre-stressed. The upper beams and the lower cable-supported system will form a complete self-balanced structural system.

Step 3. Building the rest spans. As shown at the top right of Fig. 4, the rest spans of CBS are constructed according to step 1 and 2. The ribbed beams and cable-supported system are finished in this step.

Step 4. Fixing the upper elements of CBS. The slabs are paved on top of the beams, angle steels are inserted into the holes in the slabs, then the concrete is cast into the holes and the belts among the slabs, which is shown at the bottom left of Fig. 4.

Final step. Finishing the construction. The scaffold supports are dismantled sequentially, the floor turns into an integrated and stable structural system. A final rendering of CBS with a large interior space and high-efficiently mechanical properties is shown at the bottom right of Fig. 4.

3. Research prototype

The whole construction process introduced above can be divided into two key phases, i.e., tensioning phase and dismantling phase, which were simulated by FEM. The mechanical behaviors including displacements of key positions, the cable forces, strut forces and ribbed beam stresses were figured out, and these data were used to direct and control the practical construction.

The new gymnasium of Hebei Normal University in China is chosen as the prototype of the calculation model in this paper. The beam string structure was adopted on the second floor of this new gymnasium, which is a very similar structure to CBS. They almost have the same mechanics features and also very similar construction processes. Instead of beam string structure, the CBS was applied and this building was redesigned. For this gymnasium, there are 13 standard spans and each span is 42.25 m long. The standard span is composed of 10 standard units which is shown in Fig. 1. The key dimensions of the model are shown in Fig. 5. Note the strut is V type which is shown in cross section 2-2 in Fig. 5. The circular steel tube with section of 159 mm × 10 mm (external diameter × thickness) is adopted, and the cable is steel strand with section of 80 mm in diameter.

4. Study on tensioning phase

4.1 Theoretical analysis

(I) Cable pre-stress

The rational pre-stress implemented in cables is the key problem in construction of CBS which guarantee enough load-bearing capacity. The static equilibrium algorithm (Chen and Qiao 2010) is used to solve this issue. In the construction step 2, the cable pre-stress is applied after all of the ribbed beams are constructed and assembled together. When the pre-stress is applied, the structure will deform upwards. In general, the maximum upward deformation of the structure is limited less than 1/600 of the span (Qiao 2010, Chen and Qiao 2010). Because the spans are independent from each other in the tensioning phase, one standard span is chosen as the calculation model.

(II) Tensioning phase analysis

The FEM software Midas/Gen was used to analyze the mechanics features of CBS. In step 2, the upper ribbed beams are constructed and connected together, then the cable-supported system is installed and the cable pre-stress is implemented. In order to ensure the forces to be transmitted and distributed as evenly as possible, the cable pre-stress is divided into four grades to apply. The horizontal displacement and vertical deformation at the position of 1/4 span and mid-span are collected under the action of each grade tension. The results are shown in Table 1.

