Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
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Study on the Key Issues of Beam String Structures

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Abstract

Parameter analysis is made on the beam string structure in six aspects which are respectively vector height, sag, prestress, number of strut, stiffness of upper chord and the arrangement of struts in the paper. The influence mode and effect on the mechanical properties of beam string structures due to these parameters are studied and the suggested values in practical engineering are presented then, which can provide the reference for design and type selection.

Keywords: Beam string structure; vector height; sag; prestress; arrangement of struts

1. Model Description

In the progress of type selection, analysis and design, there are six main factors that affect the mechanical properties, which are respectively the vector height R1, the sag R2, the prestress, number of strut, stiffness of upper chord and the arrangement of struts, and the definition of each parameter is presented in Fig.1. What we should do for different projects in practical engineering is to select a reasonable value for each parameter. Considering the influence mode and impact effect on the mechanical properties vary with the parameter value, analysis of examples are made in the paper and by the comparison among different parameter values we are aiming to conclude the influence mode and degree on the mechanical performances of each parameter so as to provide the reference for the design in practical engineering.

The selected calculating model is as follows: the span is 72.0m, the vertical height difference Δh between the two supports is 4.0m, the sag is 4.0m and the upper chord adopts the triangular truss, whose height is 1.8m and width is 2.0m. The section of upper chord adopts $\Phi 245\times 12$, the section of the bottom chord adopts $\Phi 245\times 14$ and that of the web member, top diagonal and horizontal members are chosen as $\Phi 127\times 8$. The vertical strut is selected as $\Phi 159\times 10$ and the section of the cable as $\Phi 6\times 199$. The initial prestress of the cable is1600 kN, the lower end support is hinged and the upper one can slip in direction of span, and Q345 is used here as the material. To study the influence on the mechanical properties due to these parameters better, two kinds of load case are adopted here. The first load case(LC1) can be prescribed that the nodal force of upper chord of triangular truss is FZ=-11.9kN, and that of bottom chord is FZ=-10.8kN; load case 2(LC2) is that nodal force of upper chord is FZ=3.5KN.

When the analysis of one parameter is done, others are assumed unchanged, that is to say the target parameter varies individually, and consequently the mechanical response of structures is obtained when this parameter is prescribed different values.

Object of investigation: the mid-span vertical displacement UZ, the horizontal displacement of slip supports UX, the axial force of upper chord members and that of bottom chord members (respectively at mid-span and end-span), the axial force of struts and the cable force.

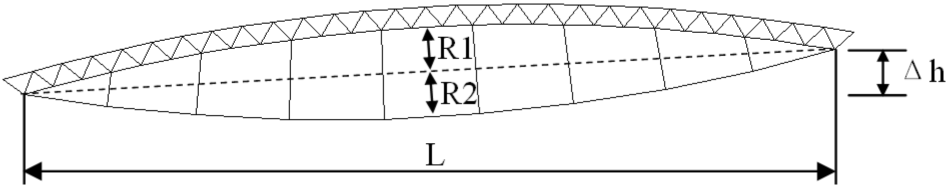
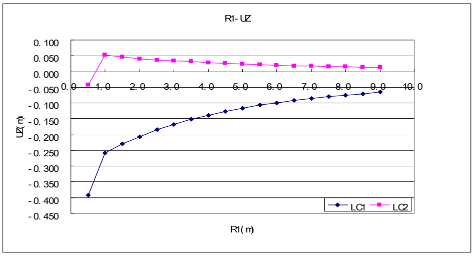


Fig.1 Calculating model and definition of parameters

2. Effect of Vector Height

The vector height R1 increases from 0.5m to 0.9m based on the basic model, accordingly the rise-span ratio from 1/144 to 1/8.5. The node displacement, truss internal force, cable force and the axial force of struts corresponding to different vector heights are respectively displayed in Fig.2 to Fig.7.