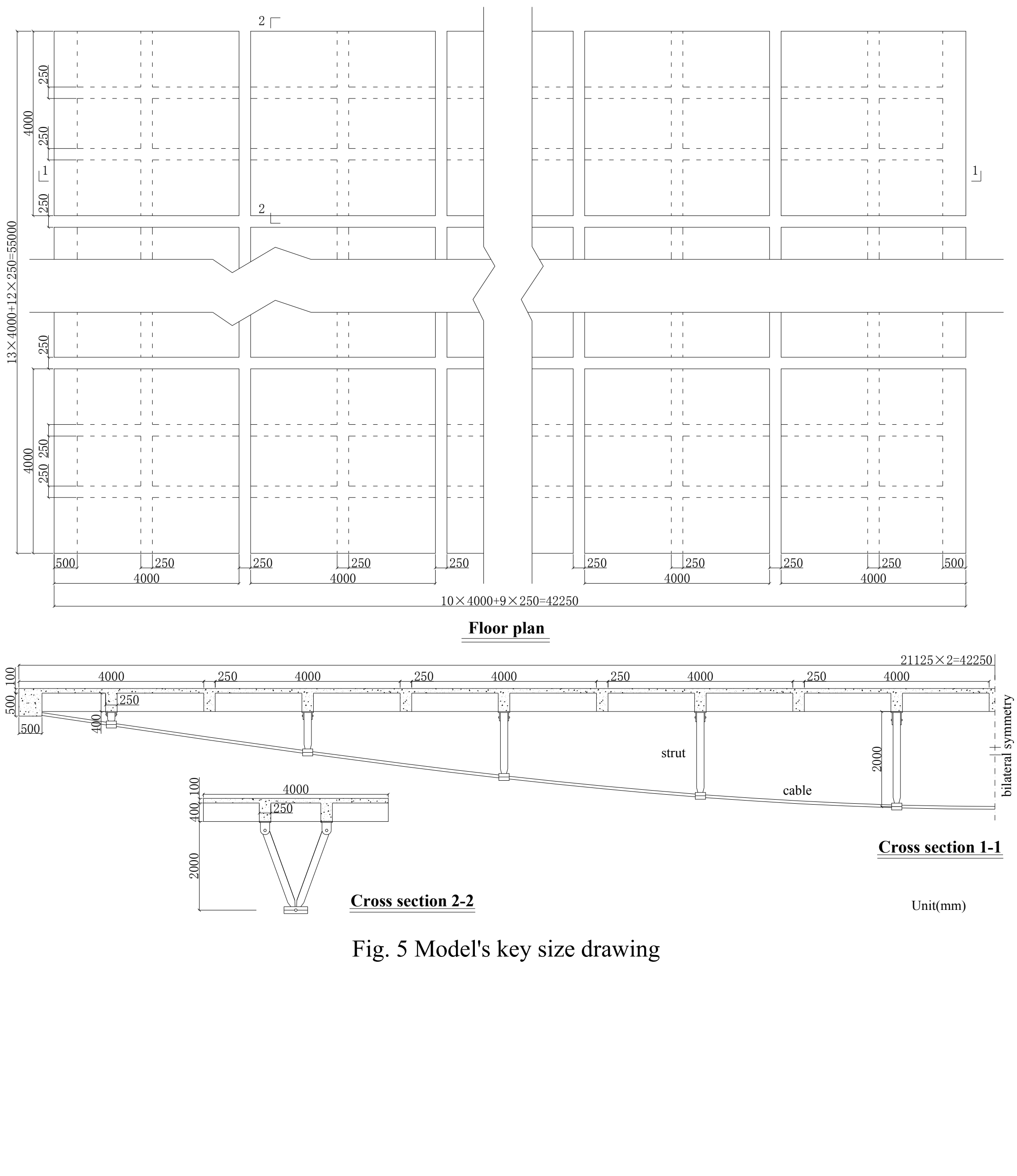

Fig. 5 Model's key size drawing

Table 1 Deformation in each tension grade

Grade	Ratio (%)	Tension (kN)	Vertical disp. (mm)		Horizontal disp. (mm)
			1/4Span	Midspan	
1	65	1200	9.8	4.2	2.8
2	80	1500	16.5	5.5	3.9
3	90	1700	25.4	19.8	5.2
4	100	1900	67.6	63.8	7.6

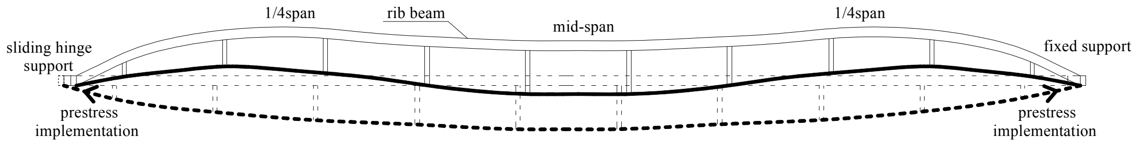

Fig. 6 Final deformation in step 2

The boundary conditions of CBS include a sliding hinge at one end and a fixed support at the other. The horizontal displacement happens at the sliding hinge support, this configuration makes CBS a self-balancing pre-stressed structure and no thrust at the supports. After the construction step 2 is finished, the final deformation of CBS is shown in Fig. 6 in which the dash line is the shape of CBS in the zero state. All of the deformation discussed in this paper is with respect to this zero state. Displacement above this zero state is positive while below is negative.

4.2 Experimental Research

(I) Scaled physical model

A 1:5 scaled model with three standard spans is designed and fabricated to verify the theoretical analysis results in the tensioning phase. The scale factors can be determined according to the similarity constant and similarity ratio relationship in static loading experiment of engineering structure. For the geometric dimension shown in Fig. 5, the ratio of scaled model to the full scale model is 1:5. The physical model in the tensioning phase is shown in Fig. 7.

(II) Tension and displacement

For the cable tension and structural displacement, the ratio of scaled model to the full scale model is respectively 1:25 and 1:5. In consequence, the cable tension and the corresponding displacements of key positions in each tension grade of tensioning phase were figured out and shown in Table 2. In the experiment, for the convenience, the pre-tensions were applied by tightening the bolts at the end of the cables. In order to guarantee that the tension in Table 2 were applied to the end of each cable grade by grade accurately, the force of the end of each cable was measured and controlled. Moreover, the displacements were recorded after each tension grade was reached. The force of the end of each cable, namely the actual applied tensile force, will be compared with the corresponding theoretical prediction in Table 2. Note that the key of the construction is to control the deformation using the displacements of certain positions. So the displacement values monitored in each grade are controlled as close to the values in Table 2 as possible. If the actual applied tensile force deviates the corresponding tension control value in