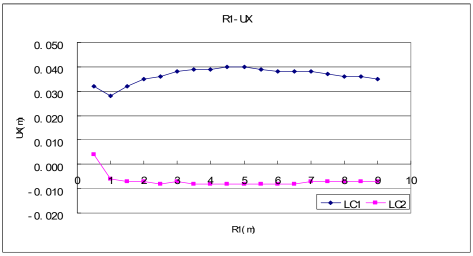
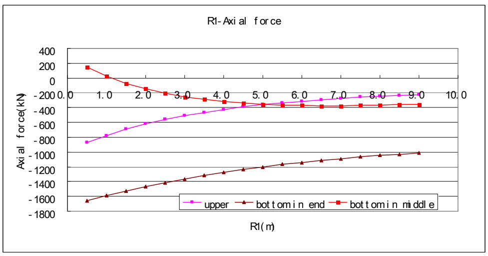


Fig.2 Mid-span displacement UZ Fig.3 Horizontal displacement of slip supports UX



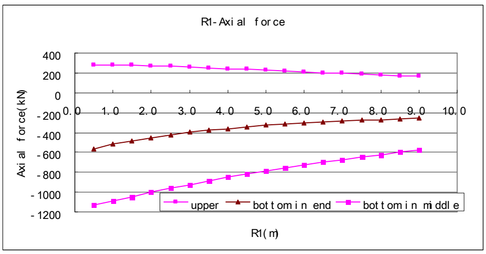


Fig.4 Axial force of truss members in LC1 Fig.5 Axial force of truss members in LC2

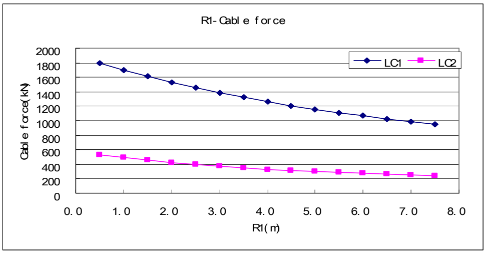


Fig.6 Cable force corresponding to different vector heights

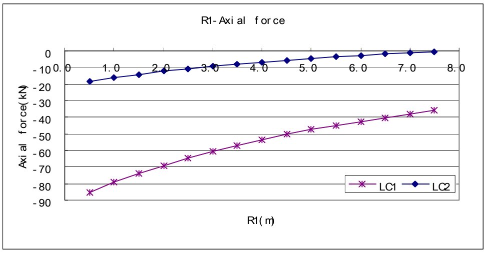


Fig.7 Axial forces of struts corresponding to different vector heights

Conclusions on changing characteristics of displacements of the key points and internal forces of members with the increasing vector height can be made through Fig.2 to Fig.7 as follows:

(1) The mid-span vertical displacement decreases in parabola type, the horizontal displacement of slip supports shows a tendency that firstly increases and then decreases in condition 1 but the influence in condition 2 is slight.

(2) The axial force of upper chord members in triangular truss, cable force and the axial force of struts decrease in parabola type.

(3) The node displacement and internal force of truss members in condition 1 exhibit a more obvious effect by changes of vector height than in condition 2.

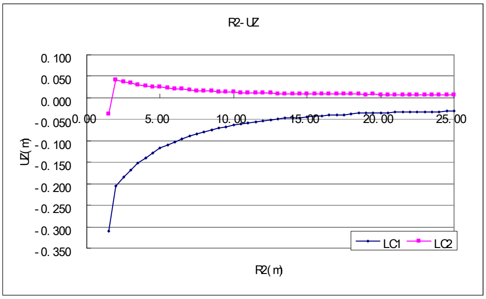
(4) The abnormal changes of results appear when the vector height is relatively small, see Fig.2 and Fig.3.

(5) The changing rates of all curves show a descending trend with incensement of vector height.