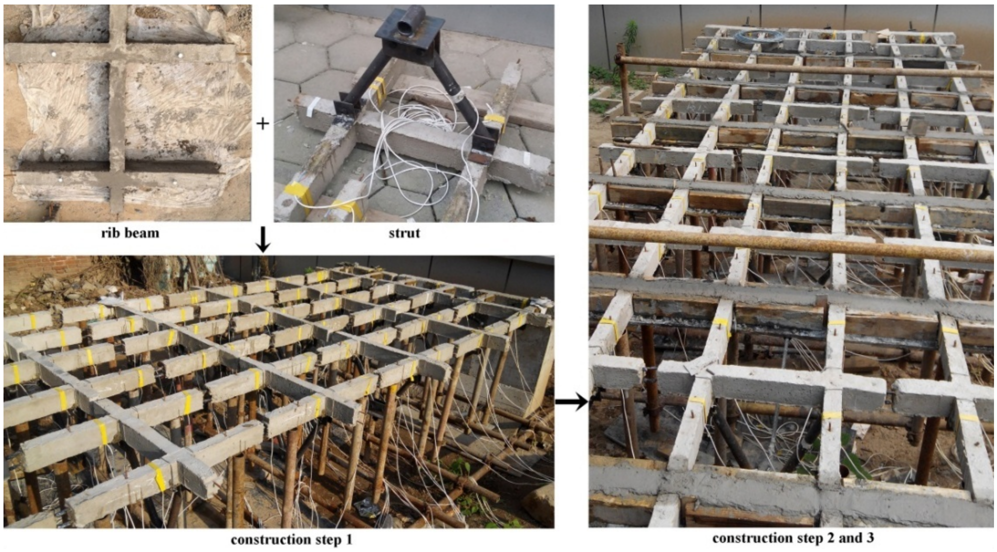

Fig. 7 Scaled physical model in tensioning phase

Table 2 Control data in experiment

Grade	Ratio (%)	Tension (kN)	Vertical disp. (mm)		Horizontal disp. (mm)
			1/4Span	Midspan	
1	65	48	1.96	0.84	0.56
2	80	60	3.3	1.1	0.78
3	90	68	5.08	3.96	1.04
4	100	76	13.52	12.76	1.52

Table 2 too much, and the displacements recorded are still not close to the control values in Table 2, it means something wrong happens to the construction and the tensioning must be stopped for troubleshooting.

(III) Data measurement

In the experiment, the displacements were measured by dial indicators. For each standard CBS span, four indicators were mounted at two 1/4 span points, mid-span point, and sliding hinge support, which are shown in Fig. 8. The force of the end of each cable was measured by INV3080B-BCF cable force tester, which is shown in the bottom right of Fig. 9.

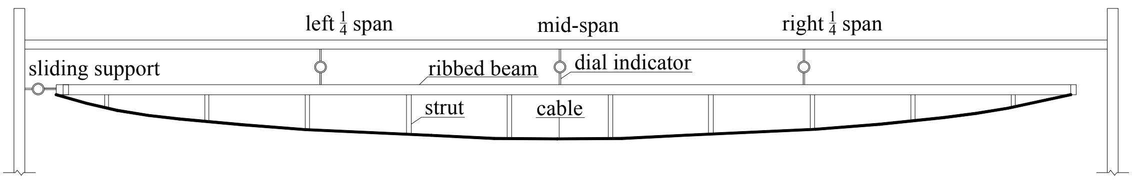

Fig. 8 Final deformation in step 2

Fig. 9 Displacement surveying and cable force testing

Table 3 Tension comparison between theory and experiment

Grade	Ratio (%)	Theoretical tension (kN)	Practical tension (kN)	Error (%)
1	65%	48	57.41	19.6
2	80%	60	67.08	11.8
3	90%	68	74.46	9.5
4	100%	76	81.17	6.8

Table 4 1/4 Span vertical displacement comparison between theory and experiment

Grade	Theoretical disp. (mm)	Left 1/4 span		Right 1/4 span	
		Practical disp. (mm)	Error (%)	Practical disp. (mm)	Error (%)
1	1.96	2.00	2.0	2.03	3.6
2	3.30	3.11	-6.1	2.98	-9.6
3	5.08	5.21	2.4	5.24	3.1
4	13.52	13.80	2.1	13.97	3.3

(IV) Experimental result analysis

The scaled physical model experiment was carried out according to the experiment scheme introduced above, the data were monitored and recorded. The results are shown in Tables 3-6 comparing with the theoretical data.

It was discussed in the section of Tension and Displacement that the deformation monitored must be controlled as close to the theoretical deformation as possible during cable tensioning by adjusting the cable tension. The most ideal deformation we can find is the current practical displacements shown in Tables 4-6, the practical and theoretical values are close in each grade,

Table 5 Mid-span vertical displacement comparison between theory and experiment

Grade	Theoretical disp. (mm)	Practical disp. (mm)	Error (%)
1	0.84	0.80	-4.8
2	1.1	1.0	-9.1
3	3.96	4.06	2.5
4	12.76	13.26	3.9

Table 6 Horizontal displacement comparison between theory and experiment

Grade	Theoretical disp. (mm)	Practical disp. (mm)	Error (%)
1	0.56	0.59	5.4
2	0.78	0.75	-3.8
3	1.04	1.1	5.8
4	1.52	1.58	3.9

especially in the final grade, the errors between them are all less than 4.0%.

For the cable tensioning, first, the theoretical value in each grade is applied to the cable. Secondly, displacements are recorded, and then the cable force is finely adjusted in order to make the actual deformation as close to the theoretical deformation as possible. It is clear in Table 3, when the practical deformation is controlled in an ideal state in each tensioning grade, the actual tension implemented is larger than the theoretical value. The error in grade 1 is 19.6%, but it decreases to 6.8% in the final grade.

5. Study on dismantling phase

After the cable tensioning of each span of CBS is finished in the construction step 3, the slabs are paved on top of the ribbed beams and then post-poured belts among slabs will be cast in the construction step 4. In this process, the scaffold will support the pre-stressed CBS until the construction step 4 is finished completely and the floor turns into an integrated and stable structural system. Then these scaffold supports will be dismantled sequentially. The analysis in tensioning phase has been carried out above, the mechanical features of CBS in dismantling support phase are discussed in this section.

The support dismantling involves force redistribution of the whole structure. The irrational dismantling will cause terrible uneven force redistribution which can bring some hidden safety hazard to the structure, even structural failure. Thus, it is important to find rational method to dismantle supports. As a rule, four laws should be obeyed in the dismantling. (1) The force redistribution should be guaranteed to carry on slowly. (2) In the process of force redistribution, all of the elements should be kept into elastic phase and the eternal strain is forbidden. (3) Interaction among the supports should be considered during dismantling. (4) The dismantling method should be safe, controllable and convenient. Based on these rules, three dismantling schemes will be discussed and an optimal scheme is determined. The numerical calculation is carried out by FEM software Midas/Gen.

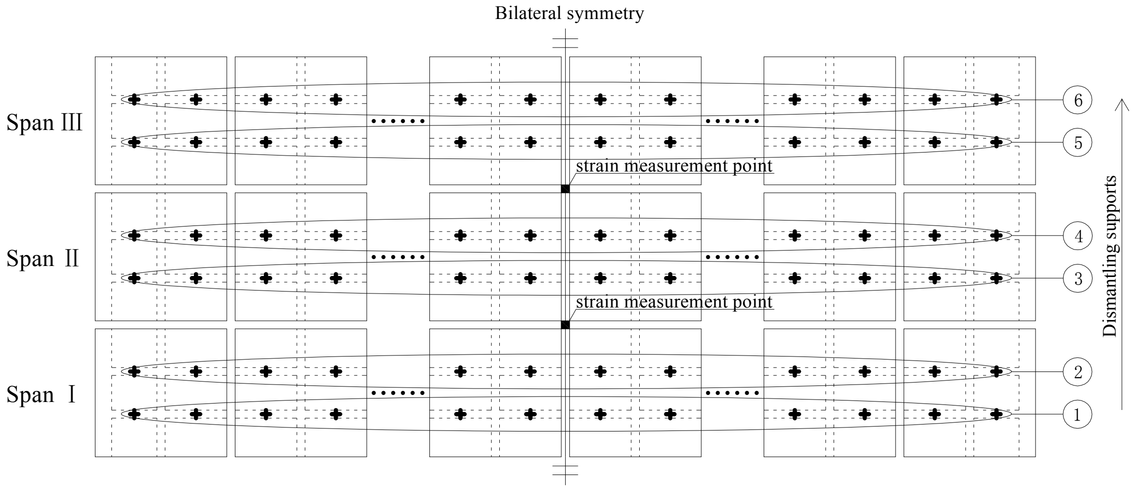

Fig. 10 Support dismantling process of scheme ONE

5.1 Theoretical analysis

(I) Scheme ONE

Three standard spans of CBS are modeled in order to mimic the physical model. The dismantling process is implemented from span I to III, namely, from group 1 to 6, which is shown in Fig. 10.

Compared with the steel, the tensile strength and ductility of the concrete is very low. Consequently, during the dismantling phase, the concrete elements in the CBS should bear forces evenly. Sharp changing of deformation or stress may cause the crack and even damage of the concrete elements. During the tensioning phase, the CBS deforms upwards, the concrete ribbed beams will bear stresses. During the dismantling phase, the CBS deforms downwards, so the stresses of the ribbed beams will reduce, but the stresses of post-poured belts will start to increase from zero. Thus, in order to learn about the influence of dismantling on mechanical behaviors of CBS, the stress changing of the key positions of post-poured belts (the lower surface of the post-poured beam belt) are observed during dismantling phase, which is shown in Fig. 10. Moreover, the maximum vertical displacement of the mid-span point of each span is investigated. The analysis results are shown in Figs. 11 and 12. Note that the change rate is used to evaluate the speed of change, the bigger change rate means the faster speed of change. Change rate is equal to the difference between two adjacent ordinate values.

It can be seen from Fig. 11, the span I of CBS deforms downwards and the vertical displacement reduces from the initial value of 63.8 mm to 17.2 mm when the supports of group 1 and 2 are dismantled, but the span II and III do not change. The span II of CBS starts to deform downwards and the vertical displacement decreases from the initial value of 63.8 mm to 14.5 mm when the supports of group 3 and 4 are dismantled. In this process, the mid-span displacement of span I reduces from 17.2 mm to 14.2 mm, and the span III starts to deform downwards as well. The vertical displacement in span III reduces from the initial value of 63.8 mm to 63.1 mm. After the supports of group 5 and 6 are dismantled, the span I does not change any more, while the span II changes from 14.5 mm to 12.1 mm and the span III changes sharply from 63.1 mm to 14.1 mm. Above, the maximum change rate of the displacement is 35.8 mm.