So one can see a necessary vector height is a must in practical engineering, however it is not bigger always better because the influence on the internal force and displacement made by the vector height is limited when it increases to some extend. Thus, here in practical engineering vector height is suggested as 4.0m to 6.0m and corresponding rise-span ratio should be prescribed from 1/18 to 1/12.

3. Effect of Sag

Based on the basic model the sag increases gradually from 1.5m to 25m and corresponding sag-span ratio from 1/48 to 1/2.88. The node displacement, truss internal force, cable force and the axial force of struts corresponding to different sags are respectively shown from Fig.8 to Fig.13.



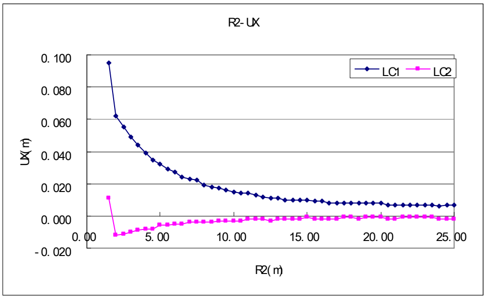
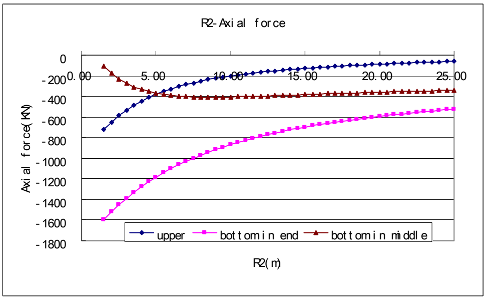


Fig.8 Mid-span displacement UZ Fig.9 Horizontal displacement of slip supports UX



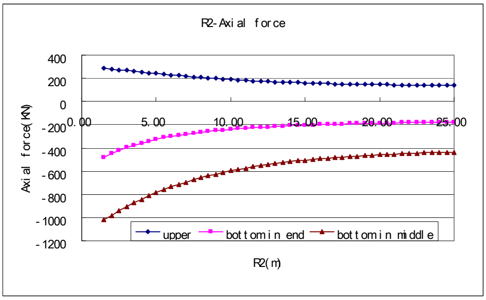
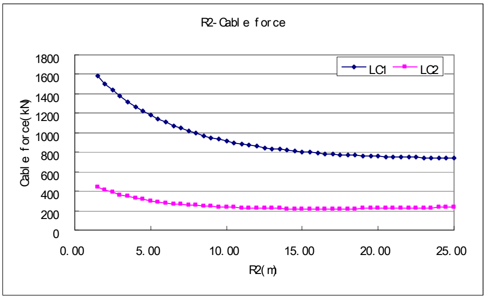


Fig.10 Axial force of truss members in LC1 Fig.11 Axial force of truss in LC2



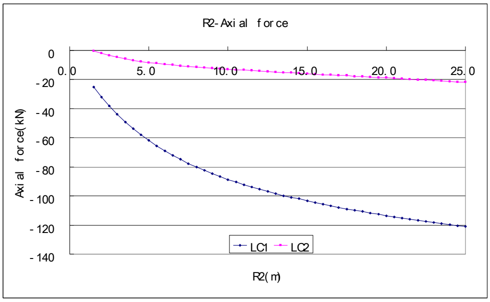


Fig.12 Cable force corresponding to different sags

Fig.13 Axial forces of struts corresponding to different sags

By studying on Fig.8 to Fig.13 we can find that displacements of the key points and internal forces of members follow some disciplines as bellow when the sag gradually increases:

(1) The mid-span vertical displacement and the horizontal displacement of slip support decrease in parabola type.

(2) The axial force of upper chord members in triangular truss and cable force cut back in parabola type but the axial force of struts goes up in parabola type.

(3) The node displacement and internal force of truss members in condition 1 exhibit a more obvious effect by changes of sag than in condition 2.

(4) The abnormal changes of results appear when the sag is relatively small, see Fig.8 and Fig.9.

(5) The changing rates of all curves show a descending trend with the increase of sag.