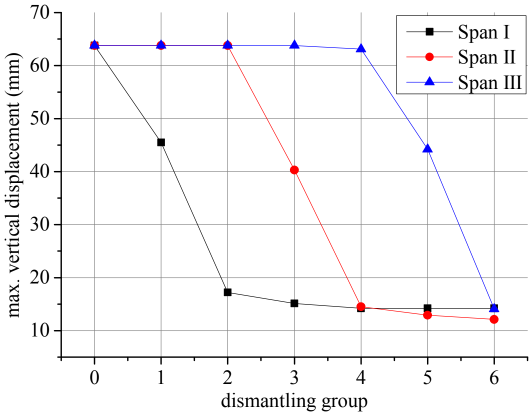

Fig. 11 Dismantling influence on displacement

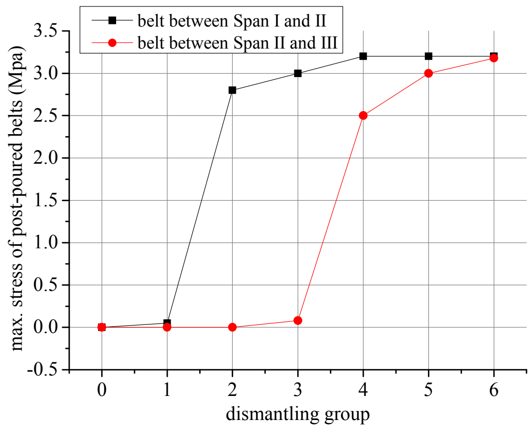

Fig. 12 Dismantling influence on stress

In the meantime, it is clear in Fig. 12, when the supports of group 1 and 2 are dismantled, the stress of post-poured belt between span I and II increases from 0 to 2.8 Mpa, but the stress of post-poured belt between span II and III does not change. After the supports of group 3 and 4 are dismantled, the stress of post-poured belt between span I and II continues to increase from 2.8 to 3.2 Mpa and the stress of post-poured belt between span II and III increases from 0 to 2.5 Mpa. After the supports of group 5 and 6 are removed, the stress of post-poured belt between span I and II does not change any more, and the stress of post-poured belt between span II and III continues to increase from 2.5 to 3.18 Mpa. Above, the maximum change rate of the stress is 3.2 Mpa.

To sum up, we can easily find out that each span of CBS has some mechanical independence such that each individual's construction affects the others' weakly. Especially the influence on the

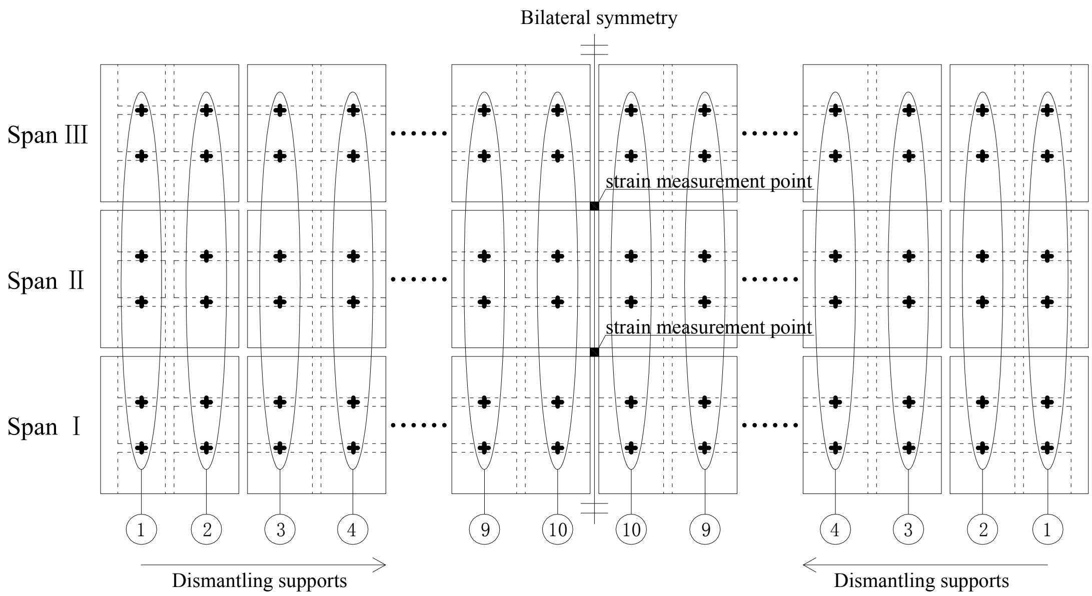

Fig. 13 Support dismantling process of scheme TWO

interval spans is almost zero. Moreover, both displacement and stress change sharply in some certain dismantling phases in the model, this is because too many supports are removed for each time. We can predict that it is an optimal method to dismantling three spans of CBS at the same time and the supports dismantling of each span is well subdivided to avoid sharp changes caused by dismantling too many supports at each time. Based on this rule, another two schemes are discussed in the following.