Again from above, in practical engineering it is necessary to prescribe a sag value, however the saying “the bigger, the better” fails here also for the reason that the influence on the internal force and displacement made by the sag is limited when it increases to some extend and at the same time, the cable force is reduced to a very small value while the axial force of struts increases, which is adverse to structures. What’s more, the increase in sag will reduce the effective use of indoor space.

Therefore a desirable value for the sag in practical engineering can be from 2.0m to 5.0m and the corresponding sag-span ratio is from 1/36-1/14.4.

2. Effect of Prestress

The initial prestress increases from 100kN to 3000kN based on the basic model and corresponding cable force increases from 319.0kN to 643.4kN after form-finding. When the prestress is different, Fig.14 to Fig.21 respectively present the node displacement, truss internal force, cable force and the axial force of struts accordingly.

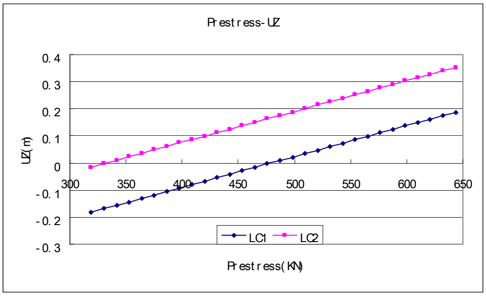


Fig.14 Mid-span vertical displacement corresponding to different prestress (m)

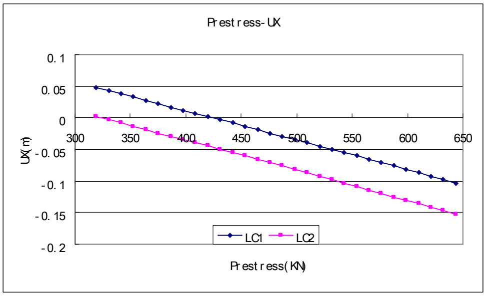


Fig.15 Horizontal displacement of slip supports corresponding to different prestress (m)

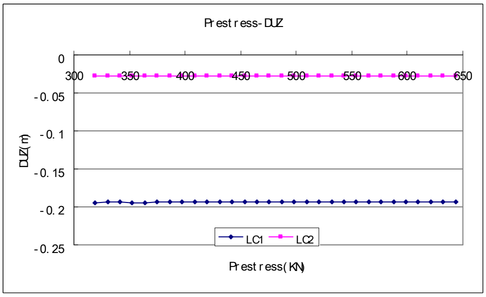


Fig.16 Mid-span vertical displacement

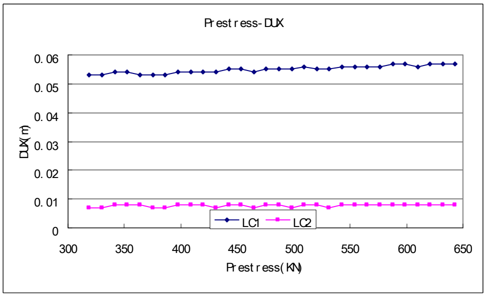


Fig.17 Horizontal displacement of slip supports

compared with the equilibrium (m) compared with the equilibrium (m)

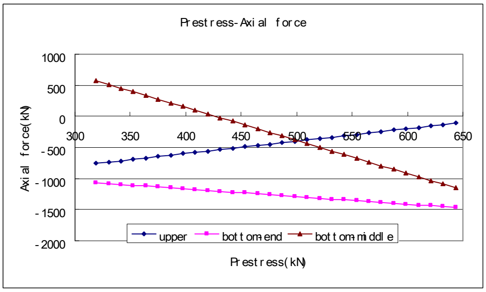


Fig.18 Axial force of truss members in LC1

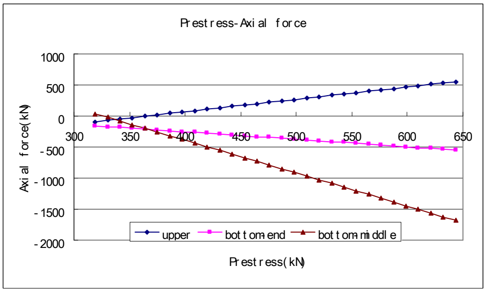


Fig.19 Axial force of truss members in LC2

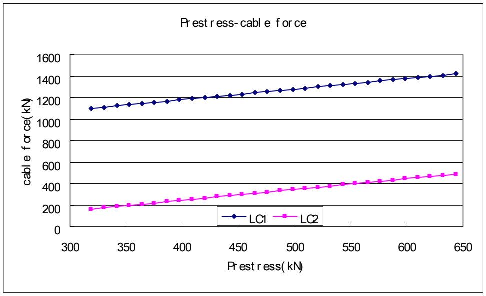


Fig.20 Cable force corresponding to different prestress (m)

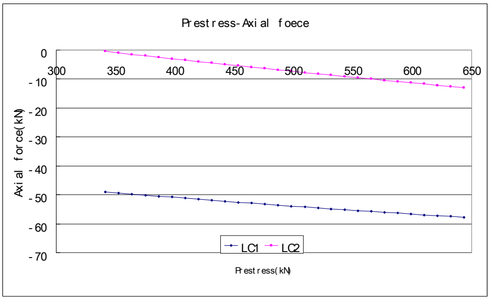


Fig.21 Axial forces of struts corresponding to different prestress (m)

We can educe from Fig.14 to Fig.21 that variation of displacements of the key points and internal forces of members with initial prestress shows the following properties:

(1) When based on the initial statement, the mid-span vertical displacement and the horizontal displacement of supports show a trend that varies linearly. The mid-span vertical displacement decreases gradually and it is transformed from downward displacement to upward displacement. And the horizontal displacement of supports is changed from outward movement into inward movement. However when definition of the displacement is based on the equilibrium state after form-finding, little change of the displacement with the increase of initial prestress is indicated.

(2) A linear variation of the axial force of upper chord members in triangular truss is shown and the axial force of upper chord members decreases gradually with the prestress increase, and especially when subjected to wind suction, it will be shifted from pressure to tension. The axial force of bottom chord members stays at pressured state and goes up with the increase of the prestress. The cable force and axial force of struts have a tendency to increase linearly.

The increase of initial prestress has good effect to reduce the displacement and improve the mechanical properties of structures, but an excessive prestress can have an adverse impact on the stability of struts. Thus the determination of initial prestress should be based on the actual load, stiffness of upper chords and other factors.

3. Effect of Number of Strut

In order to investigate the impact on the internal force of members and displacement in certain extent due to the number of strut changes, the number of struts is increased from one to twelve in the case of unchanged load, section of members and prestress. Because the number of struts should match with the sublevel number of bottom chords in the triangular truss as the upper chord, in some cases corresponding adjustment is made for the sublevel number of upper chords. The calculated results are presented by Fig.22 to Fig.27.