(II) Scheme TWO

In the dismantling scheme TWO, supports in the three spans of CBS are removed at the same time and ten groups of supports are made. The dismantling process is symmetrically performed from the ends to the middle, namely, from group 1 to 10, which is shown in Fig. 13.

In the dismantling process, the maximum displacement and stress of the post-poured belts were investigated to evaluate the influence of dismantling on mechanical behaviors of CBS. The analysis results are shown in Figs. 14 and 15.

It is obvious in Figs. 14 and 15, for the displacement, each span almost has the same changes during the removing of the supports. The displacement changes evenly with the dismantling of the first eight groups of supports, but sharp change happens when the supports of group 9 and 10 are removed. For the stress, it almost has the same changing law. The maximum change rate of the displacement and stress are respectively 33.4 mm and 2 Mpa.

(III) Scheme THREE

Opposite to scheme TWO, in scheme THREE, The dismantling process is symmetrically performed from the middle to two ends, namely, from group 1 to 10, which is shown in Fig. 16.

Likewise, the maximum displacement and stress of the post-poured belts are investigated to observe the influence of dismantling on mechanical behaviors of CBS. The analysis results are shown in Figs. 17 and 18.

It is seen clearly from Fig. 17 and 18, for the displacement, each span almost has the similar changing rule and the change goes gently along with the removing of the supports and no obviously sharp change happens during the whole removing. For the stress, it almost has the same changing pattern. The maximum change rate of the displacement and stress are respectively 11.1 mm and 0.79 Mpa. Compared with scheme ONE and TWO, both the change rate of the displace-