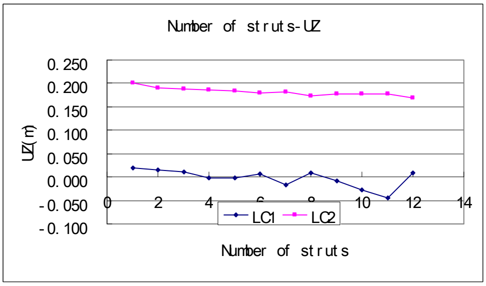


Fig.22 Mid-span vertical displacement

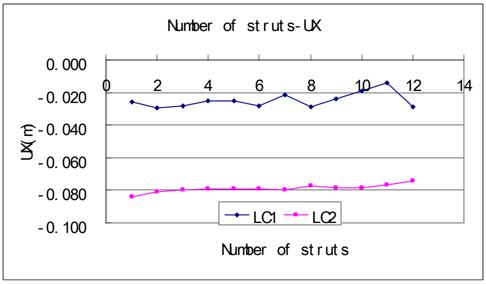


Fig.23 Horizontal displacement of slip supports

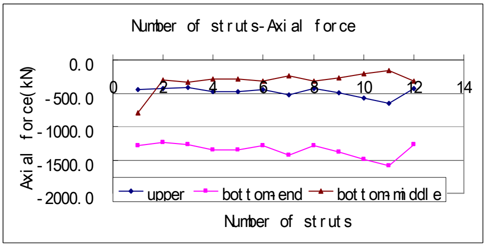


Fig.24 Axial force of truss members in LC1

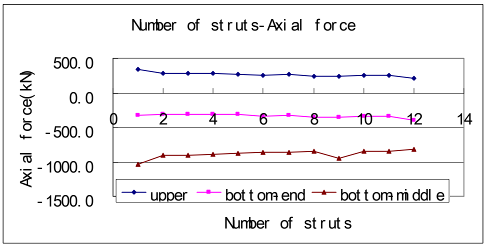
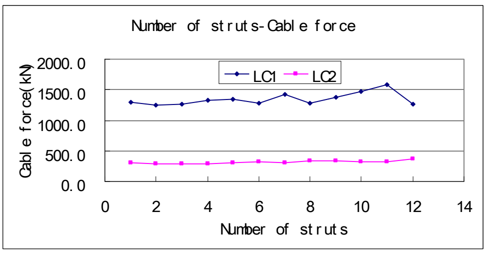


Fig.25 Axial force of truss members in LC2



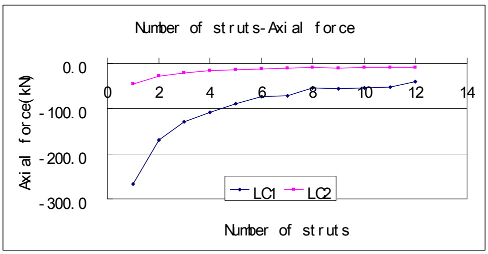


Fig.26 Cable force corresponding to different numbers of struts (kN)

Fig.27 Axial forces of struts corresponding to different numbers of struts (kN)

Through the analysis results in Fig.22 to Fig.27, we can see the influence on cable force, displacement and internal force of truss due to the increase of number of struts is not very significant and comparatively speaking the impact on internal force of the strut itself is more remarkable.

It should be noted that the number of struts will affect the sublevel number of chords in the triangular truss so as to affect truss stiffness of its own. Therefore the factors that affect structures when number of struts is increased are not only the number of struts but also the stiffness of upper chords of the truss.

Because the increase in the number of struts can be a very good way to reduce the internal force of strut itself, it will be excellent to the stability of its own when an appropriate number of struts is adopted. When the number of struts is very small, for instance it is 1, the internal force in the struts and bottom chords is very big, so it is suggested that there be a need to increase the number of struts appropriately and we can take more than three, of course the number depends on the actual span and architectural effect.

4. Effect of Upper-chord Truss

The stiffness of upper-chord truss depends on three aspects of factors, height, width and section of members respectively. We can see from the basic mechanical knowledge that for the truss structures height is a main factor to affect the structural performance. Thus this section will focus on the effect on the structural performance of beam string structures by the upper-chord triangular truss. Also, increase the height of the truss from 0.5m to 5.0m on the premise that the span, sag, member section and cable prestress are constant. Fig.28 to Fig.33 shows the calculated results.

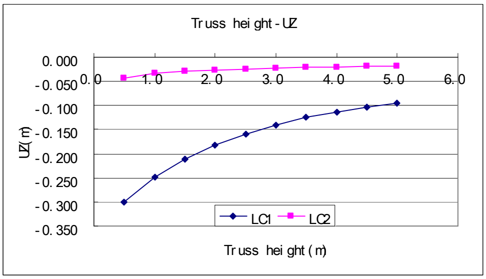


Fig.28 Mid-span vertical displacement

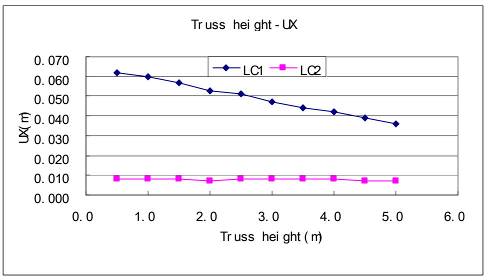


Fig.29 Horizontal displacement of slip supports

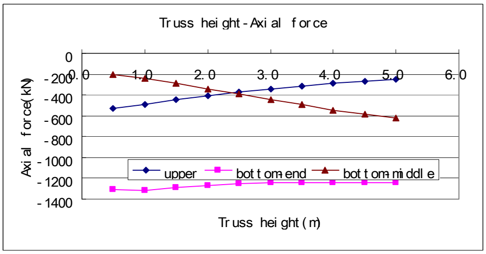


Fig.30 Axial force of truss members in LC1

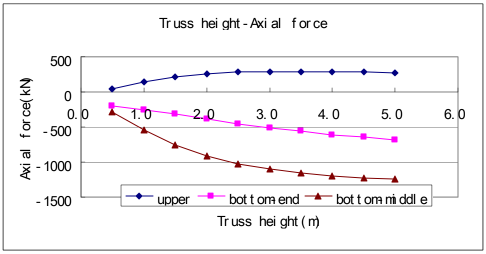


Fig.31 Axial force of truss members in LC2

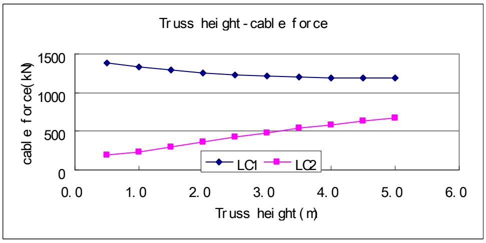


Fig.31 Cable force corresponding to different truss heights (kN)

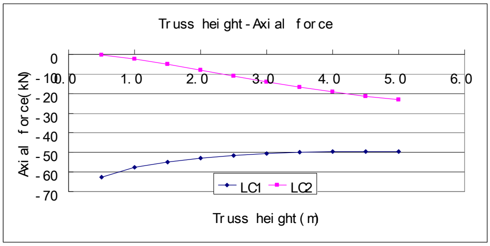


Fig.32 Axial forces of struts corresponding to different truss heights (kN)

We can make a conclusion about the displacements of the key points and internal forces of members with the increasing stiffness of upper-chord triangular truss from Fig.28 to Fig.33, as below:

(1) The increase of the height of the triangular truss can significantly reduce the structural displacement.

(2) The increase of the height of the triangular truss can reduce the internal force of members in LC1.

(3) When the height of the triangular truss increases, the cable force decreases in LC1 but increases in LC2, which can prevent the relaxation of the cable.

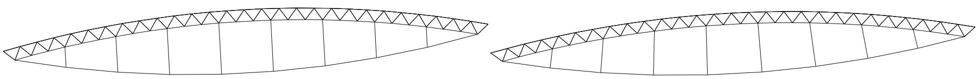
(4) The internal force of struts in LC1 can be reduced by increasing the height of the triangular truss and at the same time the internal force subjected to wind suction can be maintained.

Based on the analysis results merely, the higher the truss is, the better it is. Increasing the height of the triangular truss can improve the mechanical properties of structures and prevent the relaxation of the cable subjected to wind suction. However, it is impossible in reality and it is a must to determine the height by the load, span and prestress comprehensively.