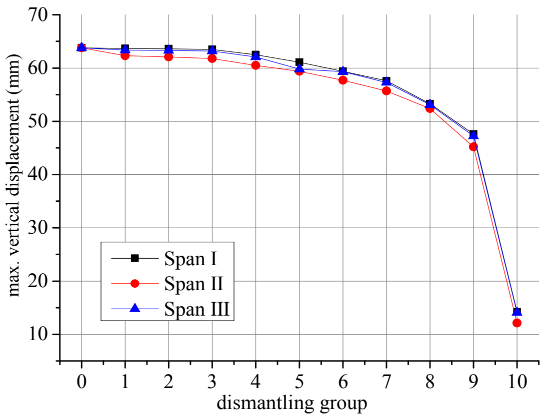

Fig. 14 Dismantling influence on displacement

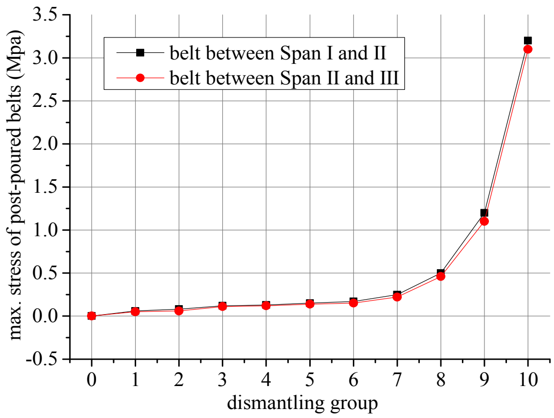

Fig. 15 Dismantling influence on stress

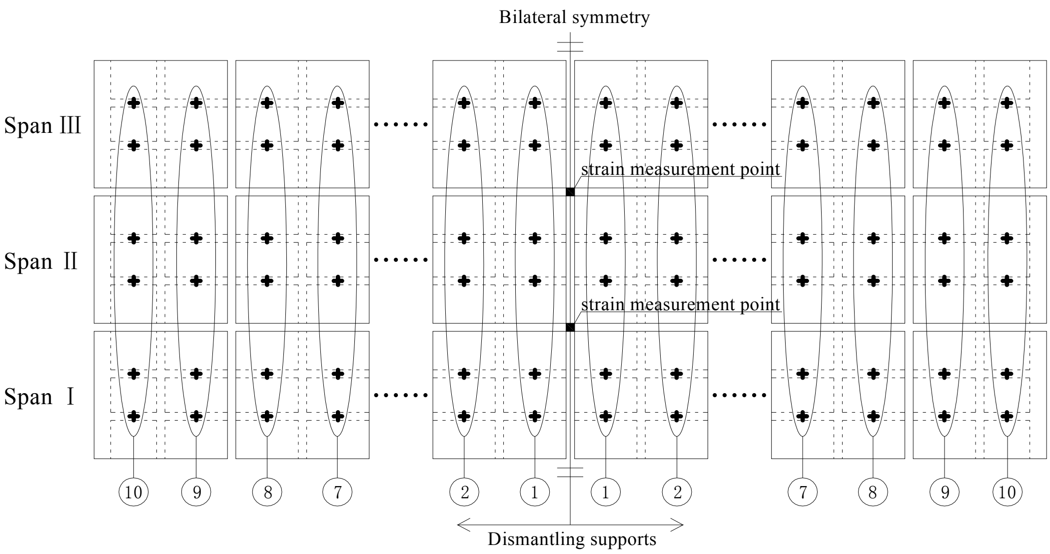

Fig. 16 Support dismantling process of scheme THREE

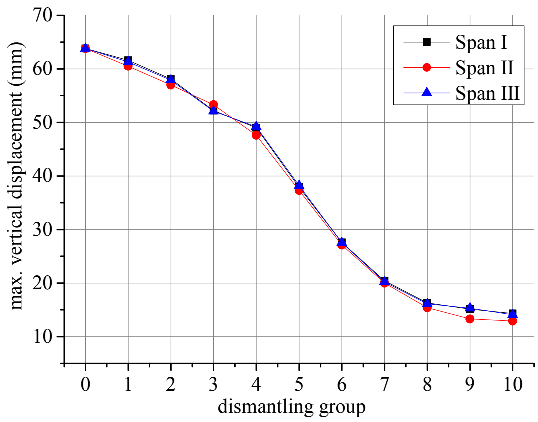

Fig. 17 Dismantling influence on displacement

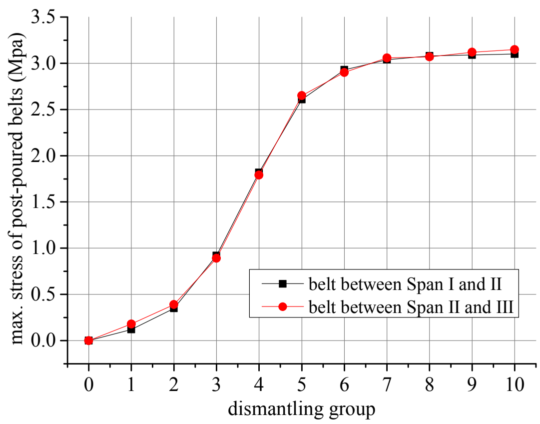

Fig. 18 Dismantling influence on stress

ment and stress in scheme THREE reduce significantly. The scheme THREE will be implemented in the construction of the physical model in the following section.

5.2 Experimental research

(I) Scaled physical model

The experimental research on tensioning phase has been finished above. The experimental research on dismantling phase will be discussed in this section. After the construction step 3, the construction step 4 of the physical model are made according to the rules introduced in the section of Basic Elements and Construction, and the supports dismantling scheme THREE is applied in the experiment, the whole process is shown in Fig. 19.

Fig. 19 Physical model in dismantling phase

(II) Data measurement

In the experiment, the YE2539 high speed static strain indicator, two strain collection extension boxes and one computer were employed as the strain measurement system, which is shown in Fig. 20. The strain measurement points of the post-poured belts (the lower surface of the post-poured beam belt) are shown in Fig. 16.

The displacements are measured by the dial indicators, and for each standard span of CBS the vertical displacement of the mid-span point is monitored, which are shown in Fig. 21.

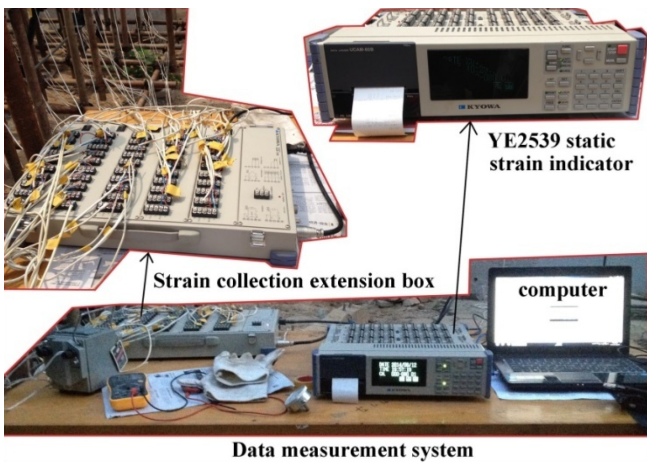

Fig. 20 Strain measurement system

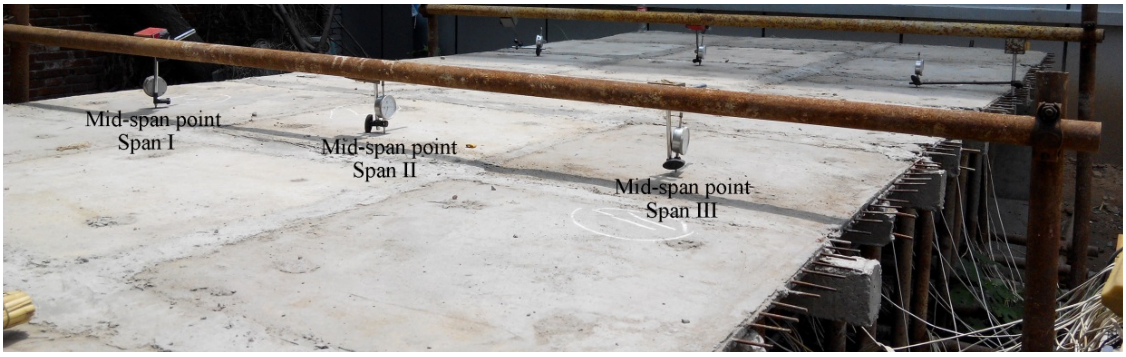

Fig. 21 Displacement indicator distribution

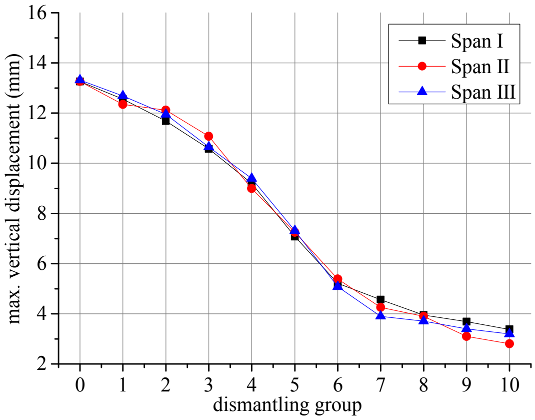

Fig. 22 Dismantling influence on displacement

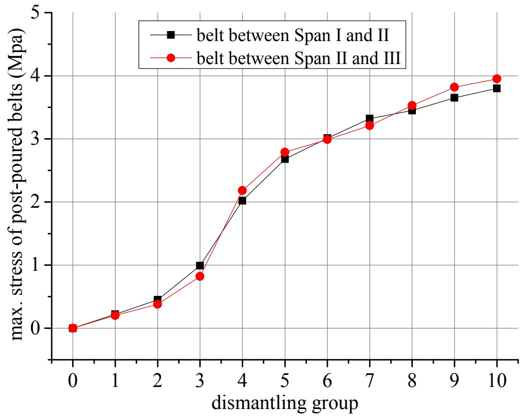

Fig. 23 Dismantling influence on stress

(III) Experimental results analysis

The 1:5 scaled physical model experiment was carried out according to the experiment scheme introduced above, the data were surveyed, recorded and compared with the theoretical data, the results are shown in Figs. 22-23 and Table 7. Note that error = (experimental value - theoretical value) / experimental value.

It can be seen from Figs. 22 and 23, the change rule is similar to that of the theoretical result. For both displacement and stress, the curves change gently, and no obviously sharp change happens during the whole dismantling. Furthermore, it is clear in Table 7, for the displacement, the maximum error between experimental and theoretical values is -13.3%, for the stress, it is about 20.3%, and for the cable force, it is 12%,. Considering the imperfection of physical model, errors induced by scaled factors, and data measurement errors, the error range listed in Table 7 can be considered rational. It indicates that the dismantling scheme THREE is reasonable which can guarantee the CBS well behaves according to the design during the construction and after the construction. In a word, even and slow change of the mechanical behaviors, moderate dismantling steps, convenient and controllable dismantling support grouping as well as less mutual interference with each span, all of the above indicates scheme THREE is an optimal support dismantling method.

Table 7 Displacement and force of key positions after dismantling supports

Item	Mid-span vertical disp. (mm)			Stress of post-poured belt (Mpa)		Cable force (kN)		
	Span I	Span II	Span III	Between span I and II	Between span II and III	Span I	Span II	Span III
Experimental value	2.71	2.49	2.69	3.8	3.95	111.81	116.88	112.38
Theoretical value	3.07	2.8	2.96	3.1	3.15	100.85	102.85	101.15
Error	-13.3%	-12.4%	-10%	18.4%	20.3%	9.8%	12%	10%

6. Conclusions

Based on the previous research on the cable-supported structures, the standard fabrication and construction method for CBS are proposed after studying the mechanical behaviors of CBS during the whole construction phase. The feasibility and rationality are supported by theoretical analysis and the experimental study on a physical model. The key conclusions drawn in this study are listed as follows.

(1) The standard construction method including five steps and two key phases (tensioning phase and dismantling phase) is proposed. Step 1, assembling beam elements of the first span. Step 2, connecting beam elements by casting concrete in site, installing the lower cable-supported system and then tensioning the cable. Step 3, repeating the step 1 and 2, finishing the whole construction of ribbed beam and cable-supported system. Step 4, paving the slabs and casting the post-poured belts. Step 5, dismantling the supports sequentially and finishing the construction of CBS.

(2) The tensioning construction method based on the deformation controlling is studied. The research results indicate that on the premise of controlling the practical deformation as close to the theoretical deformation as possible, the practical tension applied to the cable is usually larger than the theoretical value. The error in this study is only 6.8%.

(3) Based on the four general rules, three support dismantling schemes are discussed. Scheme ONE indicates that each span of CBS has certain level of mechanical independence such that each individual's construction does not affect the others significantly. Especially the influence on the interval spans is hardly visible. On the basis of this independence, scheme THREE is proposed. Even and slow change of the mechanical behaviors, moderate dismantling steps, convenient and controllable dismantling support grouping and less mutual interference with each span, all of the above means scheme THREE is an optimal supports dismantling method. Further, the experimental research also indicates that scheme THREE can guarantee the CBS behaves identically with the numerical analysis results in the construction and service state.

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