5. Arrangement of Struts

There are two different methods in practical engineering with respect to the arrangement of strut. In the first method all struts parallel to each other, and the practice is to find out the midpoint of cable and that of bottom chord first and then based on the line connecting the two midpoints, to set up struts which parallel to the line. The other method is that all struts are set in the normal direction of the arc line of bottom chord, see Fig.34.

The mechanical properties of structures and path of force transfer are different when different arrangement of struts are applied, especially the path of force transfer between struts and cable is obviously different. In order to study the specific differences between these two arrangement ways, load analysis is respectively made in two examples, and by comparing the internal forces and displacement in different load cases, we are trying to give out reasonable answers. The calculated results of two models are listed in Table 1 to Table 4.



(a) Model1 (b) Model2

Fig.34 Arrangement of struts

Table 1 Displacement of two kinds of arrangements (mm)

	LC0		LC1		LC2	
	UX	UZ	UX	UZ	UX	UZ
Mode1	-84	203	46	-159	-8	28
Mode2	-84	203	45	-157	-8	27

Table 2 Axial force of truss of two kinds of arrangements (kN)

	LC1		LC2	
	Fmax	Fmin	Fmax	Fmin
Mode 1	41.4	-1099	467.3	-1037
Mode 2	44.5	-1082	466.2	-1034

Table3 Axial force of struts of two kinds of arrangements (kN)

	LC1		LC2	
	Fmax	Fmin	Fmax	Fmin
Mode 1	-49.704	-52.164	-1.103	-1.166
Mode 2	-46.375	-54.717	-1.014	-1.131

Table4 Cable force of two kinds of arrangements (kN)

	LC1		LC2	
	Fmax	Fmin	Fmax	Fmin
Mode1	1074	1054	24.289	23.85
Mode2	1059	1059	23.312	23.296

Note: LC0 represents the equilibrium state after Form-finding; LC1 represents load case 1 and LC2 load case 2.

From the results listed in above tables, the impact on the upper-chord truss, the axial force, cable force and displacement of key points by the two arrangements of struts does exist but is not obvious, specifically within %5.

The main difference is that in the second arrangement cable forces are more uniform, which is of great importance when it comes to practical projects, because slip phenomenon exists in the projects that have already been completed and this is extremely detrimental to mechanical properties of structures in use. On the one hand, after sliding re-distribution of internal forces of struts and cable will happen, then neither the internal force nor the displacement matches the initial results, which threats the safety seriously and causes a great deal of threat to stability of structures; on the other hand, the friction generated by sliding may have a damage to the protective layer, thereby affect the anti-corrosion performance of cable; in addition, if the slip is too large, it may change the indoor architectural effect.

6. Conclusions

The paper has made an analysis on six parameters that affect the mechanical properties of beam string structures, including vector height, sag, prestress, number of strut, stiffness of upper chord and the arrangement of struts. After analysis, some conclusions are made as follows: The most obvious factors to affect the mechanical properties of beam string structures are vector height and sag; prestress is the basis of establishment of structures; what the number of struts impacts directly is the internal forces of strut itself; the height of upper-chord truss is also a main factor to control the displacement and relaxation of structures; reasonable arrangement of struts provides a guarantee for the structural safety and reasonable operation. For the actual engineering, we can take the following proposed parameter values:

(1)The desirable rise-span ratio is 1/18-1/12;

(2)The desirable sag-span ratio is 1/36-1/14.4;

(3)The size of upper chords and members can be determined by the situation that the cable doesn't relax;

(4)The prestress can be determined by the displacement and internal force under the vertical downward load;

(5)The number of struts can be taken more than three depending the span and actual conditions, and if the span is large, the struts can be set more than usual, generally in practical engineering desirable numbers are six to ten.

(6)Since the slip phenomenon exists between the cable and the struts, the second arrangement of struts is more preferable.

At last, it should be noted that different span sizes and loads may lead to different mechanical performances, so for the practical engineering, the selection of each parameter can refer to some of the results of this paper, and at the same time taking the examples of existing projects into account, together with analysis, the parameters are finally determined.

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